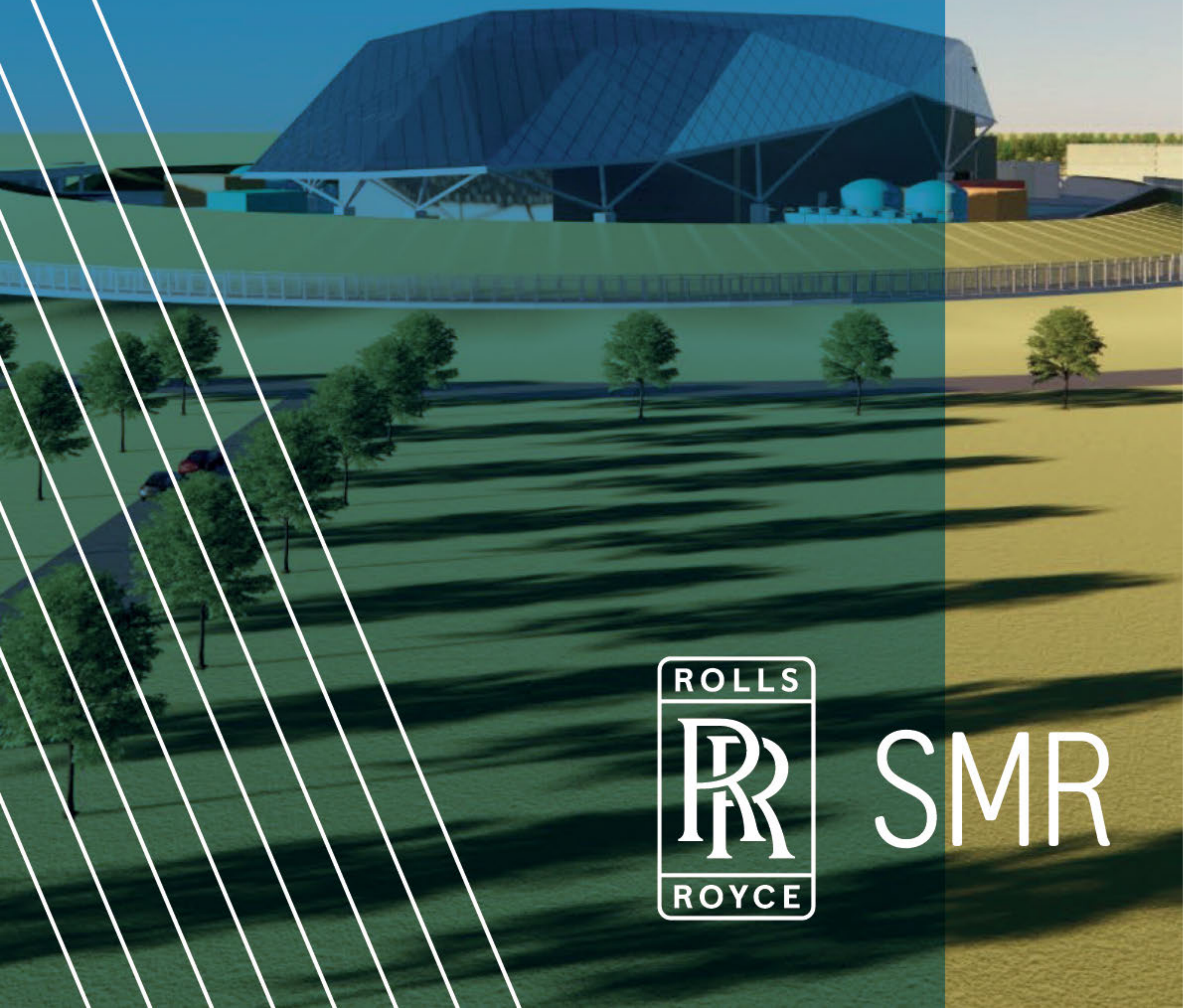
NIA REPORT

REGULATORY JUSTIFICATION APPLICATION

ROLLS-ROYCE SMR LTD

July 2024
(updated May 2025)



ROLLS ROYCE SMR

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FIGURES

RECORD OF CHANGE ADDED

Date	Revision Number	Status	Reason for Change
July 2024	1	Issue	First issue of NIA Report Regulatory Justification Application Rolls-Royce SMR Limited
January 2025	2	Issue	Second issue of NIA Report Regulatory Justification Application Rolls-Royce SMR Limited in response to request for additional information from the justifying authority Changes have been made to the following paragraphs: 1.2.1 Footnote added to CTP definition 2.7.2 additional clarification of core fuel load added Numerical values in Paragraphs 5.9.11, 10.12.16 and Tables 9, 13 and 14 are amended as a result of a change made in reference data Additional paragraphs added after 7.2.38 to provide additional information Additional detail on climate change consideration is added in Chapter 8 Annex 1 contains additional commentary on how the modular concept is advantageous to decommissioning Also minor template/editorial updates for overall consistency and accuracy
May 2025	3	Issue	Third issue of NIA Report Regulatory Justification Application Rolls-Royce SMR Limited in response to request for additional information from the justifying authority. Additional information is added to: • Chapter 5 to clarify differences between the RRSMR and other comparable justified practices. • Chapter 6 to quantify spent fuel arisings. • Chapter 10: – clarifying the minimisation of radiography during construction of the RRSMR, and – to emphasise the inclusion of passive safety features and their affect on exposures to workers and people offsite. Also minor template/editorial updates for overall consistency and accuracy.

0: INTRODUCTION AND PROPOSED PRACTICE

0.1 Introduction

Background

0.1.1 In 2020 the United Kingdom ("UK") Government published an Energy White Paper- Powering our Net Zero Future **[1]**.The Energy White Paper set out the Government's *"Ten Point Plan to lay the foundations for a Green Revolution"*[1] stating *"Nuclear power provides a reliable source of low-carbon electricity. We are pursuing large-scale nuclear, whilst also looking to the future of nuclear power in the UK through further investment in Small Modular Reactors and Advanced Modular Reactors."*[2] The government gave further focus to energy security and net zero publishing the policy paper Powering up Britain **[2]** in 2023 which sets out how government will enhance energy security, seize economic opportunities and deliver on net zero commitments.

0.1.2 The Government's National Policy Statement **[3]** states: *"Nuclear plants provide continuous, reliable, safe low-carbon power. They produce no direct emissions during operation and have indirect life cycle GHG emissions comparable to offshore wind. Power stations with an estimated lifetime of 60 years provide large amounts of low carbon electrical power, using a relatively small amount of land. Nuclear, alongside other technologies could also offer broader system benefits, such as low carbon hydrogen production through electrolysis, or low carbon heat. In addition, nuclear generation provides security of supply benefits by utilising an alternative fuel source to other thermal plants, with a supply chain independent from gas supplies. Our analysis suggests additional nuclear beyond Hinkley Point C will be needed to meet our energy objectives. Nuclear technology is developing and opportunities for flexible use may grow as the energy landscape evolves. The role of nuclear power could be fulfilled by large-scale nuclear fission, Small Modular Reactors, Advanced Modular Reactors, and fusion power plants."*[3]

0.1.3 As outlined in the British Energy Security Strategy **[4]**, the government is increasing its plans for deployment of civil nuclear power by 2050s. To facilitate this, government has set out a number of nuclear ambitions, including developing an overall siting strategy for the long term, which could include both GW-scale and advanced fission technologies. This will inform the development of a new nuclear national policy statement for the deployment of nuclear power stations after 2025.[4]

0.1.4 The UK government policy paper Civil Nuclear: Roadmap to 2050 **[5]** states *"As part of a massive investment in home-produced clean energy, nuclear will offer the reliable, resilient, and low-carbon power we need to reach net zero by 2050, and ensure our energy security"*, whilst affirming the *"ambition for up to 24 GigaWatts (GW) of nuclear capacity by 2050, which would cover up to a quarter of the country's projected electricity demand."*[5]

0.1.5 The Rolls-Royce Small Modular Reactor ("RR SMR") is a nuclear reactor technology designed by Rolls-Royce SMR Limited. One of the steps required prior to licensing a new nuclear power station in the UK is to submit an application for 'regulatory justification' seeking a decision pursuant to regulation 9 of the Justification of Practices Involving Ionising Radiation Regulations 2004 (as amended) **[6]** (the "Justification Regulations") that the RR SMR design is 'justified'.

0.1.6 The principle of "Justification" is derived from the recommendations **[7]** of the International Commission on Radiological Protection ("ICRP"). This principle requires that *"any decision that alters the radiation exposure situation should do more good than harm."*

0.1.7 The requirements of this principle for new sources of radiation have been adopted by the International Atomic Energy Agency ("IAEA") in its Fundamental Safety Principles **[8]**, Principle 4 *"Facilities and activities that give rise to radiation risks must yield an overall benefit."* and its Radiation Protection and Safety of Radioactive Sources: International Basic Safety Standards[6] Requirement 10 **[9]**: "Justification of Practice"; *"The government or regulatory body shall ensure that only justified practices are authorised."*

1] Energy White Paper Pg 11 Energy White Paper (publishing.service.gov.uk)

2] Energy White Paper Pg 12 Energy White Paper (publishing.service.gov.uk)

3] EN1 Para 3.3.50-3.3.51. EN-1 Overarching National Policy Statement for Energy (publishing.service.gov.uk)

4] UK Government have, at the time of writing, carried out a consultation on a new approach to siting beyond 2025 and intend to produce a new National Policy Statement for nuclear power -EN7 during 2024. National Policy Statement for new nuclear power generation: new approach to siting beyond 2025 (publishing.service.gov.uk)

5] Civil Nuclear: Roadmap to 2050 pg 3 Civil Nuclear: Roadmap to 2050 (publishing.service.gov.uk)

6] www-pub.iaea.org/mtcd/publications/pdf/pub1578_web-57265295.pdf

0.1.8 The Justification Regulations, provide the regulatory framework for enabling the determination of whether an existing or proposed class or type of practice involving ionising radiation is 'justified'.[7] This considers the expected individual and societal benefits and the potential risks, including potential detriment to health. Only practices that are 'justified' may be authorised by the regulatory bodies.

0.1.9 A "practice" is "a human activity that can increase the exposure of individuals to radiation from a radiation source and is managed as a planned exposure situation". The term "practice" includes a wide range of activities including nuclear power generation and supporting activities such as nuclear fuel manufacture, management of spent fuel and radioactive waste alongside decommissioning which are all an inevitable consequence of the original practice.

0.1.10 Anyone seeking to undertake a new type of practice must make an application for a justification decision. The Justifying Authority will then make a decision regarding whether it is a justified practice.

0.1.11 The Justification Regulations were amended in 2018 to transpose the 2013 European Commission Basic Safety Standards Directive ("BSSD13") **[10]** into UK law. The Justification Regulations (as amended) provide that the Secretary of State making the justification decision cannot also promote or use the practice in question. As a result, the Justifying Authority for new nuclear reactors is now the Secretary of State for the Department of Environment, Food and Rural Affairs.

0.1.12 After Brexit, the Justification Regulations became 'retained UK law' pursuant to sections 2-4 of the European Union (Withdrawal) Act 2018. Post Brexit, the UK law continues to embody the IAEA's Fundamental Safety Principles and its International Basic Safety Standards which now directly underpin the Justification Regulations.

0.1.13 In 2013, we submitted an application to the Justifying Authority seeking justification of new nuclear power stations in the UK, specifically relating to the UK ABWR designed by Hitachi-GE (the "2013 Application"). On 11th February 2015, the Secretary of State, the "Justifying Authority" for nuclear power under the Justification Regulations, published his decision **[11]**, that the UK ABWR design was justified. This decision was then endorsed by both Houses of Parliament (the "2015 Justification Decision"). This Application seeks 'Justification' of the Proposed Practice defined in Chapter 1. It should be noted that the Justification of the RR SMR is being sought in a similar respect to the current UK new nuclear power programme. If the RR SMR were justified, this would provide UK utilities, developers and large energy consumers with an additional choice of technology to deploy in pursuance of their development plans. It is noted that another Justification Application has recently been submitted by Newcleo for a similar practice.

0.1.14 This Application follows a similar structure to our 2013 Application and will demonstrate the arguments from our 2013 Application remain valid for the RR SMR technology and have been updated in this application to take into account any new information and events since the 2015 Justification Decision was issued.

0.1.15 The main policy changes and new information produced since our 2013 Application include the following:

- This Application draws on conclusions from the 2015 Justification Decision document issued in response to our 2013 Application, as well as Government policy statements and publications issued since that decision, including in particular the National Policy Statements for energy infrastructure (EN-1) 2024 **[3]**.
- This Application addresses regulatory developments which have occurred since the 2015 Justification Decisions were issued, including the Nuclear Energy (Financing) Act 2022 **[12]**, which introduced a Regulated Asset Base (RAB) model as an option to help fund future nuclear projects, and the Policy Paper Implementing Geological Disposal 2018 **[13]**, which sets out the framework for the long-term management of higher activity radioactive waste through geological disposal.
- The Application uses updated costs estimates for building nuclear reactors (based on 2016 Electricity Generation Costs report **[14]**).
- This Application includes information specific to the RR SMR technology.

0.1.16 The Guidance on the application and administration of The Justification of Practices Involving Ionising Radiation Regulations 2004 was issued in 2019 and revised in 2023 **[15]**. This Application follows the guidance and is informed by the previous Justification process for new nuclear, particularly the following documents:

- Our 2008 Application **[16]**
- The 2010 Justification Decisions **[17]** and **[18]**
- Our 2013 Application **[19]**
- The 2015 Justification Decision **[20]**

7] "justified" in relation a class or type of practice means justified by its economic, social or other benefits in relation to the health detriment it may cause" Part 2 s4.2 https://www.legislation.gov.uk/uksi/2004/1769

Purpose of the Justification Application

0.1.17 Justification is a high-level assessment that is intended to take place early in the series of decision-making processes applicable to a new class or type of practice.[8] It is designed to establish, before a new class or type of practice is introduced, that such practice will provide an overall benefit.

0.1.18 The strict legal test set out in the Justification Regulations requires that the individual or societal benefit resulting from a class or type of practice outweighs the health detriment[9] it may cause.

0.1.19 Under the guidance, our Application not only assesses the potential radiological health detriment associated with the Proposed Practice, but also any other potential detriments that could be significant when considered against the benefit derived from that practice. This Application provides a wide-ranging review of other potential (non-radiological health) detriments of the Proposed Practice, which are summarised against the benefits in the final chapter, so as to identify the net benefit

0.1.20 In line with the approach described above, this Application focuses on the potentially very significant benefits to the UK of the Proposed Practice such as—the delivery of low carbon energy; and increased energy security. It also considers other potential benefits—including economic benefits to the nuclear supply chain.

Regulatory Context

0.1.21 It is important to note that a conclusion that a practice is justified does not in itself allow practices of that class or type of practice to be conducted. This is because the Justification process is generic, and not project or site-specific. A new nuclear power station could only be constructed and operated once a range of specific consents have been obtained as part of the normal and rigorous process of regulatory scrutiny. These consents would only be forthcoming once the relevant principles of radiological optimisation have been applied. These include that any potential adverse impacts identified would be either avoided altogether or mitigated using Best Available Techniques ("BAT") to such an extent that they were As Low as Reasonably Practicable ("ALARP").[10]

0.1.22 It is worth emphasising that although this Application relates to new nuclear power station technology, the UK nuclear industry has almost 70 years' experience of operating nuclear power stations within a robust goal setting regulatory regime that places the onus on operators to demonstrate to regulators that the prescribed regulatory principles for safety, security, safeguards and environmental protection have been met. It has an excellent record of safety and looking after the welfare and health of both its workers and the public and environmental protection. The existing regulatory system will continue to evolve in line with technological and societal developments to remain effective.

0.1.23 Following the accident at Fukushima in March 2011, the then Secretary of State for Energy and Climate Change requested that Dr Mike Weightman, the then Her Majesty's Chief Inspector of Nuclear Installations, examine the circumstances of the Fukushima accident to see what lessons could be learnt to enhance the safety of the UK nuclear industry. The final report was published in September 2011 **[21]**. It highlighted the robustness of the regulatory regime: *"Consideration of the accident at Fukushima-1 against the ONR Safety Assessment Principles for design basis fault analysis and internal and external hazards has shown that the UK approach to identifying the design basis for nuclear facilities is sound for such initiating events."*

0.1.24 The global industry has a wealth of operating experience (around 20,000 reactor years) and the continuing sharing of best practice will help to improve safety and operational standards throughout the world.

Structure of Application

0.1.25 The following chapters provide an overview of all potential detriments, radiological and non-radiological, and sets these against the specific identified benefits of the Proposed Practice. Chapter 1 includes a description of the Proposed Practice for which a Justification decision is sought. The remainder of the Application is divided into 5 parts:

8] For convenience, the term "class or type of practice" is abbreviated in this document to "practice".

9] Health detriment is the reduction in length and quality of life occurring in a population following exposure, including those arising from tissue reactions, cancer and severe genetic disorder. [15]

10] ALARP is frequently used by the Office for Nuclear Regulation whilst the Environment Agency and Natural Resources Wales use a similar term as low as reasonably achievable (ALARA), the two terms are interchangeable.

- A discussion of the potential benefits of the Proposed Practice in terms of security of supply and climate change (Chapters 2 and 3 respectively)
- An assessment of the potential impacts of the Proposed Practice on the UK economy (Chapter 4)
- Identification of the potential radiological health detriments of the Proposed Practice (Chapter 5)
- Identification of the potential non-radiological health detriments associated with the Proposed Practice (Chapters 6 to 8). Chapter 6 deals with the potential non-radiological health detriments linked to radioactive waste management and decommissioning, Chapter 7 covers non-radiological environmental impacts and Chapter 8 covers non-proliferation, security, industrial safety, impacts of climate change and considerations of extreme events and severe accidents.
- A final section (Chapter 9) that summarises the comparison between the net benefits and the detriments.

Applicant Details

0.1.26 This Application is being made by the Nuclear Industry Association ("NIA") of 4th Floor, York House, 23 Kingsway, London WC2B 6UJ ("the Applicant") with the support of Rolls-Royce SMR Limited of Moor Lane, Derby, Derbyshire. DE24 8BJ (Company Number 13039768). This Application includes information on the RR SMR designed by Rolls-Royce SMR Limited.

0.1.27 RR SMR technology could be deployed by any operator in the UK in the future, including by our other members.

0.1.28 The NIA is the trade association, information and representative body for the civil nuclear industry in the UK. It represents more than 300 companies operating in all aspects of the nuclear fuel cycle, including the operators of the nuclear power stations, the international designers and vendors of nuclear power stations, and those engaged in decommissioning, waste management and nuclear liabilities management. Members also include nuclear equipment suppliers, engineering and construction firms, nuclear research organisations, and legal, financial and consultancy companies.

0.1.29 The NIA's address is:

Nuclear Industry Association
4th Floor, York House
23 Kingsway
London
WC2B 6UJ

0.1.30 [redacted]

1: INTRODUCTION AND PROPOSED PRACTICE

1.1 Introduction

1.1.1 This Application seeks a Justification decision for a new type or class of practice pursuant to regulations 9 and 12 of the Justification of Practices Involving Ionising Radiation Regulations 2004 **[22]** as amended (the "Justification Regulations").

1.1.2 This chapter describes the "class or type of practice" for which Justification is being sought. Annex 1 contains a description of a non-site-specific version of the RR SMR, that is currently being designed by Rolls-Royce SMR Limited, and for which justification is sought. Annex 1 also provides a brief description of how the RR SMR design will incorporate further improvements and enhancements and will need to take account of UK conditions and regulatory requirements. The annex includes evidence which demonstrates the figures and statistics which support the level of the benefits and detriments identified in the chapters of this Application. A description of the nuclear fuel cycle is provided in Annex 2.

1.2 Proposed Practice

1.2.1 This Application is made to support the construction, operation and, ultimately, the decommissioning of new nuclear power stations in the UK by reference to the Rolls-Royce SMR Limited technology. The class or type of proposed practice for which Justification is sought (the "Proposed Practice") can be summarised as:

"*The generation of power*[11] *from nuclear energy using uranium dioxide fuel of low enrichment in fissile content in a light water cooled, light water moderated thermal reactor currently known as the RR SMR designed by Rolls-Royce SMR Limited.*"

1.2.2 We have designed this definition of the Proposed Practice by studying the approach taken by the Justifying Authority in determining the "class or type of practice" in response to the options presented in previously approved Justification Applications, **[11]**, **[17]**, and **[18]**. Accordingly, the definition of Proposed Practice aligns with the definitions of previously justified new nuclear power station practices.

1.2.3 We recognise that it is for the Justifying Authority to determine what the "class or type of practice" is, and whether it is capable of being considered as a new class or type of practice for the purpose of the Justification Regulations. We ask the Justifying Authority to consider the Proposed Practice to determine whether it agrees with our proposed definition.

1.2.4 The main attributes of the Proposed Practice are set out in Table 1. We have included non-technical characteristics to provide further explanation of the attributes of the Proposed Practice which are relevant to the assessment of its benefits and detriments. It should be noted that the values relating to radiological doses are regulatory limits and the actual radiological dose from the RR SMR to workers and the public, will be minimised in line with regulatory requirements.

1.2.5 The RR SMR, which is the subject of the Proposed Practice, is designed by Rolls-Royce SMR Limited. The RR SMR draws upon standard Pressurised Water Reactor ("PWR") technology that has been used in hundreds of reactors around the world.

1.2.6 The RR SMR power station will have the capacity to successfully generate 470 MWe of low carbon energy, equivalent to more than 150 onshore[12] wind turbines and enough to power a million homes for 60 years. RR SMR utilises fission by neutrons in the thermal spectrum and utilises industry standard low enriched uranium dioxide fuel. Light water is utilised in the design as both a moderator and a coolant.

1.2.7 Most light water reactors being constructed in the world today belong to what are known as Generation III/III+ reactors. These designs have evolved from the PWRs and Boiling Water Reactors ("BWRs") that were constructed in the 1980s and many are still in operation today. The RR SMR is considered to be Generation III+ technology. These evolutionary reactors have incorporated improvements to offer enhanced safety levels and efficiency. Further details of enhanced safety levels incorporated in the design of RR SMR are presented in Annex 1.

1.2.8 Justification is a process which involves the initial, high-level assessment of the benefits and detriments of the Proposed Practice. It is not intended to substitute more detailed examinations of reactor designs by the regulators. The Generic Design Assessment ("GDA"), later regulatory

11] Power, as measured in Mega Watts thermal (MW_{th}) which could be used for the provision of heat and/or the generation of electricity.

12] An average onshore wind turbine produces around 2.5 to 3 megawatts (MW), in comparison to the offshore average of 3.6 MW. Onshore vs offshore wind energy: what's the difference? | National Grid Group steps, and design development to optimise the design can be expected to introduce design changes; none of these regulatory and optimisation processes is expected to have an adverse effect on the balance of benefits and detriments set out in the application (indeed optimisation may further reduce the radiological detriment), as the basis for the expectation that once made the Radiological Justification decision should not need to be reviewed. As was the case with the 2010 and 2015 Justification Decisions for the AP1000®, EPR™ and UK ABWR reactor designs.

1.2.9 The benefits of carbon reduction and security of supply described in this Application are relevant to all commercial nuclear reactor technologies currently being considered for deployment by UK nuclear entities and will remain the same regardless of technology developments to optimise the design

Table 1: Main Attributes of the Proposed Practice

Characteristic	Defining Attribute of Proposed Practice	Further Information provided in this application
Basic Nuclear Characteristics		
Fission process	Thermal energy fission	Annex 1
Fuel	Low enriched Uranium Dioxide fuel	Annex 1
Moderator	Light Water	Annex 1
Coolant	Light Water	Annex 1
Radiological Health Detriment[13]		
Normal operation - workers	Effective individual dose in calendar year: Below legal limit 20 mSv/ yr. averaged over any consecutive 5 years, 50 mSv in any one year[14] Average for defined groups less than UK regulatory Basic Safety Level (10 mSv/yr)[15]	Chapter 5 and Annex 4
Normal operation – public	Below 1 mSv/yr legal dose limit.[16] Maximum individual dose in calendar year complies with Environmental Permitting Regulations:[17] 0.3mSv/y from new plant	Chapter 5 and Annex 4
Accident Risk	Meets UK regulatory Basic Safety Level criteria for accident risk	Chapter 5
Security of Supply		
Origin of Fuel	Available from a diverse range of politically stable countries	Chapter 2
Readiness for implementation	First of a Fleet expected early 2030s RR SMR currently going through GDA process.	Annex 1
Carbon "Footprint"		
Lifecycle CO_2 emissions	Considered low carbon	Chapter 3
Radioactive Waste and Decommissioning		
Radioactive wastes and spent fuel arisings	Compatible with UK disposal or interim storage plans	Chapter 6 and Annex 3

1.3 Scope of the Proposed Practice

1.3.1 The nuclear fuel cycle comprises a series of processes related to the production of power from uranium in nuclear power reactors and the management of the resulting radioactive waste products.

13] Figures relate to regulatory limits not planned exposure levels.

14] IRR17 Schedule 3 Part 1- Classes of persons to whom dose limits apply Paragraph 1.

15] Office for Nuclear Regulation SAPs 2014, Rev 1 (Jan 2020) Paragraph 712.

16] IRR17 Schedule 3 Part 1- Classes of persons to whom dose limits apply Paragraph 5.

17] These requirements are included in Schedule 23, Part 4, Paragraph 2(1) of The Environmental Permitting (England and Wales) Regulations 2016.

1.3.2 Annex 2 provides a brief description of the key aspects of the Proposed Practice pertinent to this Justification Application. Information on all aspects of the nuclear fuel cycle related to the current Application is provided, including those that occur outside of the UK, or that constitute separate practices in their own right. For completeness, the potential health detriments associated with these aspects are considered later in this Application.

1.3.3 Table 2 presents the activities related to the Proposed Practice, which are considered in this Application. Nuclear power plants need to be supported by facilities for fuel manufacture and for managing spent fuel and radioactive waste. The ICRP **[23]**, recommends that for the purposes of Justification, radioactive waste management and waste disposal operations are treated as part of the practice generating the waste.

Table 2: Activities Related to the Proposed Practice

Activity	Existing Practice
Uranium extraction (mining and milling or in-situ leaching)	Takes place outside the UK
Conversion	Takes place outside the UK
Enrichment[18]	Yes
UK Fuel Fabrication	Yes[19]
Radiographical Inspection of welds during construction	Yes
Generation of energy by RR SMR	No
RR SMR Spent Fuel Management	No
RR SMR Radioactive Waste Management	No
Decommissioning of RR SMR plants	No
Transport of fresh fuel, spent fuel and radioactive waste	Yes
Final disposal of RR SMR Low-Level Waste (LLW)	No
Final Disposal of RR SMR Intermediate-Level Waste (ILW), High-Level Waste (HLW) and spent fuel	No

1.3.4 A number of activities, namely conversion, enrichment, fuel fabrication and transport of fresh fuel, spent fuel and radioactive wastes are already justified as Existing Practices.[20] Information on these is included in this Application which shows that RR SMR technology does not introduce any new material considerations in respect of these activities. Uranium extraction and conversion do not take place in the UK but are included for information purposes.

18] With respect to enrichment, we note that this is currently undertaken in the UK at Urenco's Capenhurst site. According to Urenco's 2022 annual report (Urenco_AR2022.pdf), Urenco had a global enrichment capacity of 17,900t separative work. This capacity is more than sufficient to fuel a proposed UK fleet of 24GWe nuclear generating capacity. However, Urenco already has customers for this output, and is currently responding to massive disruption in the market following a voluntary move away from Russian supply. It is increasing production capacity to accommodate both current customers and UK new build customers if the existing practice of Enrichment was all undertaken in the UK.

19] RR SMR fuel is not currently manufactured in the UK or elsewhere, but it is expected to be similar to fuel that is already manufactured in UK facilities.

20] Justified by virtue of being a class or type of practice existing in the UK prior to 6 February 2018. Under paragraph 5 of the Justification Regulations, a practice is justified if a practice in that class or type of practice was carried out in the United Kingdom before 6 February 2018. These practices are listed in Annex 3 of DEFRA guidance. The Justification of Practices Involving Ionising Radiation (Amended) Regulations 2018; Guidance on their application and administration, Version May 2023.

2: SECURITY OF SUPPLY BENEFIT

The new Overarching National Policy Statement ("NPS") for Energy (EN-1), published in November 2023[21] makes important statements regarding security of supply:

> *"Our objectives for the energy system are to ensure our supply of energy always remains secure, reliable, affordable, and consistent with meeting our target to cut GHG emissions to net zero by 2050."*

The new NPS is also clear about the role of nuclear power in achieving those goals, especially in establishing greater independence from global gas markets:

> *"Nuclear fission already provides the UK with continuous, reliable, safe low carbon power. Nuclear plants produce no direct emissions during operation and have indirect life cycle GHG emissions comparable to offshore wind. Power stations with an estimated lifetime of 60 years provide large amounts of low carbon electrical power, using a relatively small amount of land. Nuclear, alongside other technologies could also offer broader system benefits, such as low carbon hydrogen production through electrolysis, or low carbon heat. In addition, nuclear generation provides security of supply benefits by utilising an alternative fuel source to other thermal plants, with a supply chain independent from gas supplies."*

The Government specifically includes Small Modular Reactors (SMRs) within its policy approach to achieving these goals.

> *[...] Our analysis suggests additional nuclear beyond Hinkley Point C will be needed to meet our energy objectives. Nuclear technology is developing and opportunities for flexible use may grow as the energy landscape evolves. The role of nuclear power could be fulfilled by large-scale nuclear fission, Small Modular Reactors, Advanced Modular Reactors, and fusion power plants."*

The Proposed Practice is a prime example of the utilisation of Small Modular Reactors in providing firm, dispatchable nuclear power necessary to complement intermittent renewables in maintaining the stability and security of the Great Britain ("GB") electricity system.

The adoption of the Proposed Practice would provide secure, low-carbon electricity, directly meeting UK government policy ambitions and providing a significant benefit to the UK from a security of supply perspective.

2.1 Introduction

2.1.1 This Chapter substantiates the benefits of the Proposed Practice in supporting the security and reliability of the GB electricity supply. The benefit is due to the firm, dispatchable source of generation represented by the Proposed Practice.

2.1.2 To substantiate this benefit, the Chapter:

- Identifies the UK's requirement for security of electricity supply and the risks to its continued delivery, as highlighted by Russia's invasion of Ukraine (Section 2.2.1);
- Distinguishes the role of firm and dispatchable sources of generation, such as the Proposed Practice, from that of intermittent renewable sources in ensuring security of supply, and identifies their increasing importance as the UK economy becomes more dependent on electricity in the decades ahead (Section 2.3);
- Identifies the UK Government's sustained policy recognition of the contribution of nuclear generation to security of supply, including that of Small Modular Reactors, in support of the British Energy Security Strategy (Sections 2.9-2.11);
- Identifies the benefit of smaller-capacity modular sources of generation, such as the Proposed Practice, in reducing the need for the grid system to hold reserve generation capacity in case of unplanned loss (Section 2.6); and
- Identifies the contribution of the Proposed Practice to energy independence and its lack of vulnerability to offshore malicious damage (Section 2.11.6).

21] Department for Energy Security and Net Zero, "Overarching National Policy Statement for Energy (EN-1)", November 2023: https://assets.publishing.service.gov.uk/media/655dc190d03a8d001207fe33/overarching-nps-for-energy-en1.pdf, pages 33-34.

2.2 Background

Why Security of Supply Matters

2.2.1 People, industry, commerce, Government and public services all depend on the reliable supply of energy to function properly. Delivering that reliable supply of energy at an affordable price ensures that the UK remains competitive globally and contributes to the population's quality of life. Interruptions to supply, and the increased costs which would result, would have a substantial adverse social and economic impact. In fact, the UK estimates the Value of Lost Load, that is the value that electricity consumers attribute to preserving security of supply, at £6,000 per MWh.[22]

2.2.2 Before Russia's invasion of Ukraine in February 2022, the significant risks to the security of supply in the UK were considered to centre on the capacity, diversity, and reliability of the sources of fuel supply and electricity generation, together with the scale and responsiveness of demand. Thus, they were perceived as determined primarily by technical capability and rational economic decision-making, mediated by price signals.

2.2.3 Russia's attempted weaponisation of gas supplies before and after its invasion of Ukraine, and the subsequent effects of gas price rises on overall inflation, underscore the severe risk of importing gas from global markets to sustain our leading source of electricity. The UK Government has identified an urgent need to reduce gas imports and to build up sovereign sources of electricity, including nuclear, in its place.

2.2.4 This Chapter looks at the potential security of supply benefits that would result from the adoption of the Proposed Practice, taking all these risks into account.

2.3 Contribution to GB Electricity Supply

2.3.1 To achieve the benefits to society identified above, it is crucial that the GB electricity system is provided with a mix of generating, interconnection, and storage sources that, in aggregate, deliver high confidence that demand will be met.

2.3.2 The Proposed Practice is an important means of contributing to this mix through the generation of reliable, dependable, baseload energy. Each unit of the Proposed Practice has a net electrical output of approximately 470 MWe, from a site of just 2.15 hectares, providing power for approximately one million homes.[23] Irrespective of the other characteristics of nuclear as a source of generation, this ability to generate energy from a sovereign source is a substantial benefit to be considered when making a Justification decision.

2.4 Robustness of the GB Electricity System

2.4.1 Over recent years the UK Government and the regulator Ofgem have been driving development of a more flexible energy system.[24] In this context, "flexible" refers to a range of new technologies and services, both distributed and central, and on both the generation and demand sides, that maintains the security of supply by the electricity system at significantly reduced cost. The resulting developments include the Capacity Market ("CM") and increased storage and interconnector capacity together with demand-side management, alongside a continued increase in renewable generation.

2.4.2 However, electricity cannot yet be stored in quantities sufficient to meet national demand, for example over the duration of a winter anticyclone which can last a month or more.[25] The battery installation claimed as the world's largest grid support facility at the time of writing has a total capacity of 3,000 MWh and output of 750 MW.[26] Although important in providing short-term flexibility, such a facility would contribute little over this period against forecast GB winter demand in excess of 45 GWe.[27] Thus the vast majority of demand must still be met by the capability to generate or import electricity.

22] Elexon, Annual Review of the Value of Lost Load (VoLL) and Loss of Load Probability (LoLP), 2023: https://www.elexon.co.uk/documents/groups/isg/2023-meeting/269-september/isg269-04-annual-review-of-voll-and-lolp-2023/.

23] Rolls Royce, "Small Modular Reactors", https://www.rolls-royce.com/innovation/small-modular-reactors.aspx#/. Accessed 27 November 2023.

24] Upgrading Our Energy System – Smart Systems and Flexibility Plan, July 2017, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633442/upgrading-our-energy-system-july-2017.pdf.

25] Met Office, National Meteorological Library and Archive Fact sheet 4 — Climate of the British Isles https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/library-and-archive/library/publications/factsheets/factsheet_4-climate-of-the-british-isles.pdf

26] Vistra Corporation, Vistra Zero, 2022 https://vistracorp.com/vistra-zero/

27] National Grid ESO, Winter Outlook Report, September 2023: https://www.nationalgrideso.com/document/289136/download.

2.4.3 Furthermore, notwithstanding increased energy efficiency and demand-side management, overall demand is projected to rise as electrification becomes more widespread, in vehicular transport and domestic heating, for example.[28] As the national economy and energy system become more dependent on electricity into the future, security of supply will become even more vital.

2.4.4 Over and above its contribution to energy supply, nuclear generation has characteristics that make it a significant contributor to the robustness of the generation mix, and hence to security of supply for decades ahead. The next part of this Chapter describes this further substantial benefit of the Proposed Practice.

2.5 Role of Firm and Dispatchable Plant

2.5.1 The contribution of nuclear generation to the robustness of the electricity system rests in the first place on its characteristics as firm, dispatchable plant.

2.5.2 The demand for electricity within GB varies all the time. However, a significant proportion of demand is required 24 hours a day, such as for the continuous operation of industry and essential infrastructure. Firm, dispatchable plants are the bedrock in meeting this continuous demand. The key attribute of such plants is their ability to generate continuously in a reliable and predictable way, as dispatched by the operator of the electricity grid system, together with their favourable economic characteristics when operated in this way. Such plants are generally operated continuously at high capacity.

2.5.3 New nuclear power stations with their low variable costs, high availability, and low Greenhouse Gas ("GHG") emissions constitute firm, dispatchable plants and are well suited to meet the continuous component of future demand. The Proposed Practice is designed to share these attributes.

2.5.4 Nevertheless, the European Utility Requirements ("EUR") for Light Water Reactors ("LWR")s[29] and the GB Grid Code[30] and Connection and Use of System Code,[31] which govern connection of generating plant with the national electricity transmission system, specify requirements for the capability to flex generated output to enable load following and frequency response. These capabilities can make a substantial contribution to the stability and robustness of the electricity system. There is already substantial experience of operating nuclear plant in these flexible modes, for example in France and Germany (before its nuclear stations were closed), and of the technical and economic implications of doing so.[32] For decades, France has demonstrated that a reliable and responsive system can be run with more than 70% of generation provided by nuclear, and the French nuclear fleet to this day adjust its output quite substantially to accommodate variations in demand and renewable output.[33] Fluctuations, including spikes, have traditionally been accommodated in the UK by responsive thermal power plants, particularly gas generation, but all modern nuclear reactors, including that covered by the Proposed Practice, are designed to be able to load follow and provide other Grid services if required.

2.5.5 The Proposed Practice is designed to comply with the requirements of the GB codes, though the extent of operation in these modes will be subject to system requirements and commercial negotiation in respect of its individual implementations.

2.6 Impact on Need for Reserve Generation

2.6.1 Notwithstanding the benefits of nuclear generation as firm, dispatchable plant, it remains the case that from time-to-time individual nuclear generating units may undergo unplanned outages ("trips" or "scrams"), reflecting the absolute priority of nuclear safety and conservative decision-making—including automatic or manual decisions to cease generation. Likewise, planned outages may take longer than anticipated to ensure that plant is able to operate to the high standards of the industry.

28] Committee on Climate Change, The Sixth Carbon Budget The UK's path to Net Zero, 2020: https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf, p. 115.

29] European Utility Requirements for LWR Nuclear Power Plants, http://www.europeanutilityrequirements.org/Welcome.aspx.

30] National Grid ESO, Grid Code, https://www.nationalgrideso.com/industry-information/codes/grid-code, see for example Connection Conditions CC.6.3.7 and Appendix 3

31] National Grid ESO, Connection and Use of System Code, https://www.nationalgrideso.com/industry-information/codes/connection-and-use-system-code-cusc, see for example 4.1.3 – Frequency response

32] IAEA Nuclear Energy Series, NP-T-3.23, Non-baseload Operation in Nuclear Power Plants: Load Following and Frequency Control Modes of Flexible Operation, 2018, https://www-pub.iaea.org/MTCD/Publications/PDF/P1756_web.pdf see for example p.18, Section 3.2

33] See Réseau de Transport d'Électricité (RTE), eCO$_2$mix - Power generation by energy source: https://www.rte-france.com/en/eco2mix/power-generation-energy-source#.

2.6.2 To ensure continued operation of the GB electricity system within the statutory standard of frequency control,[34] the electricity system operator is required by the Grid Code[35] and Security and Quality of Supply Standards[36] to make provision for sufficient reserve to be available to contain and sustainedly correct any deviation resulting from such loss of infeed, up to a specified limit. This contributes to the technical challenge and economic cost of operating the GB electricity system, with the estimated annual cost of procuring frequency response and reserve of the order of £200 million.[37]

2.6.3 The currently specified most onerous loss for the grid is 1,800 MWe.[38] By contrast, the output from each RR SMR within the Proposed Practice is 470 MWe. While an individual power plant site may contain more than one reactor, unplanned outages are unlikely to be correlated between these. It is possible for incidents, such as grid faults, to affect multiple reactors at the same time, but since the unit size is far below the 1,800 MWe threshold, the risk is substantially reduced, and good operating practice should also mitigate it. As a result, the most onerous loss due to the Proposed Practice is unlikely to approach the current 1800 MW.

2.6.4 While it will contribute substantially to energy supply, the Proposed Practice is not expected to present additional technical difficulty or cost to the system operator in respect of reserve capacity. Indeed, since like all nuclear generating stations, they will use synchronous generators with substantial rotational inertia due to the mass of their rotors, RR SMRs would add to the stability of the electricity system, thus contributing to alleviate the difficulty of frequency control.

2.7 Availability of Nuclear Fuel

2.7.1 Since nuclear fuel has a high energy density relative to fossil fuels, it is readily capable of being stockpiled at several stages in the manufacturing process. This makes nuclear power stations relatively immune from short term fluctuations in the availability of fuel. In this respect, they are very different from, for example, gas-fired power stations, which require a continuous supply of new fuel to generate electricity. A typical modern thermal nuclear reactor will be refuelled only every 12 to 24 months, and the RR SMR within the Proposed Practice is designed to operate for 18 months with high availability at full power before needing to be refuelled. If a refuelling could not take place as scheduled, the reactor could continue to operate for several months, although the maximum power output would slowly decline.

2.7.2 Furthermore, the physical quantity of fuel required is modest compared with that for fossil-fuelled plants. The Organisation for Economic Co-operation and Development ("OECD")'s Nuclear Energy Agency ("NEA") and the IAEA periodically review world uranium market fundamentals in their series of "Red Books". In the 2022 Red Book they calculated that the net generating capacity of 393 GWe of commercial reactors connected to electricity grids worldwide as of 1 January 2021 required a total of about 60,100 tonnes of natural uranium ("tU") annually.[39] The Rolls-Royce SMR in the Proposed Practice would require approximately 4.3 tonnes of uranium (enriched to no more than 5%), of which a third is replaced every 18 months, for a 470 MW plant.

2.7.3 Such modest quantities make stockpiling practicable at several points through the processes between mining of uranium and loading of fuel assemblies into reactors. Many years' worth of fuel could be stored in a relatively small area if future supply became uncertain. Furthermore, the two countries with the largest known reserves of uranium, Australia and Canada, are democracies closely aligned strategically with the UK. Australia, for instance, has the largest known reserves of uranium, approximately 1.6 million tonnes, equivalent to more than 25 years' of current global demand.[40]

2.7.4 It should be noted that the UK owns a uranium stock of approximately 110,000 tonnes from past reprocessing of spent fuel and other activities.[41] If required by any concerns over uranium supplies from abroad, the UK could re-enrich this material for use at facilities designed with additional shielding to allow use of reprocessed uranium. Given that it is common practice to

34] National Grid ESO, Frequency Response Obligations - Statutory, Code and Operational Standards https://www.nationalgrideso.com/document/10411/download

35] National Grid ESO, Grid Code, Issue 6 Revision 14, October 2022 https://www.nationalgrideso.com/document/162271/download

36] National Grid ESO, National Electricity Transmission System - Security and Quality of Supply Standard Version 2.5, April 2021 ("SQSS") https://www.nationalgrideso.com/electricity-transmission/document/189561/download

37] Department for Business, Enterprise and Industrial Strategy, Review of Electricity Market Arrangements Consultation Document, 2022, p.36 fig.4 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1098100/review-electricity-market-arrangements.pdf

38] SQSS, p.59 https://www.nationalgrideso.com/electricity-transmission/document/189561/download

39] Nuclear Energy Agency and the International Atomic Energy Agency, Uranium 2022 - Resources, Production and Demand ("2022 Red Book") https://www.oecd.org/publications/uranium-20725310.htm page.12

40] World Nuclear Association, "Supply of Uranium": https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx. Accessed 28 November 2023.

41] Nuclear Decommissioning Authority and Department for Business Energy and Industrial Strategy, "2022 UK Radioactive Material Inventory": https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1134901/2022_Materials_Report_-_010223.pdf, page 21.

stockpile fuel and fuel inputs at each stage of the front-end nuclear fuel cycle, the UK would have years to prepare for taking such a step.

2.8 Reliability of Generation

2.8.1 The Proposed Practice uses a PWR, the most common reactor technology in the world. Its prospective reliability can be inferred from thousands of reactor-years of operational experience from evolutionary predecessor designs of PWR.

2.8.2 The World Nuclear Association's "World Nuclear Performance Report 2023" shows that PWRs have a worldwide capacity factor of nearly 80%. This is despite unique problems in the French reactor fleet in 2022 and the fact that the French PWRs frequently load follow. In North America, the capacity factor is above 90%.[42]

2.8.3 The UK's only PWR Sizewell B, has a lifetime load factor of 83.5%, with 99% load factor in 2022.[43] This accounts for both planned and unplanned outages.

2.8.4 Given the performance of PWRs globally and the UK's experience as a nuclear operator, it is reasonable to assume that the Proposed Practice would achieve these high capacity factors, which would bolster the UK's security of electricity supply.

2.9 UK Government Policy

UK National Policy on Nuclear Generation Infrastructure

2.9.1 Whatever the potential benefits for security of supply of nuclear generation in general and the Proposed Practice in particular, these would remain theoretical without a framework for their practical implementation that recognises and values these benefits. This is achieved through the UK Government's policies and its frameworks for policy implementation.

2.9.2 The bedrock for effective implementation of policy on nuclear developments within the GB's energy mix is the land-use planning system for major infrastructure, established under the Planning Act 2008[44] and the Localism Act 2011.[45] This legislation provides for National Policy Statements which, once designated, set out the UK Government's objectives for the development of nationally significant infrastructure in a particular sector.

2.9.3 The need for secure electricity supplies in GB, and for new, large-scale infrastructure to be brought forward as soon as possible to meet that need, is confirmed as firm Government policy in the overarching National Policy Statement for Energy ("EN-1"). This was approved by the House of Commons and designated in January 2024[46] and remains in force at the time of writing. EN-1 states:

"Our objectives for the energy system are to ensure our supply of energy always remains secure, reliable, affordable, and consistent with meeting our target to cut GHG emissions to net zero by 2050, including through delivery of our carbon budgets.. This will require a step change in the decarbonisation of our energy system."

2.9.4 EN-1 identifies a growing need for energy capacity:

"Our analysis suggests that even with major improvements in overall energy efficiency, and increased flexibility in the energy system, demand for electricity is likely to increase significantly over the coming years and could more than double by 2050 as large parts of transport, heating and industry decarbonise by switching from fossil fuels to low carbon electricity".

2.9.5 EN-1 also makes an important statement regarding the contribution that new nuclear power stations can make towards achieving the necessary capacity:

"We need to transform the energy system, tackling emissions while continuing to ensure secure and reliable supply, and affordable bills for households and businesses. This includes increasing our supply of clean energy from renewables, nuclear and hydrogen manufactured using low carbon processes"

42] World Nuclear Association. "World Nuclear Performance Report 2023": https://www.world-nuclear.org/getmedia/0156a8d7-01c6-42d9-97be-3f04f34cb8fa/performance-report-2023-final.pdf.aspx, pages 6-7.

43] IAEA Power Reactor Information Systems, "Sizewell B": https://pris.iaea.org/pris/CountryStatistics/ReactorDetails.aspx?current=263.

44] Planning Act 2008, c.29 https://www.legislation.gov.uk/ukpga/2008/29/pdfs/ukpga_20080029_en.pdf

45] Localism Act 2011, c.20 https://www.legislation.gov.uk/ukpga/2011/20/pdfs/ukpga_20110020_en.pdf

46] Department of Energy and Climate Change, Overarching National Policy Statement for Energy (EN-1),("EN-1"), 2023 EN-1 Overarching National Policy Statement for Energy (publishing.service.gov.uk)

2.9.6 In its White Paper[47] preceding designation of the National Policy Statement EN-1 in 2011, the Government recognised the effectiveness of the regulatory framework for the safe and secure transport of nuclear materials that such new nuclear power stations might require:

"...given the safety record for the transport of nuclear materials and the strict safety and security regulatory framework in place, the Government believes that the risks of transporting nuclear materials are very small and there is an effective regulatory framework in place that ensures that these risks are minimised and sensibly managed by industry. The Government believes that this is not a reason not to allow energy companies to invest in new nuclear power stations."

2.9.7 The Government designated a fresh EN-1 on 17 January 2024 that stated that *"our analysis suggests additional nuclear beyond Hinkley Point C will be needed to meet our energy objectives. Nuclear technology is developing and opportunities for flexible use may grow as the energy landscape evolves. The role of nuclear power could be fulfilled by large-scale nuclear fission, Small Modular Reactors, Advanced Modular Reactors, and fusion power plants."*

2.9.8 In particular, in its new Overarching National Policy Statement for Energy (EN-1), that came into force on 17 January 2024,[48] the Government specifically included potential SMRs within its policy approach, of which the Proposed Practice is a prime example:

"Nuclear fission already provides the UK with continuous, reliable, safe low carbon power. Nuclear plants produce no direct emissions during operation and have indirect life cycle GHG emissions comparable to offshore wind. Power stations with an estimated lifetime of 60 years provide large amounts of low carbon electrical power, using a relatively small amount of land. Nuclear, alongside other technologies could also offer broader system benefits, such as low carbon hydrogen production through electrolysis, or low carbon heat. In addition, nuclear generation provides security of supply benefits by utilising an alternative fuel source to other thermal plants, with a supply chain independent from gas supplies. [...] Our analysis suggests additional nuclear beyond Hinkley Point C will be needed to meet our energy objectives. Nuclear technology is developing and opportunities for flexible use may grow as the energy landscape evolves. The role of nuclear power could be fulfilled by large-scale nuclear fission, Small Modular Reactors, Advanced Modular Reactors, and fusion power plants."

2.9.9 As regards potential locations for its implementation, the National Policy Statement for Nuclear Generation (EN-6),[49] designated in 2011, identifies a limited number of sites that are considered potentially suitable for deployment of new nuclear power stations before 2025. However, the Government anticipates introducing a new EN-7 to reflect the wider range of nuclear power technologies identified above and their potential deployment beyond 2025, stating that:

"A new NPS for nuclear electricity generation infrastructure deployable after 2025 will be developed to reflect the changing policy and technology landscape for nuclear"[50]

2.9.10 Thus, in summary, the Proposed Practice includes a design of an SMR falling specifically within the range of nuclear technologies the Government believes may be necessary to deliver the UK's energy needs,[51] with the new NPS expected to be directly relevant to its deployment in GB, both as regards its design and the wider range of potentially suitable sites for deployment.

2.10 Implications of the Invasion of Ukraine for UK infrastructure

2.10.1 The invasion of Ukraine in February 2022 led to a progressive rebalancing of the UK Government's policy priorities and intent for electricity infrastructure in the UK. Furthermore, experience under the more adversarial geopolitical environment since the invasion has demonstrated additional vulnerabilities in the UK's electricity infrastructure.

47] Meeting the Energy Challenge – A White Paper on Nuclear Power, Cm 7296, Department for Business, Enterprise and Regulatory Reform, 2008 (2008 White Paper") https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/228944/7296.pdf

48] Department for Energy Security and Net Zero, "Overarching National Policy Statement for Energy (EN-1)", November 2023: https://assets.publishing.service.gov.uk/media/655dc190d03a8d001207fe33/overarching-nps-for-energy-en1.pdf, pages 33-34.

49] Department of Energy and Climate Change, National Policy Statement for Nuclear Power Generation (EN-6), Volumes I and II, 2011, ("EN-6") https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47859/2009-nps-for-nuclear-volumeI.pdf and https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/47860/1943-nps-nuclear-power-annex-volII.pdf

50] Department for Business, Energy and Industrial Strategy, Planning for New Energy Infrastructure – Draft National Policy Statements for energy Infrastructure, September 2021, p.11 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1015302/nps-consultation-document.pdf

51] Department for Business, Energy and Industrial Strategy, Advanced Nuclear Technologies, 2022 https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies

2.10.2 Prior to the invasion, the Government's 2020 Energy White Paper[52] anticipated a substantial increase in the UK demand for electricity, requiring a major increase in low carbon sources to achieve the national Net Zero target:

"Our modelling suggests that overall demand could double out to 2050. This is because of the electrification of cars and vans and the increased use of clean electricity replacing gas for heating. As a result, electricity could provide more than half of final energy demand in 2050, up from 17 per cent in 2019... This would require a four-fold increase in clean electricity generation with the decarbonisation of electricity increasingly underpinning the delivery of our net zero target."

2.10.3 The Government identified in the Statutory Security of Supply Report 2021,[53] that security of supply through the transition to Net Zero would require more flexible and dispatchable generation, with substantial reliance on increasing international interconnector capacity together with increasing electricity storage capacity as the most economic framework to accompany and enable the increasing contribution of renewable sources.

2.10.4 Underpinning this framework was confidence that security of supply would be ensured by market mechanisms, including the CM together with the UK's diverse market in gas supply:

"The purpose of the CM is to ensure security of GB's electricity supply at least cost to consumers, by providing all forms of capacity with the right incentives to be on the system and to deliver electricity when needed. The CM ensures there is sufficient reliable capacity available during periods of electricity system stress, for example during cold, still periods with high demand and low wind generation.... We remain confident that GB's gas security will be maintained thanks to the diversity of supply sources and established market mechanisms.... To date, GB has always secured the gas required; and BEIS, Ofgem and National Grid analysis has all concluded that it will remain well-positioned to do so. A key factor in GB's ability to secure the necessary gas is an appropriately incentivised, flexible, and accessible market."

2.10.5 Based on this confidence, physical investment to underpin security of supply had been significantly curtailed:

"Since the closure of Rough as a natural gas storage facility by Centrica Storage Limited in 2018, GB has had no long-range storage facilities, with the remaining being mid-range storage. The closure of Rough prevented the costly necessary repairs being passed on to consumers, and storage deliverability has proved sufficient since despite a cold 2020/2021 winter."

2.11 Rebalancing of Policy toward Energy Independence

2.11.1 The invasion of Ukraine in February 2022 has caused the Government to shift its position to emphasise the new geopolitical reality and the consequent importance of increased energy independence, including a renewed emphasis on new nuclear generation:[54]

"New nuclear is not only an important part of our plans to ensure greater energy independence, but to create high-quality jobs and drive economic growth... An ambition of up to 24GW by 2050 to come from this safe, clean, and reliable source of power. This would represent up to around 25% of our projected electricity demand."

2.11.2 This intent has been crystallised as the British Energy Security Strategy,[55] which states:

"Most critically, when we have seen how quickly dependence on foreign energy can hurt British families and businesses, we need to build a British energy system that is much more self-sufficient... We can only secure a big enough baseload of reliable power for our island by drawing on nuclear. Our aim is to lead the world once again in a technology we pioneered so that by 2050, up to a quarter of our power consumed in Great Britain is from nuclear... We will also collaborate with other countries to accelerate work on advanced nuclear technologies, including both Small Modular Reactors and Advanced Modular Reactors (AMRs)."

2.11.3 Other areas of the UK energy infrastructure policy have also changed substantially to reflect the new emphasis on energy independence, demonstrating its very high importance for security of supply:

52] HM Government, Energy White Paper – Powering our Net Zero Future, CP337, December 2020 ("2020 White Paper") https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf

53] Department for Business, Energy and Industrial Strategy, Statutory Security of Supply Report 2021, HC 898, December 2021 ("SoS Report 2021") https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1040468/statutory-security-of-supply-report-2021.pdf

54] Department for Business, Energy and Industrial Strategy and Prime Minister's Office, Nuclear energy: What you need to know, April 2022 https://www.gov.uk/government/news/nuclear-energy-what-you-need-to-know

55] HM Government, British Energy Security Strategy, April 2022 ("BESS") https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1069969/british-energy-security-strategy-web-accessible.pdf

"Centrica has announced the reopening of the Rough gas storage facility, having completed significant engineering upgrades over the summer and commissioning over early autumn." [56]

2.11.4 Subsequently, media reports of an investigation into the failure of the Nord Stream 1 gas pipeline off Bornholm indicate that this revealed extensive, serious damage:[57]

"A video shot by Norwegian robotics company Blueye Robotics, published by Swedish newspaper Expressen, now appears to show a 50m-long tear in the Nord Stream 1 pipe."

2.11.5 It appears that geopolitical tensions following the invasion of Ukraine may have risen to the point of malicious damage to energy infrastructure. Whether true in this case or not, it suggests that there is at least the possibility of malicious damage to other offshore energy infrastructure. In the case of the UK, such infrastructure includes both electricity and gas interconnections and the connections to offshore wind farms. As noted above, the UK's dependence on each of these is expected to increase over the next decades.

2.11.6 By contributing to a baseload of reliable power, the Proposed Practice would directly support the British Energy Security Strategy. Located on sites within the UK it would also avoid the offshore vulnerability demonstrated by the damage to the Nord Stream pipeline.

2.12 Summary of Results and Conclusion

2.12.1 In summary, the Proposed Practice offers distinct benefits to security of supply.

2.12.2 Firstly, nuclear energy has a track record of providing the UK with a secure, large-scale source of electricity. The Proposed Practice would make a substantial contribution to extending this into the future, when the overall magnitude of electricity demand and the extent of dependence on electricity are expected to grow as the UK economy is decarbonised towards Net Zero by 2050.

2.12.3 Secondly, as the GB electricity system develops toward the target of Net Zero by 2035, a significant tranche of firm, dispatchable low-carbon generation continues to be required as part of the generation mix to complement intermittent renewable sources. New nuclear power stations, including the Proposed Practice, are ideally suited to this role. Their optimum contribution has increased as decarbonisation targets have become more ambitious.

2.12.4 Thirdly, the Proposed Practice would contribute to ensuring a diverse range of technologies and fuel sources within the generation mix, adding to its robustness and resilience. A role for SMRs, of which the Proposed Practice is an example, is recognised and supported by UK Government policy as part of the British Energy Security Strategy.

2.12.5 Fourthly, the Proposed Practice can rely on the extensive global experience of operating PWRs, which has led to substantial improvements in PWR capacity factor over the decades and very high reliability of these generating technology.

2.12.6 In summary, the Proposed Practice would provide a substantial benefit to the UK's security of electricity supply.

56] Centrica plc, Centrica re-opens Rough storage facility, October 2022 https://www.centrica.com/media-centre/news/2022/centrica-re-opens-rough-storage-facility/

57] Thomas Johnson, New Civil Engineer, Nord Stream explosions caused 50m of damage to ruptured pipeline, 20 October 2022 https://www.newcivilengineer.com/latest/nord-stream-explosions-caused-50m-of-damage-to-ruptured-pipeline-20-10-2022/#:~:text=More%20details%20of%20the%20damage,50m%20of%20pipe%20is%20missing

3: CLIMATE CHANGE AND NET ZERO BENEFITS

The Climate Change Act 2008 established a legally binding carbon reduction target for the UK. Section 1(1) of the Act, as amended in 2019, states that:[58]

> *"It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 100% lower than the 1990 baseline"*

The Intergovernmental Panel on Climate Change ("IPCC")'s latest Synthesis Report warns that "*All global modelled pathways that limit warming to 1.5°C… with no or limited overshoot, and those that limit warming to 2°C…, involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade."* [59]

The International Energy Agency (IEA)'s report Net Zero by 2050: A Roadmap for the Global Energy Sector projects a doubling of nuclear capacity worldwide to reach net zero.[60]

In the UK, the Government recognises the significant contribution SMRs can make:[61] to meeting its climate change and net zero goals *"We are pursuing large-scale nuclear, whilst also looking to the future of nuclear power in the UK through further investment in Small Modular Reactors and Advanced Modular Reactors."*

The Government's Civil Nuclear: Roadmap to 2050 published in 2024 further stated that *"to deliver energy security while driving down costs our long-term ambition is the deployment of fleets of SMRs in the UK."* [62]

The Proposed Practice is a leading example of an SMR. Since it will utilise LWR technology, the Proposed Practice would, alongside other LWRs, generate the lowest lifecycle carbon intensity of any firm power generating source.

The United Nations Economic Commission for Europe (UNECE) 2022 study Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources found that relative to other low carbon technologies capable of delivering firm electricity, nuclear's GHG emissions are significantly lower.[63]

The Proposed Practice is well suited to close the shortfall in firm, low carbon capacity. Its adoption would provide a significant benefit to the UK from a climate change perspective and in meeting the UK's net zero target.

3.1 Introduction

3.1.1 This Chapter substantiates the benefit of the Proposed Practice in mitigating the severe adverse impacts on the climate that arise as a result of anthropogenic GHG emissions, and in meeting the associated legally binding requirement to achieve Net Zero now embodied in UK legislation.

3.1.2 The benefit is due to the ability of the Proposed Practice, utilising proven PWR technology, to generate reliable electricity with very low GHG emissions.

3.1.3 To substantiate the significance and magnitude of this benefit, this Chapter:

- Identifies why this issue is of critical importance globally, together with the UK's response to its significance and urgency through its legally binding commitment to Net Zero by 2050 (Sections 3.2.1-3.2.2);
- Summarises the current trajectory of the electricity sector's contribution to Net Zero and its shortfall against this target, worsened by the declining contribution of nuclear generation unless augmented by further new build (Section 3.2.3);

58] Climate Change Act 2008 http://www.legislation.gov.uk/ukpga/2008/27/part/2#printLegislationModPdf ; Climate Change Act 2008 (2050 Target Amendment) Order 2019, SI2019:1056, https://www.legislation.gov.uk/uksi/2019/1056/pdfs/uksi_20191056_en.pdf

59] IPCC, Synthesis Report of the IPCC Sixth Assessment Report 2023: Summary for Policymakers, IPCC, Geneva, Switzerland https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_SPM.pdf p.21, paragraph B.6.

60] International Energy Agency, Nuclear Power and Secure Energy Transitions, 2022: https://www.iea.org/reports/nuclear-power-and-secure-energy-transitions.

61] Department for Business, Energy and Industrial Strategy, Energy White Paper, Powering our Net Zero Future CP337 December 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf p.12

62] Department for Energy Security and Net Zero, Civil Nuclear: Roadmap to 2050, January 2024: https://assets.publishing.service.gov.uk/media/65c0e7cac43191000d1a457d/6.8610_DESNZ_Civil_Nuclear_Roadmap_report_Final_Web.pdf, pp. 20-1.

63] United Nations Economic Commission for Europe, "Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, 2020: https://unece.org/sites/default/files/2022-08/LCA_0708_correction.pdf, Figure 1.

- Highlights the UK Government's policy commitment to new nuclear generation as a key part of its policy intent for Net Zero by 2050 and, as a major contribution to this, for full decarbonisation of the electricity system from 2035 onwards (Section 3.2.4);
- Summarises the Committee on Climate Change's concern on the shortfall in actions necessary to achieve this commitment, together with its reservations on demonstration of Carbon Capture and Storage ("CCS") as a potential alternative to nuclear in generating firm low carbon electricity (Section 3.2.5);
- Summarises existing authoritative assessments of the GHG emissions for nuclear power technologies as benchmarks for assessing the contribution of the Proposed Practice to reducing GHG emissions during the timescale of its potential implementation (Section 3.6);
- Substantiates the very low prospective lifetime GHG emissions of the Proposed Practice, expressed as gCO_2e/kWh supplied to the electricity network using the approach set out below (Sections 3.6.6-3.6.20); and
- Establishes the potential contribution of the Proposed Practice to the UK's overall emissions in sustaining a low carbon electricity system through to the Net Zero target, and its significant benefit relative to Combined Cycle Gas Turbines ("CCGT") with CCS as a leading non-nuclear alternative for firm generation (Section 3.7).

3.2 Background

Why Climate Change Matters

3.2.1 There is scientific consensus that human activities are causing global climate change. The burning of fossil fuels, changes in land use, and various industrial processes are adding GHGs,[64] particularly carbon dioxide ("CO_2"), to the atmosphere. The CO_2 concentration has already increased by some 48% since pre-industrial times,[65] primarily from fossil fuel emissions and secondarily from net land use change emissions, and it continues to do so.

3.2.2 The IPCC's Working Group concerned with mitigation has highlighted the substantial risk that global warming will exceed 1.5°C:

"Without a strengthening of policies beyond those that are implemented by the end of 2020, GHG emissions are projected to rise beyond 2025, leading to a median global warming of 3.2 [2.2 to 3.5]°C by 2100." [66]

3.2.3 Global warming of this magnitude would have substantial consequences for both the environment and people's lives. These include extreme temperatures, increases in frequency, intensity and/or amounts of heavy precipitation, an increase in intensity or frequency of droughts, and continued sea level rise, with climate-related risks for health, livelihoods, food security, water supply, human security and economic growth, each becoming more severe if global warming increases beyond 1.5°C.

3.2.4 In an early response by the UK to this threat, the Climate Change Act 2008[67] (the "2008 Act") established the world's first legally binding climate change target, requiring an 80% reduction in GHG emissions from 1990 levels by 2050. This was upgraded in 2019 to a "net zero" target as described below.

3.2.5 The 2008 Act also established the Committee on Climate Change ("CCC") with the purpose of, amongst other functions, advising the UK Government on emissions targets and reporting to Parliament on progress made in reducing GHG emissions and preparing for climate change.[68]

3.2.6 Subsequent to the 2008 Act, the UK has taken part in the international commitment made through the Paris Agreement to strengthen the response to this threat, which it ratified in 2016.[69] The aims of this Agreement include keeping the global temperature rise to well below 2°C above pre-industrial levels, and to pursue efforts to limit any such increase even further to 1.5°C.

64] GHGs comprise the seven direct greenhouse gases under the Kyoto Protocol: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6) and Nitrogen trifluoride (NF_3) – see Department for Business, Energy and Industrial Strategy, National Atmospheric Emissions Inventory, Overview of greenhouse gases https://naei.beis.gov.uk/overview/ghg-overview.

65] Annual average atmospheric CO_2 at Maunakea (close to Mauna Loa Observatory) in 2021 was 416.45 ppm, relative to pre-industrial level of about 280 ppm. Data from NOAA Earth System Research Laboratory, Trends in Atmospheric Carbon Dioxide https://gml.noaa.gov/ccgg/trends/data.html

66] IPCC AR6 WG III Climate Change 2022: Mitigation of Climate Change: Summary for Policymakers, April 2022 https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

67] Climate Change Act 2008 http://www.legislation.gov.uk/ukpga/2008/27/data.pdf

68] Part 2 of Climate Change Act 2008; see also sections 33 to 36 setting out functions of the CCC.

69] Department for Business, Energy and Industrial Strategy, UK ratifies the Paris Agreement, 2016 https://www.gov.uk/government/news/uk-ratifies-the-paris-agreement

3.2.7 At the UK level, in 2019 the CCC recommended a new emissions target for the UK: Net Zero GHG by 2050. This has subsequently been implemented into UK law as a change to the target within the 2008 Act,[70] representing the first occasion on which a major economy has enshrined a legal commitment to Net Zero. The Secretary of State has confirmed to Parliament that this Net Zero target includes international aviation and shipping.[71]

3.2.8 The CCC's 2023 Progress report found that, while UK emissions in 2022, the last fully available year, are 46% below 1990 baseline levels, *"the rate of emissions reduction will need to significantly increase for the UK to meet its 2030 NDC and the Sixth Carbon Budget."* [72]

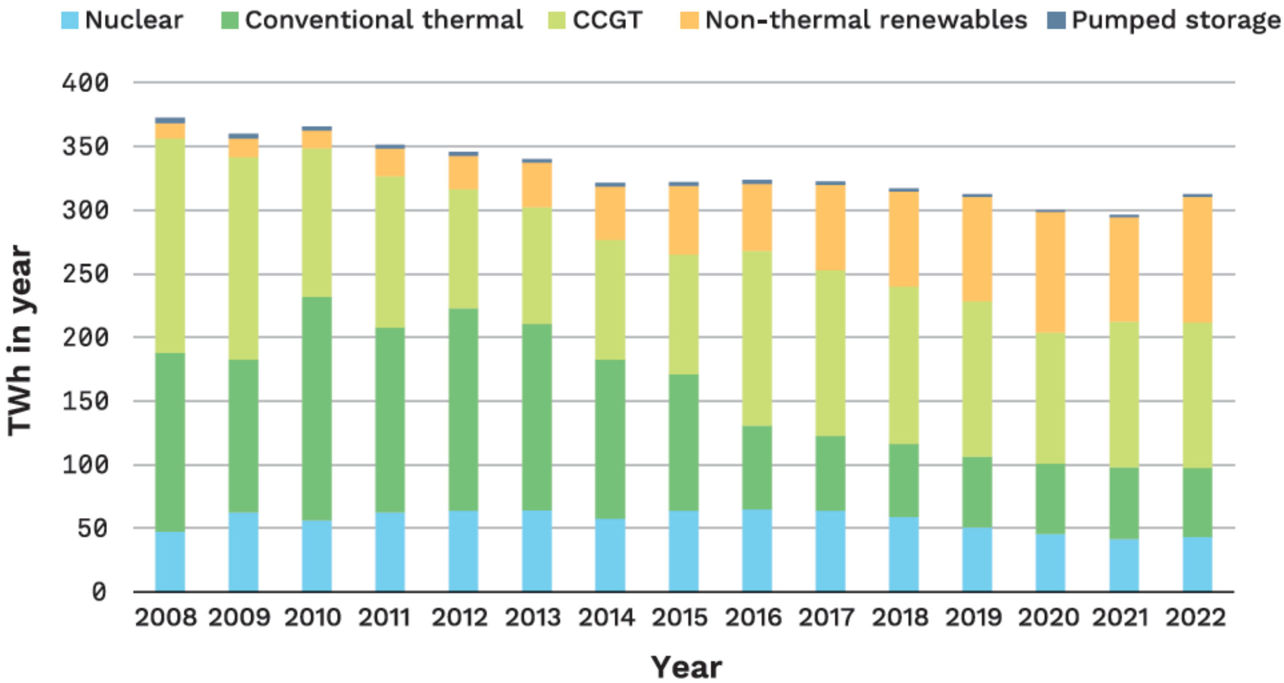
3.3 Contribution of the Electricity Sector to Net Zero

3.3.1 Meeting Climate Change Act targets has already required a substantial reduction in the UK's dependence on fossil fuels. In the UK's electricity sector, the contribution to the response to the threat has required reduced reliance on gas and especially coal, while increasing the amount of electricity generated through low-carbon technologies such as renewables and nuclear.

3.3.2 The overall change in electricity mix is illustrated in Figure 4.1 below showing its development between 2008 and 2022. This demonstrates the continued growth of renewable generation, the decrease in fossil-fired generation, especially coal, and the decrease of nuclear power generation within a decreasing overall total.

3.3.3 This change has been driven by a combination of positive UK Government policy on renewable energy[73] and a sustained reduction in the cost of renewables and the retirement of older nuclear power stations. The distinction between intermittent renewable and firm, dispatchable sources of low carbon electricity, including nuclear, is important for security of supply, as described in the previous Chapter, together with the reasons why they are not interchangeable.

Figure 1: Mix of fuel used for UK electricity generation since 2008[74]



70] The Climate Change Act 2008 (2050 Target Amendment) Order 2019, SI 2019 No. 1056 https://www.legislation.gov.uk/uksi/2019/1056/made/data.pdf

71] House of Commons Hansard, 12 June 2019, Volume 661 https://hansard.parliament.uk/commons/2019-06-12/debates/A348AE4C-8957-42C8-8180-0F59E597E3EA/NetZeroEmissionsTarget

72] Climate Change Committee, Progress in reducing emissions: 2023 Report to Parliament: https://www.theccc.org.uk/wp-content/uploads/2023/06/Progress-in-reducing-UK-emissions-2023-Report-to-Parliament-1.pdf, page 16.

73] Department of Energy and Climate Change, 2010 to 2015 government policy: low carbon technologies, 2015 https://www.gov.uk/government/publications/2010-to-2015-government-policy-low-carbon-technologies/2010-to-2015-government-policy-low-carbon-technologies

74] Data taken from Department for Energy Security and Net Zero, Historical electricity data: 1920 to 2022 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224644/electricity_since_1920_historical_data.xls.

3.3.4 Underpinning this distinction, the contribution of renewables fluctuates and depends significantly on the weather, with wind generation for example dropping 14 per cent between 2020 and 2021 despite increased capacity because of unusually low wind speeds, but then rising 20 per cent in 2022.[75] At the end of the period shown, about 35% of electricity was still generated from fossil fuels, as the loss of baseload nuclear capacity has partially offset the gains from the addition of variable renewable capacity, which must at present be backed up by fossil fuel generation.

3.3.5 A significant contribution has also been made by reducing the UK's overall consumption of electricity through demand reduction. However, as discussed below, reducing the carbon content of the UK's wider heat and transport energy needs over the coming decades is expected to require an overall substantial increase in the amount of electricity generation needed.

3.3.6 With regard to the contribution of nuclear to the reduction in GHG, Figure 4.1 shows that nuclear output initially increased after 2008, with improved performance by the UK's Advanced Gas-cooled Reactor ("AGR") power stations, reaching a peak of approximately 20% of generation. However, three of the seven AGR power stations have ceased generation, and the remaining four stations are currently scheduled to cease generation completely by 2028: the operator intends to run them *"as long as it is safe and commercially viable to do so"*, while acknowledging that there are life limiting factors.[76] From a peak of nearly 13 GW in 1995, the UK's existing nuclear fleet will be reduced to just the 1.2 GW station at Sizewell B by 2028. That station is expected to operate until 2055, if a 20-year life extension is successful. Thus any increase in the nuclear contribution to decarbonisation targets from the mid-2030s and onward will have to come from new nuclear power stations.

3.3.7 In terms of new builds, only Hinkley Point C is currently under construction, with Sizewell C having been granted Development Consent,[77] a Nuclear Site Licence,[78] and its Radioactivity Substances Activity Permit, Combustion Activity Permit, and Water Discharge Activity Permit,[79] and at the time of application awaiting a Final Investment Decision ("FID"). When Hinkley Point C and Sizewell C are connected to the grid, the UK will still have only 7.7 GW of operational nuclear capacity, less than it had as late as 2021.[80] At the same time, electricity demand is expected to grow by 50% by 2035 and to double or even triple by 2050.[81]

3.3.8 Against this background, implementation of the Proposed Practice from around 2030 onwards could contribute very materially in sustaining the role of nuclear to the UK's legal commitment to Net Zero by 2050.

3.4 Government Policy Intent on Achieving Net Zero

3.4.1 To meet the challenge of the legally binding Net Zero target, the CCC's scenarios demonstrate the importance of decarbonising the UK's electricity sector, with all power produced from low-carbon sources, whilst at the same time accommodating around a doubling in demand noted above.

3.4.2 The UK Government's policy intent recognises the significant contribution that nuclear can make to achieving Net Zero, and the breadth of agreement internationally on the complementary roles of nuclear and renewable sources in achieving this.[82]

3.4.3 Importantly its policy intent includes not just large-scale technologies, but also smaller-scale technologies including SMRs, of which the Proposed Practice constitutes a leading example:[83]

> *"Nuclear power provides a reliable source of low-carbon electricity. We are pursuing large-scale nuclear, whilst also looking to the future of nuclear power in the UK through further investment in Small Modular Reactors and Advanced Modular Reactors."*

75] Ibid.

76] EDF Energy, UK Nuclear Fleet Stakeholder Update, 2024 https://www.edfenergy.com/sites/default/files/2024-01/FM10845%20UK%20Nuclear%20Fleet%20Strategy%20Update%20V7.pdf.

77] Planning Inspectorate, The Sizewell C Project development consent decision announced, 2022 https://www.gov.uk/government/news/the-sizewell-c-project-development-consent-decision-announced; EDF Energy, Government backs Sizewell C with £700m funding announcement, 2022 https://www.edfenergy.com/energy/nuclear-new-build-projects/sizewell-c/news-views/government-investment-decision-on-sizewellc

78] Office for Nuclear Regulation, ONR grants nuclear site licence for Sizewell C https://www.onr.org.uk/news/all-news/2024/05/onr-grants-nuclear-site-licence-for-sizewell-c/.

79] Environment Agency, Environmental permits issued for new nuclear power station at Sizewell C, 28 March 2023: https://www.gov.uk/government/news/environmental-permits-issued-for-new-nuclear-power-station-at-sizewell-c.

80] World Nuclear Association, Nuclear Power in the United Kingdom: https://world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx. Accessed 27 November 2023.

81] Climate Change Committee, The Sixth Carbon Budget: The UK's Path to Net Zero, 2020: https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf, page 25.

82] UK Government, Nuclear energy: What you need to know, 2022 https://www.gov.uk/government/news/nuclear-energy-what-you-need-to-know.

83] Department for Business, Energy and Industrial Strategy ("BEIS"), Energy White Paper, Powering our Net Zero Future CP337 December 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf p.12

3.4.4 Providing a time-based target for the electricity sector, the UK Government's Net Zero Strategy includes the key policy that, as long as security of supply is maintained, the electricity system will be fully decarbonised by 2035.[84]

3.4.5 The UK Government's British Energy Security Strategy assigns a key role to nuclear generation through and beyond this time horizon, including a specific ambition to increase the civil nuclear capacity to up to 24GW by 2050.[85]

3.4.6 This represents a requirement to which implementation of the Proposed Practice from the 2030s onwards could make a very material contribution.

3.5 Requirements to Successful Achievement of Net Zero in the Electricity Sector

3.5.1 The CCC in its annual report to the UK Parliament in June 2023, called for greater clarity on the Government's nuclear deployment ambitions:

"The Government has committed to decarbonising electricity supply by 2035, subject to ensuring security of supply. It has also committed to ambitious targets for building new renewables and nuclear capacity, and has published a number of plans expanding on some aspects required for decarbonising the sector. However, in contrast to other sectors, the Government has not yet published an overarching delivery plan or strategy." [86]

3.5.2 Following this, the Government published Civil Nuclear: Roadmap to 2050, in which it stated that *"we are committing to deploy SMRs in the UK, unlocking the benefits of modularisation and replication"*, and that *"to deliver energy security while driving down costs our long-term ambition is the deployment of fleets of SMRs in the UK."* [87]

3.5.3 The Roadmap set out the following further plans relevant to the Proposed Practice:

- A new criteria-based siting policy to facilitate, inter alia, the rollout of SMRs.
- Completing the Great British Nuclear ("GBN") led Small Modular Reactor (SMR) technology selection process, announcing which technologies will be supported to achieve Final Investment Decision (FID) by 2029.
- Aim to secure investment decisions on 3-7 GW of nuclear capacity in each of the five year periods from 2030 through 2044.[88]

3.5.4 The CCC has noted the dependence of its projections on the performance of as yet unproven CCS technologies, and that unless high capture rates are demonstrated its role would have to be limited. Since fossil-fired plants equipped with CCS represent the leading potential alternative to nuclear in providing firm low carbon electricity, any such limitation would add to the urgency of need for technologies such as the Proposed Practice.

3.5.5 Moreover, the UNECE report on lifecycle emissions of electricity generators found that even if successful proven, gas with CCS technology would still have estimated lifecycle emissions of 90-221g/kWh, at least 15 times the lifecycle emissions of nuclear, estimated at 5.1-6.4g/kWh.[89]

3.5.6 Therefore, there are no currently available alternatives to the proven, scalable, reliable, firm power provided by nuclear reactors. Innovation in other technologies is welcome, but the promise of innovation should not be conceived as a replacement or displacement of proven clean technologies like nuclear.

3.5.7 Against this background of compelling need and halting delivery, a programme of new nuclear power stations, including the Proposed Practice, could provide secure, large-scale, electricity to well beyond 2050 with the emission of very low levels of GHGs. This would make a substantial contribution to the achievement of Net Zero. The basis for this expectation is substantiated in the following sections.

84] UK Government, Net Zero Strategy: Build Back Greener, October 2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf p.19.

85] UK Government, British energy security strategy, April 2022 https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy#nuclear.

86] Committee on Climate Change, Progress in reducing emissions: 2023 Report to Parliament, June 2023 https://www.theccc.org.uk/wp-content/uploads/2023/06/Progress-in-reducing-UK-emissions-2023-Report-to-Parliament-1.pdf, p.212.

87] Department for Energy Security and Net Zero, Civil Nuclear: Roadmap to 2050, January 2024: https://assets.publishing.service.gov.uk/media/65c0e7cac43191000d1a457d/6.8610_DESNZ_Civil_Nuclear_Roadmap_report_Final_Web.pdf, pp. 20-1.

88] Ibid.

89] United Nations Economic Commission for Europe, "Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, 2020: https://unece.org/sites/default/files/2022-08/LCA_0708_correction.pdf, Figure 1.

3.6 Evaluation of the Benefits of the Proposed Practice for Climate Change and Net Zero

Comparative Greenhouse Gas Emissions from the Proposed Practice

3.6.1 The PWR technology used in the Proposed Practice is proven to have very low lifecycle emissions. The United Nations Economic Commission for Europe ("UNECE") 2022 study Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, found that nuclear had a lifecycle carbon intensity of 5.1-6.4g CO_2 equivalent/kWh of electricity, the lowest of any electricity generating source.[90]

3.6.2 Electricity sources differ in the distribution of GHG emissions between the stages in the life cycle of their power plants, with fossil fuels for example resulting in high emissions during operation in generating electricity, whereas nuclear power stations emit very little GHGs directly from their operation.

3.6.3 However, all forms of electricity generation have some GHG emissions associated with the construction, commissioning and decommissioning of their plant. Nuclear has GHG emissions associated with energy use during mining, construction and operation, and also with processing and isotopic enrichment of uranium and the manufacture of nuclear fuel. Further GHG emissions occur during reprocessing (if carried out) and in the management and disposal of the spent fuel and radioactive waste.

3.6.4 To enable comparison between projects using different sources, it is useful to evaluate their performance via Life Cycle Assessment ("LCA"). This accounts for emissions from all phases of the project (mining, construction, operation, and decommissioning). Normalising the lifecycle emissions against the electricity they supply to the grid system allows for a fair comparison of the different generation methods on a per kilowatt-hour basis.[91]

3.6.5 LCAs relevant to nuclear generation generically have been developed by the IPCC and in a prospective study by workers at the Potsdam Institute of Climate Impact Research, the latter taking into account prospective future changes in the electricity system. Within the UK, assessments have been made retrospectively for Sizewell B and prospectively for the proposed Sizewell C. These are summarised in the following sections.

Relevant Comparable Assessments

3.6.6 To substantiate the emissions from the Proposed Practice, the approach taken is to:

- Identify inputs from comparable nuclear reactor technologies to the Proposed Practice;
- Establish that LCA is the appropriate metric of GHG intensity for the purpose of assessment;
- Highlight the significance of external assumptions, particularly on the GHG intensity of electricity imported during construction and used for uranium enrichment, in evaluating the LCA for any nuclear technology. Bearing in mind the expected progressive decarbonisation of the GB electricity system, this makes it important to take into account the envisaged timeframe of its implementation;
- Summarise relevant assessments of the GHG intensity of current nuclear technologies taking these external assumptions into account, to establish benchmarks relevant to implementation of the Proposed Practice;
- Characterise the additional reductions in GHG intensity relative to these benchmarks that can be expected for the Proposed Practice; and
- Demonstrate that implementation of the Proposed Practice would at least sustain and reinforce the very low GHG intensity of a fully decarbonised electricity system, and if it displaced CCGT with CCS, can be expected to reduce it significantly.

IPCC Assessment

3.6.7 In 2014, as part of its fifth Assessment Report the IPCC updated its assessment of published LCAs comparing GHG emissions from different electricity generation technologies.[92] Such assessments aim to include the GHG contributions from all stages and aspects of the technology concerned, apportioning these across the quantity of electricity delivered to the electricity system over the operational stage of the plant's life.

90] Ibid.

91] World Nuclear Association, Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources, July 2011 https://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf.

92] Bruckner, T et al, Chapter 7, in: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change ("WG III") https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter7.pdf

3.6.8 The IPCC report drew on a comprehensive review of published LCAs for nuclear generation by LWR technology, including PWRs and BWRs, covering all regions of the world.[93] This review sought to harmonise the various published estimates to a common scope and set of assumptions, including on the key characteristics of the representative nuclear power station subject to assessment.

3.6.9 The review concluded that the median LCA after harmonisation was 12 gCO_2e/kWh for LWRs including PWRs, and this was adopted in the IPCC report.

3.6.10 By comparison, the IPCC identified median emissions ranging over approximately 130-820 gCO_2e/kWh for currently available fossil-fuelled and biomass generation, and approximately 10-50 gCO_2e/kWh for renewable sources. This set nuclear generation alongside renewables as producing the lowest GHG emissions amongst the electricity generating technologies included in the study.

3.6.11 However, reflecting historic LWR practice in the majority of nations employing these technologies, most of the data in the review were drawn from reactors using a "once through" fuel cycle, assuming a standard station operating lifetime of 40 years. The review also highlighted the significance of the carbon intensity of the electricity system supplying construction of the power station and production of its fuel; the technology used for isotopic enrichment; and the grade of the uranium ore from which this fuel was derived. The contributions from all of these were included in the LCA calculation.

3.6.12 Set against the expectations for the UK in the period from around 2030 onward relevant to implementation of the Proposed Practice, the carbon intensity of the electricity system and the technology for isotopic enrichment will necessarily avoid the upper extremes covered in the review. This is because unabated coal generation in the UK is scheduled to cease in September 2024 with the closure of the UK's last operational coal-fired power station,[94] and use of gaseous diffusion technology for enrichment has ceased already.[95] This reduces the relevance of estimates based on these assumptions, which generally lie towards the top of the range of those taken into account.

3.6.13 Consequently, the median of 12 gCO_2e/kWh arrived at by the IPCC can be considered as an upper bound on the benchmark applicable to the Proposed Practice.

Prospective Study by Pehl et al

3.6.14 Balancing the IPCC's retrospective assessment, a further more recent prospective assessment has considered the full life-cycle GHG emissions of a range of technologies, taking account of the expected changes in energy systems forward to 2050.[96]

3.6.15 This projects life-cycle emissions for 2050 of 3.5–12 gCO_2e/kWh for the low carbon group of nuclear, wind and solar power, and 4 gCO_2e/kWh for nuclear generation specifically.[97] This compares with emissions from fossil fuel carbon capture and sequestration plants of 78–110 gCO_2e/kWh, and substantial but highly uncertain emissions ~100 gCO_2e/kWh from hydropower and bioenergy. Again, this sets nuclear generation alongside renewables as producing the lowest GHG emissions. In the light of these assessments, it is considered that 10 $g(CO_2)e$/kWh represents a conservative benchmark for large-scale LWR technologies implemented on the timeframe from 2030 onward relevant to the Proposed Practice.

United Nations Economic Commission for Europe Assessment

3.6.16 In 2021-2, the United Nations Economic Commission for Europe undertook renewed LCAs of the *"various utility-scale technologies for electricity generation, regarding their potential environmental impacts on human health, ecosystems, and their resource requirements."* One of the objectives of their work was to *"offer an update to the existing data of [a lifecycle study by Hertwich, de Larderel that did not address nuclear power],*[98] *by using the latest values in renewable efficiencies, electricity mixes as well as the value chain for nuclear power."*[99]

93] Warner, E S and Heath, G A, 2012, Life Cycle Greenhouse Gas Emissions of Nuclear Electricity Generation: Systematic Review and Harmonization, Journal of Industrial Ecology 16: S73–S92 ("Warner and Heath") https://doi.org/10.1111%2Fj.1530-9290.2012.00472.x

94] Uniper, Clarification on Ratcliffe on Soar power station closure date, 2023: https://www.uniper.energy/united-kingdom/news/clarification-on-ratcliffe-on-soar-power-station-closure-date/.

95] World Nuclear Association, Uranium Enrichment, 2020 https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx.

96] Pehl, M et al, Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling, 2017 Nature Energy volume 2, pages 939–945 https://www.nature.com/articles/s41560-017-0032-9

97] Evans S, Solar, wind and nuclear have 'amazingly low' carbon footprints, study finds, Carbon Brief, December 2017 https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-footprints

98] Hertwich, de Larderel, et al. Green Energy Choices: The Benefits, Risks and Trade- Offs of Low-Carbon Technologies for Electricity Production, 2016: https://resourcepanel.org/reports/green-energy-choices-benefits-risks-and-trade-offs-low-carbon-technologies-electricity, p. 17. The introduction states that *"nuclear power generation is not included because UNEP sees this technology as being under the responsibility of a different UN agency (IAEA)."*

99] United Nations Economic Commission for Europe, "Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, 2022: https://unece.org/sites/default/files/2022-08/LCA_0708_correction.pdf, p. 1.

3.6.17 For nuclear in particular, UNECE sought to provide *"a much-needed update upon data currently available in LCA databases (reflecting the higher share of in-situ leaching and the phasing out of enrichment through diffusion)."* [100] Since the front-end fuel cycle contributes a significant proportion of the lifecycle emissions of nuclear reactors, this was an important update. In-situ leaching, by which a solution is pumped through ore to dissolve and then recover the desired minerals, has a lower impact than conventional mining methods whereby the ore is physically removed from the ground, broken up, and treated to remove the desired minerals.[101] Conventional mining requires 133.4 MJ of diesel burning, 247.5 MJ of heat, and 68.1 MJ of medium voltage electricity per kg of uranium ore, versus 32.94 MJ of diesel, 103.9 MJ of heat, and 43.4 MJ of medium voltage electricity per kg of uranium oxide for in-situ leaching.[102] Likewise, centrifuge enrichment is more than an order of magnitude more energy efficient than gaseous diffusion. The World Nuclear Association estimates that *"the gaseous diffusion process consumes about 2,500 kWh (9,000 MJ) per Separative Work Unit (SWU) the amount of energy needed to enrich a given mass of uranium to the desired level, while modern gas centrifuge plants require only about 50 kWh (180 MJ) per SWU."* [103]

3.6.18 The report also chose to model *"an average PWR reactor, representative of the global production in 2020"*, for their lifecycle inventory of emissions.[104] The value of GHG emissions over the lifecycle was calculated to be 5.1g-6.4g.

3.6.19 The report further found that since water-cooled SMR designs were most advanced, they could model the lifecycle inventory ("LCI") of these designs efficiently and found that the lifecycle GHG emission of these technologies would fall into a similar range as that found for the average PWR in operation in 2020. The two designs modelled had net electrical outputs of 720 MWe and 225 MWe respectively.[105]

3.6.20 The Proposed Practice is for the operation of a water-cooled SMR with a net electrical output of 470 MWe, in the middle of the range modelled, and is, based on the proven PWR technology that underpins the UNECE report findings. It should therefore closely reflect the lifecycle emissions found.

Assessments for Sizewell B and Sizewell C

3.6.21 Turning to the UK more specifically, the scale of GHG emissions and the impact of retrospective versus prospective assessment of broadly similar PWR technologies is demonstrated by LCA assessments of Global Warming Potential ("GWP") using a common methodology applied to the existing Sizewell B[106] and the proposed Sizewell C nuclear power stations.[107]

3.6.22 This methodology evaluated the GWP through a lifecycle comprising distinct stages, summarised here as:

- Upstream (fuel supply from mining to manufacture of fuel assemblies);
- Construction (production and transport of materials, consumption of fuel, electricity and water, transport and disposal of wastes);
- Operation (production and transport of materials used, consumption of fuel, imported electricity and water, emissions, transport, treatment and disposal of wastes—up to delivery of electricity to grid system);
- Decommissioning (production and transport of packaging, consumption of fuel, electricity and water, treatment and disposal of wastes); and
- Downstream (installation and use of transmission and distribution infrastructure, waste treatment, use and emissions of SF_6—conveying electricity to a representative customer).

100] Ibid.

101] World Nuclear Association, "In Situ Leach Mining of Uranium", https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/in-situ-leach-mining-of-uranium.aspx. Accessed 27 November 2023.

102] United Nations Economic Commission for Europe, "Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, 2022: https://unece.org/sites/default/files/2022-08/LCA_0708_correction.pdf, pp. 72-3.

103] World Nuclear Association, "Uranium Enrichment", https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx#:~:text=The%20gaseous%20diffusion%20process%20consumes,(180%20MJ)%20per%20SWU. Accessed 27 November 2023.

104] United Nations Economic Commission for Europe, "Carbon Neutrality in the UNECE Region: Integrated Life-cycle Assessment of Electricity Sources, 2020: https://unece.org/sites/default/files/2022-08/LCA_0708_correction.pdf, p. 35.

105] Ibid., pp.39-40.

106] EDF Energy, Life cycle assessment of electricity from Sizewell B nuclear power plant development, May 2022 ("SZB assessment") https://www.edfenergy.com/sites/default/files/life_cycle_assessment_of_electricity_from_sizewell_b_nuclear_power_plant_development.pdf

107] NNB Generation Company, Life cycle carbon and environmental impact analysis of electricity from Sizewell C nuclear power plant Development, October 2021 ("SZC assessment") https://www.edfenergy.com/sites/default/files/szc_epd_style_doc_final_v02-00_29.10.21.pdf

3.6.23 Although included in LCAs undertaken under current international standards (ISO 14040 series), the downstream stage comprises activities that are outside the control of the power station operator. For example, a large part of their impact is due to emissions of sulphur hexafluoride (SF_6), a potent GHG used in certain switchgear used by the grid system operator. For a power station of a given capacity, they are considered substantially independent of the technology it uses. Moreover, they have not been included in a directly comparable way in several earlier assessments.

3.6.24 Accordingly, the comparison below focuses on the upstream, construction, operation and decommissioning stages (collectively, upstream and core). The data evaluated for these stages at Sizewell B and Sizewell C are summarised in Table 3.

Table 3: GWP per net kWh generated, evaluated retrospectively for Sizewell B and prospectively for Sizewell C

Lifecycle stage	Sizewell B g(CO_2)e/kWh	Sizewell C g(CO_2)e/kWh
Upstream	3.48	2.75
Construction	2.33	1.93
Operation	2.76	0.60
Decommissioning	1.58	0.26
Total upstream + core	**10.15**	**5.54**

3.6.25 These data show that, although both assessments are bounded by the IPCC assessment described above, there is a substantial difference between the values for Sizewell B and for Sizewell C. Part of this difference is attributable to the difference in assumed operating lifetime (40 years for Sizewell B vs 60 years for Sizewell C). This difference impacts particularly on the contributions from the construction and decommissioning stages, since these occur only once during the reactor lifecycle.

3.6.26 If these one-off stages are set aside, the most important remaining factors contributing to this difference are the GWP intensity of the stages with the greatest contribution from use of energy, including that used directly and that embedded in the materials used. The most significant of these stages are enrichment of fuel and operation of the power station.

3.6.27 The percentage of these totals attributed to imported electricity and diesel and embedded in materials (for operation) and to electricity usage (for enrichment) are set out in Table 4 below, alongside the corresponding implied contributions to GWP intensity.

Table 4: GWP per net kWh generated, evaluated for selected stages from data presented retrospectively for Sizewell B and prospectively for Sizewell C

Implied GWP for selected stages	Sizewell B	Sizewell C	Sizewell B	Sizewell C
	% of stage	% of stage	g(CO_2)e/kWh	g(CO_2)e/kWh
Operation stage	*(2.76 g(CO_2)e/kWh)*	*(0.60 g(CO_2)e/kWh)*		
Electricity / diesel	54%	63%	1.49	0.38
Materials	29%	27%	0.80	0.16
Enrichment stage	*(0.59 g(CO_2)e/kWh)*	*(0.22 g(CO_2)e/kWh)*		
Electricity	67%	27%	0.40	0.06
Total GWP intensity for selected stages		**2.69**	**0.60**	

3.6.28 It is clear that the GWP intensity per kWh for these stages is higher by a factor of 4 or more for Sizewell B than for Sizewell C, contributing a reduction in GWP for these stages alone of over 2 g(CO_2)e/kWh.

3.6.29 The common factor considered to underpin this difference is the GWP of the electricity supply consumed in these stages. For Sizewell B this was assessed using the contemporary UK electricity grid mix at the time of the assessment (circa 2022), expected to have been of the order of 200 g(CO_2)e/kWh, whereas for Sizewell C this was assessed using the forecast grid mix for 2035. By that point the policy intent is that the GB electricity supply will be decarbonised, subject to continued security of supply.

3.6.30 In the present case, substantial implementation of the Proposed Practice would occur from around 2030 onward. At this point the external assumptions on electricity supply will increasingly approach those for the Sizewell C assessment.

3.6.31 In conclusion, for the purpose of assessing the expected GHG intensity of electricity delivered to the GB grid from the Proposed Practice, the LCA assessments summarised above indicate benchmarks for large-scale LWR technologies implemented from around 2030 onwards of:

- A conservative value of 10 g(CO_2)e/kWh, and
- A representative value of 5.5 g(CO_2)e/kWh.

3.7 Evaluation of the Proposed Practice

3.7.1 The Proposed Practice is to operate a PWR SMR using the same enrichment percentage and the same style of PWR fuel found at Sizewell B, and intended for use at Sizewell C. The Proposed Practice also envisages the operation of a primary and a secondary circuit for the removal of heat from the reactor core, and for the operation of the conventional steam cycle in the conversion of steam into usable electricity.

3.7.2 Likewise, the Proposed Practice will benefit from the same overall reduction in grid carbon intensity seen at Sizewell C and is also designed for an initial life of 60 years, the same as Sizewell C. It should be noted that the United States Nuclear Regulatory Commission has licensed some American LWRs that are 20 years older than Sizewell B to 80 years of operation,[108] so it is highly likely that reactors as discussed in the Proposed Practice would be able to operate for at least that long, with a consequential further reduction in lifecycle carbon intensity.

3.7.3 In the light of the above it is reasonable to conclude that the Proposed Practice would see lifecycle emissions comparable to Sizewell C, and in line with the findings of the UNECE report as discussed earlier.

Net Contribution to UK's Overall Emissions

3.7.4 In 2023, nuclear power stations in the UK supplied 37.3 TWh of electricity to the grid.[109] If a series of new nuclear stations were built using the Proposed Practice to provide the same amount of electricity, and if their GHG emissions were taken as the conservative figure of 10 gCO_2e/kWh attributed to thermal LWR technology (see above), the total annual carbon emissions attributable to these power stations would be 0.37 MtCO_2e (million tonnes of carbon dioxide equivalent).

3.7.5 This is about 0.1 % of the UK's estimated total GHG emissions of 384.2 MtCO_2e in 2023,[110] and 0.9% of the total emissions of 41.1 MtCO_2e from power stations in the same year.[111]

3.7.6 The new power stations could potentially displace GHG-emitting fossil-fuelled plants. Looking retrospectively, the Nuclear Industry Association has calculated that from 1956, the UK's nuclear plants have avoided approximately 2.3 billion tonnes of carbon dioxide emissions, based on marginal fuel substitution of nuclear for fossil fuel generation in each year.[112]

108] United States Nuclear Regulatory Commission, Status of Subsequent License Renewals, https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html. Accessed 11 June 2024.

109] EDF Energy, UK Nuclear Fleet Stakeholder Update, 2024 https://www.edfenergy.com/sites/default/files/2024-01/FM10845%20UK%20Nuclear%20Fleet%20Strategy%20Update%20V7.pdf.

110] Department for Energy Security and Net Zero, 2023 UK greenhouse gas emissions, provisional figures ("GHG 2023") https://assets.publishing.service.gov.uk/media/6604460f91a320001a82b0fd/uk-greenhouse-gas-emissions-provisional-figures-statistical-release-2023.pdf, p.1

111] Ibid., p.9

112] Nuclear Industry Association, Why Nuclear? 2024. https://www.niauk.org/why-nuclear/

3.7.7 However, the timeframe for substantial implementation of the Proposed Practice is from the early 2030s onwards. Over this timeframe, the UK Government's policy intent is that the electricity system will be decarbonised by 2035, subject to security of supply. This grid decarbonisation, will, however, need to be maintained after 2035, as electricity demand rises and as the first generations of wind turbines and solar panels are retired, so 2035 is not an arbitrary "cut-off" date for new low carbon generating capacity to be online.

3.7.8 Under this scenario, as described in Chapter 2, a key function of firm, dispatchable sources of electricity such as nuclear is to ensure continued security of supply in a rapidly growing system otherwise largely supplied by intermittent renewable sources. Thus, the relevant comparison for nuclear is with alternative, more GHG-intensive sources fulfilling the same key function.

3.7.9 This source is expected to be CCGTs equipped with CCS or CCUS,[113] which is intended to separate and sequester the carbon dioxide produced by combustion in a way that permanently prevents its release to the atmosphere.

3.7.10 The UNECE 2022 study found, as noted above, that with a 90% capture efficiency, CCGT plants would have lifecycle GHG emissions of 90 to 221 gCO_2e/kWh. This compares to 5-6g for a PWR as calculated in the same report.

3.7.11 It is clear that, for all combinations of these assumptions, prospective emissions from the Proposed Practices are lower than the alternative using CCGT with CCS.

3.8 Summary of Results and Conclusion

3.8.1 This Chapter has:

- Demonstrated the critical importance of urgent and sustained action to mitigate climate change;
- Identified the UK's legally binding commitment to Net Zero by 2050, together with its policy intent for full decarbonisation of the electricity system by 2035 subject to security of supply;
- Highlighted the CCC's concerns on shortfalls in the strategy and actions necessary to achieve these targets and the Government's Civil Nuclear Roadmap, which made key commitments to which the Proposed Practice could contribute to fulfilling:
  - Fleet deployment of SMRs for long-term energy security
  - A new criteria-based siting policy to facilitate, inter alia, the rollout of SMRs
  - Completing the GBN-led Small Modular Reactor (SMR) technology selection process, announcing which technologies will be supported to achieve FID by 2029.
  - Aim to secure investment decisions on 3-7 GW of nuclear capacity in each of the five year periods from 2030 through 2044.[114]
- Summarised authoritative assessments of the GHG intensity of existing LWR nuclear technologies relevant to implementation in the 2030s onwards, identifying benchmarks of 10 (conservative) and 5.5 (representative) gCO_2e/kWh; and
- Demonstrated that the benefit in sustaining low GHG emissions through to achievement of Net Zero would exceed that of a leading alternative non-nuclear form of firm generation, CCGT with CCS.

3.8.2 Therefore, the Proposed Practice would deliver a substantial benefit through its contribution in helping to meet the UK's legal requirement for Net Zero GHG emissions by 2050, and in tackling global climate change and its severe, pervasive and irreversible impacts on people and ecosystems.

113] UK Government, Net Zero Strategy: Build Back Greener, 2021 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf p.21

114] Ibid.

4: ECONOMIC ASSESSMENT

Deployment of the Proposed Practice will not result in unreasonable or unacceptable costs being incurred by UK taxpayers or electricity consumers.

The expected costs of nuclear power stations are comparable with the costs of other forms of electricity generation, including other low carbon technologies.

Government will ensure that an appropriate framework exists to ensure that its policy objectives can be delivered. This is expected to include measures to ensure that individual projects do not go forward unless they demonstrate an acceptable cost to the consumer. Currently, the Nuclear Regulated Asset Base model will be the key mechanism for encouraging investment in low-carbon generation. This new regime provides a mechanism for the Government to determine whether it considers that a project represents value for money and would be a cost-effective addition to the UK generation mix.

The risk of severe detriment to the UK economy as a result of the impacts of a nuclear accident involving the Proposed Practice is very low.

The construction of RR SMR in pursuance of the Proposed Practice would provide short-term socio-economic benefits to local economies, as well as long-term benefits to the national nuclear supply chain. The operation of the stations would also bring long-term, wider socio-economic benefits.

4.1 Introduction

4.1.1 Chapters 2 and 3 of this Application, which relate to security of supply and carbon reduction, identify the need for, and benefits of, the Proposed Practice. This Chapter considers potential impacts of adoption of the Proposed Practice on the UK economy. In doing so, this Chapter makes a distinction between the national economic perspective and the perspective of a private sector developer who may become involved in deployment of the Proposed Practice. From the national viewpoint, it is important to establish that the costs of the Proposed Practice would not be expected to result in unreasonable or unacceptable costs being incurred by UK taxpayers or electricity consumers (i.e. it would not result in an economic detriment).

4.1.2 This submission does not rely on demonstrating an economic benefit to conclude that the Proposed Practice is justified.

4.2 What Has Changed Since Our 2013 Application?

4.2.1 Since our 2013 Application, the cost estimates for building nuclear reactors (generally, across all types of technology) have increased: construction experience in this period has demonstrated that previous cost predictions were too low. Noting that current assumptions for nuclear technologies refer only to large scale nuclear plants. The Government is in the process of obtaining costs for advanced nuclear technologies including SMRs.[115] Real construction experience available today is allowing the industry and analysts to prepare more accurate updates to future cost assumptions. These updated assumptions are presented in this Application.

4.2.2 Further, since our 2013 Application, the Government has consulted on a review of electricity market arrangements. This seeks to incentivise investment in a range of low carbon generating technologies and to facilitate investment in new capacity. As outlined below, this balancing process has a key aim to minimise costs to consumers **[24]**.

4.2.3 The Energy Act 2023 has also further amended the Nuclear Installations Act 1965 to implement the CSC which will increase the number of countries the UK has treaty relations with and thereby lower barriers to investment into the UK nuclear sector, particularly from the USA.

4.3 Policy Background

British Energy Security Strategy

4.3.1 Building from the Electricity Market Reform programme of 2013, the Government released a series of policy papers from 2020 to 2023: The ‘Energy White Paper’ **[1]**; ‘Net Zero Strategy’ **[25]**; ‘British Energy Security Strategy’ **[4]**; and ‘Powering Up Britain: Energy Security Plan’ **[2]**. These lay out the Government’s aim for the UK’s progression to Net Zero and domestic energy security.

115] Electricity Generation Costs 2023, Page 18 Electricity generation costs 2023 (publishing.service.gov.uk)

Some of the major targets of the strategy include:

- The need for greater energy independence.
- Aiming for a doubling of Britain's electricity generation capacity by the late 2030s.
- Enhancing UK strengths on wind, solar and nuclear power generation.

4.3.2 These targets, which will also help the UK to meet its commitments under the 2019 Paris Climate Accords, present a significant investment challenge. Up to £100 billion of capital investment is expected to be required across the 2020s and could support 250,000 jobs by 2030 **[1]**.

Government investment in low-carbon electricity

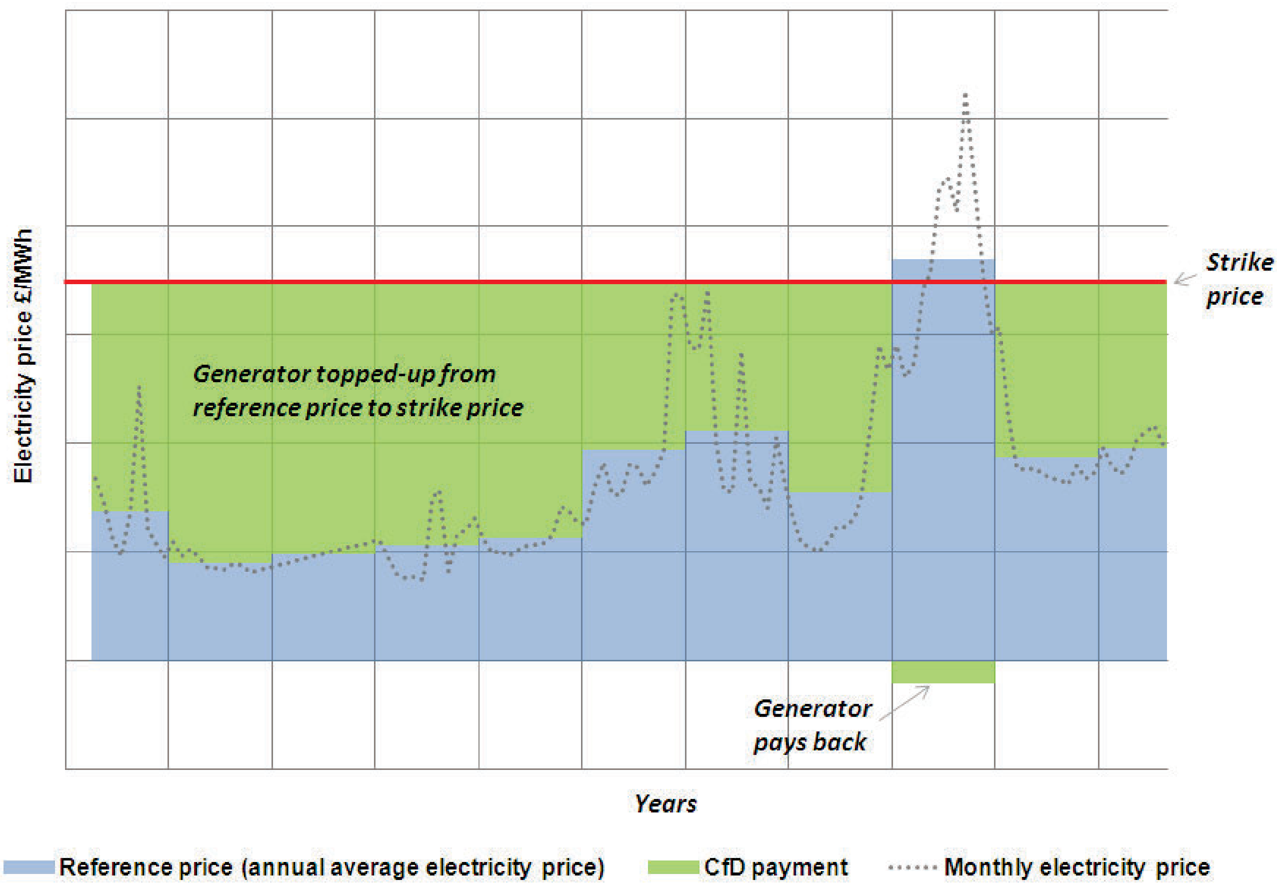
4.3.3 Following the Electricity Market Reform, the UK government created a new framework for long-term contracts with eligible electricity generators to increase certainty of revenue for investors, called Contracts for Difference ("CFDs"). These are intended to increase the rate of investment and lower the cost of capital in relation to new relevant energy infrastructure development, thereby reducing costs to electricity consumers (compared with a "do nothing" scenario). The Energy Act 2013 provides a statutory basis for CFDs **[26]**.

4.3.4 After a CFD has been agreed, when power is generated, irrespective of the price of power actually captured by the generator, under the CFD:

- if the "average reference market price" is less than the negotiated strike price, the generator will receive a "Difference Payment"—the difference between the strike price and the average reference market price (or zero); or
- if the average reference market price is more than the strike price, the operator will return the difference.

4.3.5 Figure 2 illustrates the operation of a CFD **[27]**.

Figure 2: Illustration of the operation of the Feed-in Tariff with Contracts for Difference



4.3.6 The Low Carbon Contracts Company (a UK Government owned company) is the counterparty for the CFD, meeting CFD difference payments from a compulsory levy on electricity suppliers **[28]**.

4.3.7 This mechanism increases certainty and consistency in relation to the net price that a project operator (and its investors and funders) will receive for the electricity generated by the project, thereby increasing confidence around the ability to recoup upfront investment in the project.

4.3.8 For low power or renewable applications, CFDs are awarded in auction rounds. A fixed budget is available, and suppliers enter bids of proposed strike prices for access to this budget. The lowest strike prices are awarded contracts. In addition to auctions, CFDs can also be decided by bi-lateral negotiation, such as the CFD agreed for the Hinkley Point C nuclear power plant **[29]**.

4.3.9 While the CFD scheme works well for Next of a Kind ("NOAK") renewable generators, the risk placed on the developer of a CFD-funded project may not be palatable for large, single asset projects. A project such as a wind farm may have construction issues, yet still reach some level of generation, however for a nuclear power station, one unit must be completely finished before it can start to recoup costs. The inflexibility of the CFD scheme for nuclear lead to the cancellation of the nuclear new build projects at Wylfa Newydd and Moorside by Hitachi and Toshiba respectively **[30]**.

4.3.10 In response to this, the Government introduced the Regulated Asset Base ("RAB") model for nuclear in the Nuclear Energy (Financing) Bill 2021. This system of funding allows the creation of a revenue stream before a plant starts generating. This is expected to reduce the cost of a large-scale nuclear build by up to £30 billion by reducing the requirement for risk to be priced into a CFD strike price, as well as reducing the timescale of the capital investment **[1]**.

4.3.11 The use of RAB is likely to allow for a FID on the construction EPR at Sizewell C by the Government and demonstrates the continuing commitment to nuclear as part of the net-zero aims of the UK. The specific funding framework for a potential UK SMR build is not finalised, however a lower individual cost and fleet approach could be suited to either a CFD or a RAB funding model. It is reasonable to expect Government to investigate the benefits of each option and select the route which provides the lowest expected electricity cost to the consumer, that is also consistent with all other government policy objectives, such as decarbonisation and continuity of supply.

4.4 Costs

What are Levelised Costs?

4.4.1 The Levelised Cost of Electricity ("LCOE") is the discounted lifetime cost of building and operating a generation asset, expressed as a cost per unit of electricity generated (£/MWh). It covers all relevant costs faced by the generator, including pre-development, capital, operating, fuel, and financing costs. This is sometimes called a life-cycle cost, which emphasises the "cradle to grave" aspect of the definition.

4.4.2 The levelised cost of a generation technology is the ratio of the total costs of a generic plant to the total amount of electricity expected to be generated over the plant's lifetime. Both are expressed in net present value terms. This means that future costs and outputs are discounted, when compared to costs and outputs today. Because the financing cost is applied as the discount rate, this means it is not possible to express it as an explicit part of the levelised costs in £/MWh.

4.4.3 The main intention of a levelised cost metric is to provide a simple "rule of thumb" comparison between different types of generating technologies. However, the simplicity of this metric means some relevant issues are not considered.[116] One factor not considered is the extensive system costs of connecting intermittent renewable energy sources to the grid compared to the firm dispatch power that would be provide by an SMR.

4.4.4 As the definition of levelised costs relates only to those costs accruing to the owner/operator of the generation asset, it does not cover wider costs that may in part fall to others, such as the full cost of system balancing and network investment, or air quality impacts, nor does it capture other benefits such as those described in Chapter 2 (Security of Supply).

Levelised Costs are not Strike Prices

4.4.5 The Department for Energy Security and Net Zero ("DESNZ") explained in its paper on electricity generation costs **[31]**, how levelised cost estimates differ from CFD strike prices. DESNZ explained that levelised cost estimates do not provide an indication of potential future strike

116] Electricity Generation Costs Report [31] Section 3 prices for a particular technology or plant under a CFD. Generation costs data is one input into setting strike prices. Other inputs may include:

- Revenue assumptions
- Other costs not included in DESNZ's definition of levelised cost
- CFD contract terms, including length and risk allocation
- Developments within industry
- Financing costs
- Wider policy considerations

4.4.6 Where project-specific cost discovery processes are undertaken, as is expected for early SMR projects, generation costs data used as part of the strike price setting process will be different from cost data used to calculate levelised costs. The strike price process will reflect a site specific, highly granular assessment of costs, whereas the levelised cost estimates are more high-level and generic. Therefore, as asserted earlier, it is reasonable to expect Government to exercise its judgment on whether an individual project demonstrates an acceptable cost to the electricity consumer.

Nuclear Levelised Costs

4.4.7 There are a wide range of independent external assessments of generation costs for all electricity generation technologies, including nuclear, which can be used to estimate the range of possible costs.

4.4.8 The Department for Business, Energy and Industrial Strategy ("BEIS") November 2016 paper **[32]** on electricity generation costs, which provides the most recent estimates of large-scale nuclear levelised costs **[31]**, forecasts a range of between £85-£123/MWh for First of a Kind ("FOAK") nuclear reactors commissioning in 2025, and £69-99/MWh for NOAK reactors commissioning in 2030. The paper makes use of a 9.5% technology specific hurdle rate, as described in the Department of Energy and Climate Change ("DECC") Electricity Generation Costs 2013.

4.4.9 The Electricity Generation Costs 2023 paper **[31]** released by DESNZ, does caveat the cost estimates as being for large nuclear only, and that current modelling strategies have insufficient information to estimate advanced nuclear technologies, including SMRs and AMRs. The costs for nuclear have not been updated since the 2016 version of this paper **[32]**.

4.4.10 Table 5 provides a range of assumptions for key cost components to levelised cost calculation for a FOAK reactor commissioning in 2025 **[32]**.

Table 5: Levelised Cost Estimates for Projects Commissioning in 2025

Nuclear PWR FOAK	Cost (£/MWh)
Pre-Development Costs	7
Construction Costs	66
Fixed (Operating and Maintenance)	11
Variable (Operating and Maintenance)	5
Fuel Costs	5
Carbon Costs	0
Carbon Capture and Storage Costs	0
Decommissioning/Waste	2
Total	**95**

4.4.11 Table 6 presents Levelised Cost Estimates for Projects Commissioning in 2025 and 2030, technology-specific hurdle rates, £/MWh, highs and lows reflect high and low capital and pre-development cost estimates **[32]**.

Table 6: Levelised Cost Estimates for Projects Commissioning in 2025 and 2030

Commissioning		2025	2030
Nuclear PWR – FOAK 2025 NOAK 2030	High	123	99
	Central	95	78
	Low	85	69

Other UK Government Measures

4.4.12 It is possible that other actions by Government could be relevant to the decision to bring a project forward that utilises the Proposed Practice. For example, the UK Infrastructure Bank ("UKIB") was created in 2021 to enable low carbon and community infrastructure projects. It is highly likely that a project based on the Proposed Practice would apply to be a beneficiary of investment from UKIB. In considering whether to allow a project to be a beneficiary of such a scheme, it would again be reasonable to assume that Government would not allow a project to benefit if, in light of the alternatives, it concluded that the project represented an economic detriment to the UK.

4.5 RR SMR Build Certainty

4.5.1 The Rolls-Royce SMR Limited's philosophy known as 'Build Certainty' is aimed at ensuring high confidence in achieving the declared build schedule and cost of the RR SMR. These latter two factors have a significant influence on achieving an affordable LCOE. The Build Certainty philosophy also promotes ways of actively reducing the plants' costs and build schedules whilst maintaining high quality and integrity of the built power station. The Build Certainty philosophy ensures the cost detriment associated with construction of RR SMR is much less significant than traditional large scale nuclear and will come down even further with fleet/Nth of a kind deployment.

4.5.2 The RR SMR Build Certainty philosophy has six principles as follows:

- Maximise off-site build and assembly.
- Simplify logistics flow for on-site build.
- Minimise variation across all areas.
- Reduce and simplify interfaces (plug and play).
- Increase robustness to variation.
- Reduce human interaction.

4.5.3 The aim is for RR SMR to become a product that is readily deliverable and able to be rolled out across multiple sites, at much lower cost than large-scale nuclear with build certainty and hence connection to the grid in a shorter timescale.

4.6 Economic Impacts of Accidents

4.6.1 If a severe nuclear accident occurred in the UK, then there could be an economic detriment to the UK economy. Annex 5 provides a short overview of previous severe accidents involving commercial nuclear power plants around the world.

4.6.2 The radiological and non-radiological health effects of a severe accident (such as anxiety) are outlined in Chapter 5 and Annex 5. Chapter 5 explains UK regulatory expectations and Annex 5 explains how these expectations are secured and overseen. Major economic impacts could also result from a nuclear accident, including damage to the economy and financial damage to the operator of the reactor.

4.6.3 Past experience has prompted the development of strong regulatory and corporate governance arrangements which are focused on the overriding priority of nuclear safety, which works to prevent accidents such that the likelihood of them occurring is very low. These arrangements are described in Annex 5 of this application.

4.6.4 The UK is a contracting party to the 1960 Paris Convention on Nuclear Third-Party Liability and the Brussels Supplementary Convention ("BSC"), as well as the 2004 protocols to amend these conventions. Operators in the UK bear a strict and exclusive liability to compensate victims of certain nuclear incidents under the Nuclear Installations Act 1965, amended by the Nuclear Installations (Liability for Damage) Order 2016.

4.6.5 Operators are required by section 19 of the Nuclear Installations Act 1965 to make provision (by insurance or other means) for these liabilities which must be approved by the Secretary of State and His Majesty's Treasury.

4.6.6 On ratification of the 2004 protocols in January 2022, the operator of a nuclear power station's liability for radiological property damage, personal injury or significant impairment to the environment was limited to €700m, increasing by €100m each year, to a maximum €1,200m by 2027 **[33]**.

4.6.7 For liabilities in excess of the €1,200m cap on operator liability, the BSC provides further compensation up to €300 million. The compensation is drawn from public funds made available by the contracting states collectively, following a formula established by Article 12 of the BSC **[34]**.

4.6.8 In the event of a nuclear accident during the period in which the operator liability is less than €1.2 billion, the BSC requires the use of public funds from the state in which the accident occurred to provide the difference between the operator liability and the €1.2 billion cap. As the proposed practice will not be carried out prior to 2027, the use of UK public funds, beyond those required by the Article 12 formula, will not be necessary.

4.6.9 This nuclear liability channelling regime accordingly provides protection for the UK Government and for victims of most types of nuclear incidents. The risk of a very severe accident of the type which could result in liabilities in excess of these amounts in the UK is very low as further explained in Chapters 5 and 8.

4.6.10 It is concluded that, as the likelihood of severe nuclear accidents in the UK is very low, the corresponding risk of severe detriment to the UK economy is also very low.

4.7 Socio-Economic Benefits

4.7.1 In addition to the major security of supply and carbon reduction benefits described in Chapters 2 and 3 of this Application, there would also, as with other major infrastructure and technology projects, be significant socio-economic benefits to the UK economy resulting from the deployment of SMRs.

4.7.2 Deploying a fleet of RR SMRs will unlock a range of benefits to the UK economy. Creating tens of thousands of high-skilled, well-paid jobs—primarily based in the north of England and Wales. Rolls-Royce SMR Limited is committed to UK supply chains and are targeting up to 78 per cent of UK content in its power stations—by comparison the offshore wind sector has a target of just 60 per cent by 2030. The economic benefits of this project will be spread across multiple UK regions, with the shortlisted sites for the first factory including Teesside, Sunderland and Deeside in Wales. The reactor site itself is most likely to be on or adjacent to an existing nuclear site, ensuring communities that have benefited from the nuclear sector in the past continue to do so.

4.7.3 The RR SMR model will create, over, 9000 direct, indirect and induced jobs per annum across the 10-year construction period,[117] with employment peaking at around 20,000 in 2030. Once operational, the plants will deliver, on average, 1,136 jobs in operations for the 60-year design life. This will result in substantial employment and drive productivity improvement in many of the areas shortlisted for RR SMR's factories and the SMR site locations.

4.7.4 Through SMR deployment, the UK economy will also benefit from its significant export potential, with the RR SMR included in a number of technology selection processes across Europe. If delivered, these processes could secure export potential worth tens of billions of pounds by 2030.

4.8 Conclusion

4.8.1 Based on the Government's own analysis, adoption of the Proposed Practice is highly likely to be beneficial for the UK economy when security of supply and carbon reduction benefits are considered.

4.8.2 The risks of significant detriment to the UK economy from the Proposed Practice are very low.

117] First of a fleet build schedule is expected to be 10 years, it is envisaged that timescales will reduce as economies of scale build and construction experience is gained.

5: POTENTIAL RADIOLOGICAL HEALTH DETRIMENTS

Any overall radiological health detriment from deploying the Proposed Practice would be very small. New UK nuclear power stations of the class proposed, and its associated processes, would be capable of meeting all applicable dose limits and constraints; indeed, the mature regulatory processes governing this Proposed Practice would lead to radiation doses being well below these levels.

Following optimisation the maximum level of additional dose to any member of the UK public per year would be around the same as the additional dose incurred in a return flight from the UK to New York, or through spending a week in Cornwall instead of somewhere with the UK average level of natural background radioactivity. Ahead of optimisation, it is clear maximum doses to the public will be less than 0.3 mSv per year, the UK constraint relevant to new facilities. This is taken as a bounding value for the purposes of justification of an individual dose to any member of the public from introduction of the Proposed Practice. Doses to the UK population generally will be so low as to be of no health significance.

Workers employed as a result of the Proposed Practice would receive doses comparable with, or lower than, those received currently by those employed in the nuclear power industry. The design targets for RR SMR mirror the Office for Nuclear Regulation ("ONR") Basic Safety Objectives ("BSO"), which are the higher safety levels nuclear installations endeavour to achieve. The BSO for radiation exposure is that site workers who work with ionising radiation have annual exposures below 1 mSv, and 0.1 mSv for those who do not work with ionising radiation. This is taken as a bounding value for the average level of dose to any worker in the UK assessed to arise from the Proposed Practice.

The Proposed Practice would meet the UK's stringent requirements to reduce both the likelihood and consequences of accidents and so would result in extremely low additional levels of risk, even to those closest to the site(s).

This assessment is based on a comprehensive examination of all the areas that could give rise to the potential for radiation doses to workers and members of the public or to accident risks. Although some of these activities would take place outside of the UK, all have been considered here to ensure completeness.

The UK Government is in agreement, with the explanatory notes for the 2022 British Energy Security Strategy [4] stating: *"The strategy will see a significant acceleration of nuclear, with an ambition of up to 24 GW by 2050 to come from this safe, clean, and reliable source of power".*

This conclusion has been reached by comparing anticipated maximum doses with dose limits and constraints. Here *"dose"* is assumed to be a measure of health detriment; the validity of this assumption and the scientific basis for dose limits are considered below. Doses anticipated from this Proposed Practice are also compared with those from natural background radiation and other common activities that might lead to an increased exposure from natural radiation and/or medical exposure. Finally, to give another indication of the significance of the health detriments being considered here, the doses are equated to a risk of death from induced cancer.

5.1 Introduction

5.1.1 This Chapter outlines the potential radiological health detriment to members of the public and workers from the deployment of the Proposed Practice.

5.1.2 The high-level approach in this Application provides a comprehensive examination of potential radiological health detriment. This Chapter presents substantial evidence from analysis of the Proposed Practice, and the other processes required to support the development of nuclear power plants using RR SMR technology as part of the wider UK nuclear new build programme, that the UK's regulatory radiological dose limits and constraints for workers and the public **[35]** can be met, and that the required standards for preventing and mitigating potential accidents will be delivered.

5.1.3 It is also clear that all sources of public radiation exposure that would stem from the Proposed Practice will meet the UK's dose constraint for new facilities. There is also evidence available from existing nuclear power stations and from other related activities that is available to support the Proposed Practice to illustrate the impact of UK and international safety and environmental regulation on reducing radiological health detriment below these dose limits and constraints.

5.1.4 Radiological protection comes under the purview of the ONR and environmental regulators, which are devolved in the UK. These regulators are: the Environment Agency ("EA") (being the regulator for England), the Scottish Environment Protection Agency ("SEPA"), Northern Ireland Environment Agency ("NIEA"), and Cyfoeth Naturiol Cymru/Natural Resources Wales ("NRW" in this Application). While different organisations, they follow the same principles in their administration of radiological protections.

5.1.5 Radiological protection in the UK follows the IAEAs International Basic Safety Standards **[36]** which are derived from the ICRP report ICRP103 **[23]** which was released in 2007 and is the culmination of decades of research into radiological protection, as well as the most up to date set of recommendations of the ICRP. For example, the ICRP103 principles guide the radiological protection developed principles ("RPDPs") that the EA uses to regulate radiological practices **[35]**. These align with the ICRP principles but are incorporated via Public Health England ("PHE") (now UK Health Security Agency ("UKHSA")), who are the statutory advisers to the UK government on radiological protection **[37]**.

5.1.6 Justification is the first of these principles and is, in effect, the first assessment hurdle that a practice involving the use of radioactive materials must overcome. Even if a practice is justified it may only be implemented when the way it is carried out has also been optimised—the second principle underpinning radiological protection.

5.1.7 Optimisation refers to the requirement, within the hierarchy of radiological protection principles, for radiation doses from a practice that is justified to be reduced to a level as low as is reasonably achievable ("ALARA") taking account of economic and societal factors. It is the first of four RPDPs, laid out by the EA. Optimisation involves striking a balance between the efforts (time, cost, etc.) required to reduce doses using BAT, against the dose reduction these efforts can deliver. In the UK, optimisation via BAT is implemented as a requirement within the legal processes through which a design is licensed and permitted. It is these licensing and permitting processes that have the greatest impact in determining what level of radiological health detriment is ultimately permitted. These essential regulatory processes will follow Justification if new nuclear power stations using RR SMR technology are deployed in the UK and apply to all stages of the life cycle of a station from design, construction, and commissioning, through to operation, decommissioning and final waste disposal. The application of optimisation means that, in practice, radiological doses from the nuclear industry are very significantly below legal limits.

5.1.8 It is important to understand that this Application does not address or prejudge the results of optimisation. Instead, it presents sufficient evidence to demonstrate that the first hurdle, Justification, is met. To be justified it is sufficient to show that there are Net Benefits of the practice that outweigh any potential detriments; it is not necessary to demonstrate that the practice has been optimised. If the Net Benefits of a practice are very significant (as this Application shows in Chapters 2 and 3), the first radiological protection principle, Justification, can be met by demonstrating that the detriments are by comparison small—for example, by demonstrating that the practice can be carried out within all the relevant dose limits or constraints[118] (since these have been set at levels of health risk that are relative to those risks from routine background radiation doses from all sources). This means it is not necessary to rely on precise estimates of what radiological effects will derive from applying the regulatory processes relevant to optimisation that have yet to be undertaken. Nevertheless, evidence is provided (from similar existing activities) to show that these limits and constraints can not only be met, but can be met by a large margin, and that this would apply equally to the Proposed Practice.

5.1.9 This Chapter summarises the overall scale of the potential radiological health detriment, having first identified and described all potentially significant sources of radiological health detriment associated with the processes required to support the Proposed Practice. An analysis of the potential effects of radiation in general on human health is briefly summarised in the boxes below. In addition, attention is drawn to the more detailed analysis of the effects of radiation on human health contained in Annex 4 to this Application.

5.2 Commentary on our 2013 application

5.2.1 This Application follow the same approach as our 2013 Application, but where relevant presents updated data as well as data relevant to the RR SMR, some of which is based on the other previously justified reactor designs in the UK. Of these, three of the four designs are PWRs, the same general category as RR SMR, further showing the maturity and safety of the Proposed Practice. The design and manufacturing differences between these plants and RR SMR will necessarily lead to different safety cases and operational regimes, as the mature UK regulatory process ensures that each plant is built, operated and decommissioned ensuring that risks and dose rates are kept as low as reasonably practicable, and well within legal limits.

5.2.2 In addition, supporting practices, such as enrichment, fuel fabrication and transportation are discussed. These activities are already justified and taking place in the UK, however this Application demonstrates that utilisation of these activities for the RR SMR will result in continued low radiation exposures for workers and members of the public.

118] NB We do NOT seek to argue that the practice is justified simply because it can meet dose limits or constraints; rather that by complying with these, even for those small numbers of people who could be most affected, we can be confident that the radiological health detriment will fall within a level that is small compared to the substantial benefits we demonstrate.

5.2.3 For activities that are directly related to RR SMR, such as operation and power production, this Chapter discusses how optimisation is expected to result in similar levels of exposure to the other already justified practices.

5.2.4 No material changes have been identified in updating information on potential radiological health detriment.

5.3 Dose Measurements

Dose Limits and Constraints

5.3.1 The UK in common with other countries has not defined a regulatory limit or constraint for the public in terms of collective dose or average individual dose. Instead, consistent with the ICRP recommendations which are embodied in European and UK law, these limits and constraints are framed in relation to the individual who could be most exposed, in the knowledge that this will provide a very high level of protection to all.

5.3.2 The UK limits for maximum dose received by any member of the public are laid out in the Ionising Radiations Regulations 2017 ("IRR17") **[38]** and Environmental Permitting regulations 2016 ("EPR16") **[39]**, IRR17 sets the maximum limit for any person who is not a worker or trainee on a nuclear site at 1 mSv per year, while the EPR16 creates a requirement for the environmental regulator during the planning stage for radiation protection on a nuclear site as follows:

"have regard to the following maximum doses to individuals which may result from a defined source—

(a) *0.3 millisieverts per year from any source, or*
(b) *0.5 millisieverts per year from the discharges from any single site."*

This requirement is taken from the Basic Safety Standards Directive **[40]**.[119]

5.3.3 The single source constraint of 0.3 mSv per year (as specified above) for new facilities has been adopted in this Application as a useful parameter to describe the maximum individual public dose (and health detriment) from new facilities developed in the UK as part of the Proposed Practice. The ONR states in its Safety Assessment Principles ("SAPs") **[41]** that a single source should be interpreted as a site under a single duty holder's control, in that it is an entity for which radiation protection can be optimised as a whole. A public dose of 0.3 mSv/y is therefore a bounding value[120] for the purposes of Justification of individual dose to any member of the public from introduction of the Proposed Practice.

5.3.4 The ONR's Basic Safety Level ("BSL") **[41]** for the average annual individual dose to people who work with radiation on a licensed site, which is set at 10 mSv, has been adopted, for the purposes of this Application, as the maximum average annual dose to workers from the Proposed Practice. This is taken as a bounding value for the average level of dose to any worker assessed to arise from the Proposed Practice.

5.3.5 These limits and constraints afford a high level of protection to workers and the public. This is confirmed in this Application through the evidence presented on the level of individual doses that result from existing practices that meet these UK limits or constraints.

5.3.6 The approach in this Chapter 5 is to explain the relevant UK regulatory requirements for each potential source, and to show that any relevant UK radiation dose limit (or where appropriate dose constraint) can be met (see Box 1 below for an explanation of the relevant dose limits). As explained above, we consider that this step should be sufficient to enable the Justification principle to be addressed. However, in addition and so as not to mislead those reading this Application, evidence is also presented of the scale of reduction to any radiological impact that is likely to occur as a result of applying the optimisation principle. This is done by drawing on the results of the application of UK and international regulation to similar practices of which there is already actual experience—e.g. reactor operation, transport of fuel etc.

119] "The Basic Safety Standards Directive" is Council Directive 2013/59/Euratom laying down basic safety standards for the protection against the dangers arising from exposure to ionising radiation, keeping the UK in line with international best practice.

120] This bounding value will also apply should a site contain multiple reactors, early dose optimisation carried out by RR SMR shows that the dose from multi-unit site will be significantly lower than this bounding value.

BOX 1

How well established are the dose limits for exposure to radiation?

The relationship between exposure to radiation and health detriment has been studied for more than 70 years and is kept under review by international bodies. On the basis of these and other reviews, recommendations for radiological protection are made by the ICRP and various national bodies. This Box summarises the position at the time of this application, which has not materially changed since our 2013 Application.

The health risks associated with exposure to radioactive materials are, in general, better understood than those relating to the chemical and biological toxicity of many everyday materials. While, as in all scientific fields, there remains room for refining theories and for reducing the remaining levels of uncertainty, the level of understanding is certainly sufficient to support conclusions relating to the justification of a new practice.

The advice on dose limits from the ICRP, originally promulgated in their 1990 recommendations and which has been embodied in UK regulations, can be summarised as:

- 20 mSv per year (mSv/y) for workers averaged over defined periods of five years
- not greater than 50 mSv in any one year
- 1 mSv/y for the public

It should be noted that the UK has gone further in its regulation of ionising radiation, whereby a worker may only be exposed to a dose greater than 20 mSv in a single year with the permission of the HSE.

The Committee on the Biological Effects of Ionizing Radiations ("BEIR") of the US National Research Council issued its Seventh Report ("BEIR VII") in 2006, and the United Nations Scientific Committee on the Effects of Atomic Radiation ("UNSCEAR") has published a series of reports. These reports examine the latest scientific evidence on adverse health effects. In 2007, the ICRP approved its latest set of Recommendations for radiological protection, which have been formulated on the basis of the BEIR VII and UNSCEAR reports, together with ICRP's own evaluation of the scientific evidence. While these reports are now over 15 years old, ICRP has not felt it prudent to update the recommendations, reinforcing the level of maturity in this field of study. It is also of note that the ICRP did not recommend any change to the advised system of radiation protection or to the system of dose limits used as part of protecting the public and people at work in its 2007 report from those of earlier reports.

5.4 Approach to Evaluation of Radiological Health Detriment

Assessment of Detriments from Normal Operation

5.4.1 For the public, the assessment here focuses on the potential individual radiation doses that could arise from the Proposed Practice for those aspects that would routinely take place (e.g. normal operation of the power station). Evidence is provided below from existing nuclear power stations that have been justified and subjected to UK regulation to show indicatively what level of individual dose results from this approach. Data on experience overseas is also provided to give evidence on an even larger population of reactors. These values are therefore indicative of the doses that could result from the Proposed Practice. This supports the argument that nuclear power stations using the RR SMR design would result in maximum "representative person" doses well within the 0.3 mSv/y constraint,[121] and doses to people other than the representative person would be very much lower. On the basis that UK regulation is framed so as to reduce potential radiological health impacts to the public to a low level and that regulatory constraints can be easily met, this therefore substantiates the argument that any radiological health detriment from the Proposed Practice will be very small.

5.4.2 For workers, the average individual doses are generally described since this provides an indication of the level of potential health detriment to an individual person employed on that activity over a period of time. It is less helpful to quote maximum worker doses, as these can vary considerably over the life of a facility according to the tasks being performed and the approach chosen. Maximum doses are nevertheless always kept within the legal dose limit and generally by a large margin. Information on the range of individual doses experienced in the UK nuclear industry is available in the Public

121] Early optimisation of dose levels for RR SMR show that the annual dose is significantly lower (byan order of magnitude of over a hundred) as the design progresses optimisation will continue to reduce these levels further.

Health England's report entitled "Ionising Radiation Exposure for the UK Populations: 2010 Review" **[42]**, and is also referenced throughout this Chapter for context.

5.4.3 In contrast, the figures quoted for doses to members of the public are generally those to a "representative person"—e.g. the members of the public who could be the most exposed (see Box 2 below).

BOX 2

How do we work out what the radiological health detriments might be?

The science of how radiation and radioactive materials may affect human health has been studied over a long period and has, for some years, been reviewed regularly by international and national scientific bodies. These bodies maintain their scientific independence from Governments and from commercial interests. Recommendations on the approach to be taken to protect people are made by the ICRP and these are considered by a range of national bodies. This Application is based on the authoritative advice from these bodies.

Over the many years that the subject has been studied, it has become established that exposure of people to radiation can be usefully expressed in terms of the radiation dose they receive. The dose can be derived from things that can be measured using a prescribed methodology that has been refined over the years. Radiation dose may then be used to calculate the potential health effects of any exposure to radiation using risk factors which, again, are recommended by bodies such as the ICRP and endorsed by national authorities.

The potential routes by which people could be exposed to radiation and hence receive a radiation dose are:

- External radiation dose (shine) from certain types of radioactive materials, which (if not completely shielded) could affect people in close proximity; and
- Internal radiation dose from radioactive materials that, once released, are in a form that means they could be inhaled or could enter the food chain and therefore be eaten or drunk.

To calculate potential doses to members of the public, the concept of the "representative person" is applied. Based on surveys of the habits of people living in the vicinity of a nuclear site and who could be affected by it, assumptions can be made, for example, about where they live, what they eat, how much time they spend in various locations. These can then be used to define a set of characteristics for a person whose habits would result in them being the most exposed to any radioactive discharges from the site. The hypothetical person following these habits is termed the "representative person". This approach originates from the ICRP and is one that has been adopted over several decades as part of the approach to radiation protection. In its 2007 ICRP103 guidance, ICRP advised that the term "representative person" should be used in place of the older term "critical group" to avoid any potential misunderstanding arising from the terminology. Although some dose assessments referenced in this application pre-date the 2007 ICRP Recommendations, and so originally used the term "critical group", we have adopted the newer term throughout this Application for consistency.

Designers of nuclear facilities take significant steps to prevent radioactive materials being released into the environment, except where such a release is under tightly controlled arrangements and then only for very small quantities. There have been many years' experience in making these measures more effective. This has resulted in a position where the potential releases of particular radioactive materials from particular types of nuclear facility are now well understood.

In addition, nuclear facilities both in the UK and worldwide have been subject to very extensive programmes of independent monitoring. This has resulted in a large body of information on how much radioactivity has been released into the environment and how it has subsequently behaved. These programmes have provided an important input to examining evidence of possible health effects linked to radiation around nuclear sites (see Annex 4).

There are two basic approaches to deriving figures for the additional radiation exposure caused by a nuclear site:

- The first is to use the measurements taken around the nuclear site to calculate doses to people; and
- The second is to measure the amount of radioactive material discharged (either in gaseous or liquid form) and to use computer models to calculate what radiation dose this could cause.

Both approaches have their advantages and disadvantages.

In the first approach, it is not possible to separate the dose from radioactivity due to the site from other sources of radioactivity. It can also be extremely difficult to accurately measure the level of radioactivity in the environment when the discharges are very small.

The second approach is dependent on the calculational models which tend to err on the side of over-estimating possible doses given the uncertainties involved. However, this method does show the link between the estimate of dose and a particular discharge from a particular source. Putting all this knowledge together leads to a very robust and widely accepted process for deriving the scale of potential radiological health detriment for the type of nuclear facility covered in this Application.

5.5 Assessment of Detriments from Potential Accidents

5.5.1 For potential accidents, the approach is to examine the possible additional risks from the Proposed Practice taking into account the likelihood of accidents and their potential radiological consequences. Again, for members of the public, the figures stated are for those who could potentially be most at risk (the "representative person").

5.6 Use of Collective Dose

5.6.1 This Application does not attempt to quantify the collective radiation dose for all potential sources of exposure associated with the Proposed Practice. The concept of collective dose is described in Box 3.

Box 3

Collective Dose

The "collective dose" for a particular group of people from a particular source of radiation means the sum of all the individual doses that each person receives as a result of exposure to that source. It is a useful way of examining the safety implications of something where a number of different people may be exposed to radiation at a range of different levels. The unit of collective dose is the "man-sievert". As an example: if a team of 3 people are each exposed to a dose of 1 millisievert (mSv) in carrying out a task, the total collective dose for that task is 3 man-millisieverts or (3 man-mSv).

Although it can be a useful tool in optimising the level of radiological protection—e.g. assessment of the collective dose can help to determine the best way to carry out a planned task—the mis-application of this concept can lead to some confusion.

Take, for example, the question: "What is the collective dose from cosmic radiation?". The problem in answering this question is in deciding just how many people to include, and over what time period to calculate their individual doses from this source. The answers reached would vary widely according to what is decided.

In this example the number of people chosen could be:

- The UK population (67 million);
- The world population (8 billion); or
- The world population over future generations.

Similarly, the timespan over which their doses are calculated could be chosen as:

- 1 year;
- A typical human lifetime; or
- The lifetime of the human race on the Earth.

In this example it might be of interest to know what the annual collective dose from cosmic radiation is to the UK population in one year. The answer is:

Number of people in the UK x the average annual individual dose
= 67,000,000 x 0.3 millisievert
= 20,100 man-sievert

When this is compared with the collective dose to the people working on a single unit nuclear power station (between around 0.5 and 1.5 man-sievert per year) the cosmic radiation figure above looks very large. However, this is because it is shared between a much larger number of people and the average individual doses are actually quite comparable. So in this case it makes more sense to compare the average individual doses than the collective doses. More generally, it is important to use collective dose figures very carefully; to understand what assumptions they have been based on; and to ask what they equate to in terms of an average individual radiation dose.

Because this Application indicates very low levels of representative person dose from all relevant sources and also provides figures for average individual doses, numerical estimates of collective doses to the public are not generally provided.

5.6.2 Collective dose can be a useful parameter where optimisation of radiological protection is being undertaken, especially in situations where there are judgments to be made about alternative approaches which could result in different numbers of people receiving relatively significant doses. However, since this Application concerns justification, it focuses on individual doses to those that could be most affected, and in all cases shows that these would be small. Some indication of the very low level of additional individual dose to an "average" member of the UK public is provided to confirm that these doses are so low as to be of no concern in terms of potential health detriment. These figures are derived from a calculation[122] of collective dose to a defined population using a methodology recommended by the Health Protection Agency (now "UKHSA").

5.6.3 This approach is in line with the latest Recommendations of ICRP **[23]** which provide the following guidance on the use of collective dose (or more precisely collective effective dose) in relation to the derivation of potential health detriment:

"The collective effective dose quantity is an instrument for optimisation, for comparing radiological technologies and protection procedures, predominantly in the context of occupational exposure. Collective effective dose is not intended as a tool for epidemiological risk assessment, and it is inappropriate to use it in risk projections. The aggregation of very low individual doses over extended time periods is inappropriate, and in particular, the calculation of the number of cancer deaths based on collective effective doses from trivial individual doses should be avoided."

5.6.4 It should be noted that because very few people are located in the vicinity of the releases and share the habits that are used in the assessment of doses to a "representative person", the adoption of this approach is conservative.

5.6.5 Those factors that are relatively more significant to the health detriment are treated at greater length than those whose contribution is so small as not to affect the overall balance between health detriments and net benefits.

5.6.6 The next section considers the following sources of potential radiological health detriment to the public and workers under the following headings:

- Uranium mining and extraction;
- Uranium conversion, enrichment and nuclear fuel manufacture;
- Normal nuclear power station operation[123]—radiological impact for the public;
- Normal nuclear power station operation—radiological impact for workers;
- Transport of radioactive materials—radiological impact on public and workers;
- Potential transport accidents—impact on public and workers;
- Potential reactor accidents—radiological impact for public and workers;
- Decommissioning—routine doses to workers; and
- Decommissioning impact of discharges and accidents on workers and the public.

5.7 Review of Level of Radiological Health Detriment

5.7.1 Radiation dose has been used for many years to quantify the health significance of exposure to sources of radiation—whether natural or man-made. Internationally accepted methods have been

122] EA, SEPA, NIEA, Food Standards Agency. Principles for the Assessment of Prospective Public Doses arising from Authorised Discharges of Radioactive Waste to the Environment, Radioactive Substances Regulation under the Radioactive Substances Act (RSA93) or under the Environmental Permitting Regulations (EPR-10). August 2012.

123] Normal operations also include management and disposal of radioactive waste and spent fuel.

used to estimate doses to humans from the different types of radiation exposure associated with the activities listed above. The same approach can be used to assess the doses that result from a range of everyday activities involving exposure to radioactivity (see Boxes 4 and 5 below).

Box 4

What is the level of radiation exposure (dose) to people in the UK?

The UK's safety and environmental regulatory controls are focused on ensuring that any routine exposures of the public to radioactive materials are at such a low level that the potential additional radiation dose arising from them will also be small.

The UK regulatory regime also requires that the probability of accidental releases of radioactivity from all causes is reduced to a very low level and that, notwithstanding this requirement, there are systems and procedures to mitigate any possible releases that could occur. The effectiveness of this approach in limiting the scale of any potential radiological health detriment is shown in the examples of regulated practices referred to in this Application.

Table 7 **[42]** shows how much radiation we receive from sources affecting the UK population. These show that the dose received from all man-made sources is less than the variability in naturally occurring background radiation across the UK.

Table 7: Average Annual doses due to UK population from all sources of radiation

Source	Dose (mSv)
All Natural Sources (average)	2.3
Consisting of (on average):	
Radon and Thoron	1.3
Intake of natural radionuclides (excluding radon)	0.27
Terrestrial Gamma Radiation	0.35
Cosmic Radiation	0.33
Weapons Fallout	0.005
Other environmental anthropogenic radioactivity[124]	0.0008
Exposure from the use of radiation	0.44
Consisting of (on average):	
Patient exposure from medical radiation	0.44
Occupational use of radiation	0.0004
Return airline flight, UK to USA	0.08 per trip
1 week in Cornwall, UK	0.13 per week
Working for one year as aircrew	2.4 per year

124] Includes radionuclides routinely discharged or accidentally released into the environment

Box 5

Risks

It is possible to convert assessed doses into risks using risk factors. The internationally recommended (ICRP) risk factor for total health detriment for all ages is 5.7% per Sv of which around 95% (i.e. 5.5% per Sv) is due to the risk of contracting cancer. The remaining risk arises from hereditary effects. The corresponding risk of inducing a cancer that would prove fatal is about 5%, although this value will be dependent on underlying health and medical care. The total health detriment ICRP risk factor has been adopted in Table 8 to derive the theoretical risks of health detriment associated with the individual doses presented in this Application. Applying this factor, the risks for members of the public are those set out in Table 8.

Table 8: ICRP Theoretical risk of health detriment

Source of Additional Exposure	Additional Dose	Theoretical risk of health detriment per year	
Public		Scientific	Colloquial
Public dose	Dose limit = 1 mSv per year	5.7 x 10^{-5}	Around 1 in 17,500
Bounding value for purposes of justification for individual dose to any member of the public from introduction of the Proposed Practice	Less than 0.3 mSv per year	Around 1.7 x 10^{-5}	Less than 1 in 58,500
Evidence on the maximum level of dose to any member of the UK public that currently arises from any of the activities that could be required as part of the Proposed Practice (indicates the impact of "optimisation")	Less than 0.14 mSv per year (uranium enrichment)	Less than 8.0 x 10^{-6}	Less than 1 in 125,000
Sizewell B representative person dose	Less than 0.005 mSv per year	Less than 3 x 10^{-7}	Less than 1 in 3,300,000
Population Dose			
Per caput dose to UK public from Sizewell B discharges (at full discharge authorisation limits)	Less than 3 x 10^{-6} mSv	Less than 1.7 x 10^{-10}	Less than 1 in 6,000,000,000
Per caput dose to UK public from all existing UK nuclear industry discharges	Around 0.0009 mSv per year	Around 5.1 x 10^{-8}	Around 1 in 19,500,000
Some other sources of radiation dose			
Dose from one return flight to New York per year	Around 0.1 mSv per year	Around 5.7 x 10^{-6}	Around 1 in 175,000
Dose to someone who spends 1 week per year in Cornwall (and comes from part of the UK with typical natural background level)	Around 0.15 mSv per year	Around 8.6 x 10^{-6}	Around 1 in 117,000
Dose from one Computed Tomography ("CT") scan of abdomen per year	Around 10 mSv per year	Around 5.7 x 10^{-4}	Around 1 in 1,750

5.7.2 Lower risk factors have been proposed for workers reflecting the different age profile and health compared with the general population; however, the same factor is used conservatively to calculate the risk for workers and the results are shown below.

5.7.3 It should be noted that the risk factors used above are derived on the cautious assumption that there is a linear, no-threshold relationship between radiation dose and risk. As explained in Annex 4, this approach is adopted out of prudence for the purpose of managing exposure to radiation and is likely to err in the direction of caution and so overestimate risks from low level exposure to radiation.

5.7.4 In their latest Recommendations, the ICRP specifically advise against using collective dose assessments (or the "trivial", average per caput population dose figures that can be derived from them) as a tool for risk projections or for the calculation of health effects. These risks can be set in context with reference to the information provided by PHE (now UKHSA) on its website **[43]**.

5.7.5 According to PHE, the chance of a person living in the UK contracting some type of cancer during their life is between 20-25% (between a one in five and one in four chance).

5.7.6 PHE estimates that over a lifetime the exposure of an average person in the UK to radiation from all sources contributes about 1% to the overall lifetime cancer risk they have from all causes (i.e. the 20–25% figure above).

5.7.7 Natural background radiation accounts for the vast majority of the radiation exposure contributing to this 1% cancer risk. All non-medical, man-made sources of radiation only contribute about one hundredth part of this already small 1% risk contribution above.

5.7.8 PHE therefore concludes that, compared with other known cancer risk factors in the population such as cigarette smoking, excessive exposure to sunlight and poor diet, the risk to the population from all non-medical man-made radiation is very small indeed.

5.8 Assessment of Potential Radiological Health Detriment

Uranium Mining and Extraction

5.8.1 Although uranium was once mined in Cornwall (for its application in ceramics rather than for nuclear fuel), all mining and milling of uranium, or its extraction by in-situ leaching, for use in the nuclear industry now takes place outside of the UK as part of existing, established practices. New UK nuclear power stations, including those deploying the Proposed Practice, would represent only a small additional source of demand for uranium above that arising from the international market. Potential additional radiological detriments from this part of the fuel cycle are therefore only considered briefly in this Application for completeness.

5.8.2 UNSCEAR has derived estimates **[44]**[125] of 0.025 mSv/y—using a model mine and mill having the features of existing sites—for the average additional individual radiation dose to members of the public within a 100km radius of a mining site. UNSCEAR say considerable deviation is possible for specific sites largely influenced by the mining technique and quality of the management of tailings. UNSCEAR **[44]** also reports doses to those working in the uranium mining industry and shows that doses in recent times have been below the levels set by international bodies and have been falling.

5.8.3 Uranium mining was one of the topics referred to in the 2007 consultation on nuclear power. The subsequent White Paper **[45]** concluded:

“We remain satisfied that stringent regulation here and overseas (where uranium is mined) provides adequate environmental safeguards to assess and mitigate the impacts.”

5.8.4 Any additional radiological health detriment arising from uranium mining and extraction in support of the UK’s implementation of the Proposed Practice will thus be very small.

Uranium Conversion, Enrichment and Nuclear Fuel Element Manufacture

5.8.5 Extracted uranium is supplied as uranium oxide (U_3O_8) or “yellowcake” and must be converted into other chemical forms for enrichment and incorporation into nuclear fuel. The uranium conversion,[126] enrichment and nuclear fuel assembly manufacturing services needed by any new nuclear power stations could be sourced either from the UK or from overseas suppliers. This Application considers the potential radiological health detriment of these activities on the assumption conversion, enrichment and manufacture take place in the UK.

5.8.6 The regulatory framework for nuclear fuel conversion, enrichment and manufacture is essentially the same as for the operation of a nuclear power station. A nuclear site licence is required by the Operator of any site carrying out this work, and this licence would contain conditions relevant to minimising potential radiological detriments from the site’s activities. Any such site would also require a permit from the EA/NRW under EPR 2016[127] and an approval under the permit granted under section 2 of the Nuclear Installations Act 1965 for any disposal of radioactive substances from the site. The EPR 2016 permit would place a regulatory requirement for the minimisation of any discharges into the environment through the application of Best Available Techniques (“BAT”). In addition, the IRR17 **[38]** would require controls to be in place to limit the exposure to the public and workforce.

125] Note that this is the most recent report from UNSCEAR on public exposure to ionising radiation, and that a new report on the topic was commissioned in 2020, with expected completion in 2024

126] Note that whilst uranium conversion was carried out at Springfields until 2014, it is not currently carried out in the UK, but funding has been provided by UK government for Westinghouse to develop a facility to do so from 2028. This is ahead of the date that RR SMR will require fuel.

127] ‘Authorisation’ remains the relevant term in Scotland and Northern Ireland although in this Application the terms authorisation and permitting should be read interchangeably.

5.8.7 Experience from recent nuclear fuel enrichment and fabrication in the UK has shown that this approach results in a very low level of radiological health impact from these processes, both for workers and members of the public. Publicly available figures show that the average worker doses at the two sites involved in these processes in the UK were: 0.29 mSv/y for manufacturing (in 2021 at the Springfields site near Preston) **[46]** and 0.18 mSv/y for enrichment (on average in 2020 at Urenco, the international parent company of the Capenhurst site near Chester) **[47]** This is the result of the relatively low level of radioactivity present within unirradiated (new) nuclear fuel and the very small amounts of radioactivity that are released during uranium enrichment and fuel element manufacture.

5.8.8 The environments around UK nuclear sites are monitored closely for radioactivity. Results obtained over many years for the Springfields uranium conversion and fuel manufacturing site confirm that doses to even the most exposed members of the public (the representative person) are very low. The most recent results quoted in the annual joint report by the Reactivity in Food and the Environment ("RIFE") partners (EA, Food Standards Agency, Food Standards Scotland, NRW, NIEA and SEPA) **[48]** estimated the highest representative person doses in 2022 to be 0.032 mSv/year.

5.8.9 These numbers are derived from measurements of extremely small amounts of radioactivity; they overestimate the radiological detriment due purely to conversion and fuel manufacture because not all of the radioactivity measured in the environment around Springfields will have originated from the work done on that site. For example, radioactivity originating from historic atmospheric nuclear weapons testing, from the Chernobyl accident, and from past liquid discharges from the Sellafield site will have been included. Because these are representative person doses, it is also clear that doses to the majority of people living in the vicinity will be less than these figures.

5.8.10 The same report assesses the maximum representative person dose to members of the public in the vicinity of the Capenhurst site (which amongst other activities carries out uranium enrichment) as 0.14 mSv/y in 2022. Again, this number overestimates the radiological detriment due purely to enrichment because it is based on measurements of all sources of radioactivity in the vicinity of the site, not just those arising from the enrichment process. As above, doses to the vast majority of people who do not share the habits and location of the representative person will be less.

5.8.11 Fuel enrichment and manufacturing processes required to support the Proposed Practice would be very similar to those already carried out at the sites referred to above. It is clear that doses to public and workers from these activities easily meet relevant limits and are within the relevant dose constraints for the public. The assessment above therefore provides a reasonable basis for assessing the broad scale of radiological health detriment that could arise from these processes were they to take place in the UK as part of the introduction of the Proposed Practice.

5.8.12 Thus the maximum potential radiological health detriment from these activities, if carried out in the UK in support of the implementation of the Proposed Practice, would be small. The maximum individual annual dose to any member of the public would be within the 0.3 mSv constraint. Worker doses would be well within the dose limit, and average annual doses less than the 10 mSv figure adopted for the purposes of this Application.

5.8.13 The additional average individual dose to the UK population from uranium conversion, enrichment and fuel manufacture has not been directly assessed.

5.8.14 However, given that these activities are ones that already take place in the UK and noting that the average individual dose to a member of the public in the UK from all nuclear industry activities is estimated as being around 0.0009 mSv/y (see Table 8 in Box 5 that assesses risks). This is insignificant in comparison with the dose from natural background radiation and it is clear that the additional contribution would also be insignificant.

Normal Nuclear Power Station Operation – Radiological Impact for the Public

5.8.15 Nuclear power stations in England and Wales are permitted to dispose of radioactive substances under Schedule 23 of EPR 2016 **[39]** which is enforced by the EA in England and NRW in Wales. In Scotland disposals of radioactive substances are still authorised under the Environmental Authorisations (Scotland) Regulations 2018 ("EA(S)R 2018") and are enforced by SEPA. In Northern Ireland, the use, storage and disposal of radioactive substances is governed by the NIEA under the Radioactive Substances Act 1993, as amended by the Radioactive Substances Act 1993 (Amendment) Regulations (Northern Ireland) 2011.

5.8.16 These EPR 2016 Permits and EA(S)R Authorisations permit/authorise limited discharges of low-level fluid waste (liquids and gases) to the environment, volume reduction of combustible waste by incineration on site, and limited transfer of solid low-level wastes ("LLW") (explained further in Annex 6) to other sites. It is the potential radiological detriment from these activities that is assessed in this section. As was explained earlier, EPR16 prescribes values for the dose constraint to be applied to a single site or to a new facility.

5.8.17 Other waste products containing higher levels of radioactivity (intermediate level waste) would be stored at the nuclear power station (or at an alternative licensed facility) until final disposal in a stable solid form to an engineered waste repository (see Chapter 6).

5.8.18 Spent fuel would be stored on site until transported to another nuclear site for further interim storage, disposal or, possibly, reprocessing. The potential radiological health detriments of onsite or offsite storage are included here as part of normal station operation. The radiological detriments of spent fuel transport and disposal are covered later in this Chapter. The reprocessing of spent fuel is not part of the Proposed Practice and is accordingly not addressed here. This approach aligns with the Government's position **[5]**:

"In the absence of reprocessing proposals from industry, owners of spent fuel, including from new or advanced reactors, should proceed on the basis that spent fuel will not be reprocessed."

In addition to the requirement to remain below discharge limits specified in an EPR 2016 Permit (or equivalent authorisation in Scotland or Northern Ireland), the operator is currently required to use BAT to minimise the activity of radioactive waste produced on the site that will require disposal under the Environmental Permit (or Authorisation in Scotland and Northern Ireland). In doing this the operator needs to:

- Prevent the unnecessary creation of waste or discharges;
- Minimise waste generation; and
- Minimise the impact of discharges on people and the environment on the basis that the operators use the techniques which represent BAT to achieve these objectives, as a whole.

5.8.19 For new nuclear power stations, the regulatory pressure to use BAT should ensure that actual discharges are not only within the authorised limits but are reduced still further.

5.8.20 As explained, the UK environment agencies have been directed to assess any future proposal for a permit or an authorisation to discharge radioactivity against dose constraints set at levels below the national dose limits for members of the public. This approach was originally adopted as good practice pursuant to the Euratom Basic Safety Standards Directive **[40]** relating to the implementation of the optimisation principle as part of overall radiological protection. The single site constraint protects members of the public from the cumulative effect of exposure to radioactivity from different facilities employing the proposed practice located on the same site.

5.8.21 Ahead of completing the optimisation stage, which will take place after justification as part of site-specific UK licensing and permitting, it is not possible to present definitive figures for the RR SMR against these constraints. However, estimates can be made, and confidence in the capability of the RR SMR to meet these constraints can further be derived from the following.

5.8.22 The performance of other modern reactor designs already assessed in the UK is relevant. There have been four reactor designs to complete Generic Design Assessment ("GDA") in the UK, and the annual expected dose to a representative member of the public is shown in Table 9 The AP1000®, as a Gen III+ PWR, is the most relevant comparison, whilst the UK HPR1000 and EPR™ are of slightly older Gen III PWR designs. For context, the legal limit of 0.3 mSv is equal to 300 μSv.

Table 9: Modelled Representative Person Annual Doses from GDA Submission

Reactor	Representative Person Annual Doses	Representative Person Annual Doses normalised for power output
RR SMR **[49]**	12.3 μSv	0.026 μSv/MWe
AP1000® **[50]**	14 μSv	0.013 μSv/MWe
UK HPR1000 **[51]**	22.8 μSv	0.019 μSv/MWe
EPR™ **[52]**	25.8 μSv	0.014 μSv/MWe
ABWR™ **[53]**	34.9 μSv	0.026 μSv/MWe

5.8.23 The figures in Table 9 (including those for RR SMR) are derived from GDA stage, worst-case modelling, and therefore may overstate the possible exposure in relation to the real-world radiation exposure in operating nuclear plants. For example, the total real-world dose for the representative person from the Sizewell B PWR (using similar reactor technology to the RR SMR) was below 5 µSv **[48]**, demonstrating that PWR technologies similar to that in the proposed practice are capable of operating in well within conservative GDA assessments, and hence far below the 0.3 mSv/y constraint.

5.8.24 From a European perspective, UNSCEAR reports **[44]** that on average, in Europe, an individual living 5 km from a nuclear power plant would receive an additional dose of 0.73 µSv per gigawatt-year. This would suggest that even with a large fleet of deployed SMRs, the proposed practice would produce expected doses well within regulatory limits. At these small dose levels, the risk associated with exposure becomes difficult to quantity.

5.8.25 To help contextualise these numbers, the UNSCEAR report calculated the collective dose (discussed in Box 3), integrated over 100 years, that the European population would receive. The total due to all 197 reactors in Europe would be 28 man-Sieverts. Taking the rough population of Europe (750 million people) and the average European background dose (3.2 mSv, slightly higher than the UK alone) gives an annual background contribution in Europe of roughly 2.4 million man-Sieverts.

5.8.26 For perspective, the dose rate derived for an average citizen in the vicinity of a nuclear power plant in Europe (many of which were commissioned decades ago) is nearly 100,000 times smaller than the dose rate received from other naturally occurring sources of radiation. While Permit applications for any nuclear power station(s) built as part of the Proposed Practice have not yet been made, it is clear that, even if the discharges significantly exceeded those referred to above, the potential health detriment would remain very small and immaterial in the context of the overwhelming benefits of the Proposed Practice.

5.8.27 Like the previously assessed reactor designs, the RR SMR has been designed to ensure that the requirement to keep radiation doses to the public below dose constraints and the statutory annual limit of 1 mSv/y can be achieved by a large margin. These designs build on the experience with other operating designs and incorporate features to ensure levels of safety and environmental protection that are at least as good as those provided today so that, following the optimisation stage of the radiological protection process, their impact can be expected to be similar to or even smaller than that of existing UK nuclear power stations.

5.8.28 The very low level of these radiological detriments is a direct result of the fact that only very small quantities of radioactive material are discharged during normal operation by designs of the type that would be accepted in the UK. The EA states that, as part of its principles for radioactive substances regulation **[54]** which would apply to new nuclear plants:

"We should make sure that BAT is used to:

- *prevent the unnecessary creation of radioactive waste or discharges*
- *minimise the quantity and activity of any radioactive waste that is created*
- *minimise the impact of discharges on people and the environment*

BAT is how the operator manages disposals of radioactive waste into the environment so that the public's exposure to ionising radiation is kept ALARA, and the environment is protected." [128]

5.8.29 The ONR's Safety Assessment Principles **[41]** also state that:

"Containment and associated systems should be designed to minimise radioactive releases to the environment in normal operation, fault and accident conditions." [129]

5.8.30 Radiological impact for the Public from the Proposed Practice is expected to be significantly reduced from existing PWRs. The reactor of the RR SMR contains 40 % of the inventory of Sizewell B and on a per unit basis would be expected to have a significantly smaller radiological impact during normal operation and in the event of any incident or severe accident. The major contributors to radiological dose in a PWR are those due to C-14 and Tritium (H-3). The RR SMR will produce comparable (on a dose per MW basis) levels of C-14 to existing, justified PWRs. Existing PWRs use boron for duty reactivity and power control.

5.8.31 When boron is irradiated in a nuclear reactor such as a PWR, tritium is produced. Tritium cannot be removed in waste treatment plants and periodic dilution of coolant is required to maintain tritium levels below particular criteria prior to maintenance. This tritium is then discharged to the environment, within regulated limits. The RR SMR does not use boron for reactivity control and as such the amount of tritium produced by the Proposed Practice is significantly reduced compared to existing LWRs justified in GB. As tritium is a significant contributor to total dose, so the total dose from the Proposed Practice is significantly reduced.

128] Radioactive Substances Regulation Principle 8 www.gov.uk/government/publications/radioactive-substances-regulation-rsr-objective-and-principles/radioactive-substances-regulation-rsr-objective-and-principles#principle-8-bat

129] Safety Assessment Principles ECV.2 page 117 www.onr.org.uk/publications/regulatory-guidance/regulatory-assessment-and-permissioning/safety-assessment-principles-saps

5.8.32 It is therefore reasonable to conclude that any new nuclear stations permitted or authorised in the UK as part of the Proposed Practice would result in additional radiation doses, to those most exposed, that would be less than the 0.3 mSv/y constraint. It is also reasonable to conclude that average individual doses to the UK population as a whole would be at levels so small, they would be insignificant in terms of any radiological health detriment.

Normal Nuclear Power Station Operation – Radiological Impact for Workers

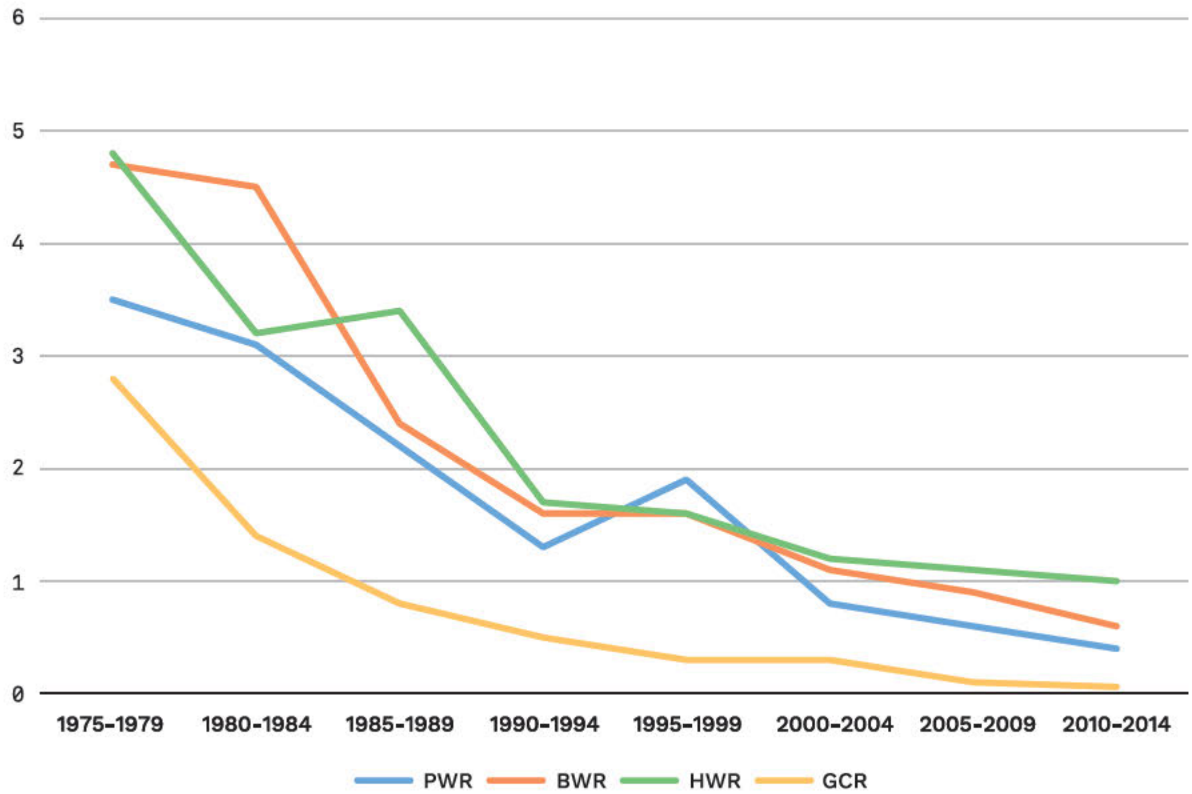
5.8.33 The UK's Ionising Radiations Regulations 2017 require employers to put arrangements in place to manage radiological protection of their workers so as to keep them ALARP. These regulations also impose a dose constraint of 20 mSv per year for routine exposures received by individuals as a result of their exposure to radiation at work. In certain conditions, when approved by the HSE, the limit can be no more than 50 mSv in any one year with the average over a 5-year period not exceeding 20 mSv per year. These regulations would be applied to protect workers from all radiation sources on-site, including interim storage of fuel and waste at any new nuclear power station(s) involving the Proposed Practice.

5.8.34 The 2016 PHE report **[42]** covering UK radiation exposure up to 2010 (the most recent available) gives the average annual radiation dose to nuclear power station workers across all operators as 0.18 mSv. To give some feel for the maximum doses, this report records 13 workers (out of more than 6,500) with individual doses in the band from 6- 10 mSv/y, and no worker receiving a dose above this level. The highest individual dose among nuclear power station workers during 2010 was less than half of the maximum dose permitted in any one year (20 mSv).

5.8.35 For further context, the same report stated that in 2010, the average radiation dose received by an offshore oil and gas worker was 0.22 mSv—higher than a worker in a nuclear power plant.

5.8.36 UNSCEAR reports **[44]** that the average individual dose to workers in PWR power stations worldwide has decreased tenfold between the reporting periods 1975-1979 and 2010-14, from 3.5 mSv to 0.4 mSv per year. The UNSCEAR report also provides data showing the trend in collective exposure per unit of power generated. This has also decreased tenfold, showing that improvements in PWR designs have helped to reduce average worker exposure over the last 50 years.

Figure 3: Average annual effective dose to monitored workers (mSv)



5.8.37 Figure 3 **[44]** shows that PWR technology has historically had the lowest worker doses of all the water-cooled technologies BWRs and PWRs. The lower doses in gas-cooled reactors are explainable for multiple reasons. Firstly, the gas cooled reactor has been used almost exclusively in Britain, where a mature regulator and strict legal limits require exposure to be kept ALARP. Secondly, AGRs and more recently built Magnox reactors (which were the only Gas

Cooled Reactors ("GCRs") operating during the 2005-2009 and 2010-2014 reporting periods) are constructed with pre-stressed concrete reinforced pressure vessels, providing a large amount of radiation shielding close to the reactor, reducing worker doses. In addition, a major source of radiation in water cooled plants comes from the activation of the cooling water circuit. GCRs use Carbon Dioxide (CO_2) gas, which is less susceptible to activation.

5.8.38 This last source of exposure has been optimised in the RR SMR design. By using a non-borated cooling circuit and potassium hydroxide chemistry, the production of tritium is greatly reduced. Following on from existing PWRs, the RR SMR in the Proposed Practice is seeking to significantly reduce the amount of cobalt present in components such as hard wearing valve seats and in base material. Cobalt, when activated, can contribute significantly to operator and maintenance doses. Reduction of the amount of cobalt in the design, coupled with the use of zinc dosing in the reactor coolant system which displaces cobalt from corrosion films such that it can be cleaned up in the plant's waste systems will significantly reduce operational and maintenance doses. The use of a potassium hydroxide chemistry will further reduce operational doses from the Proposed Practice in comparison to existing LWRs justified in GB and reduce overall chemical use.

Transport of Radioactive Materials – Radiological Impact on Public and Workers

5.8.39 Transport of radioactive materials required as part of the deployment of new nuclear power station(s) would comprise:

- The transport of new fuel assemblies to the station(s);
- The transport of spent fuel from the station(s); and
- The transport of radioactive waste materials—either during normal operation or as part of the station's decommissioning.

5.8.40 These types of transport are already undertaken within the UK and have been justified on a generic basis. Transport of radioactive material linked to new nuclear power station(s) as part of the Proposed Practice would be subject to existing UK regulations that are framed so as to ensure that any possible radiological health detriment resulting from transport is low. While the packages used in transport associated with the Proposed Practice may differ in detail from those used currently, they will be required to meet the same standards and so provide the same level of protection.

5.8.41 The UK regulatory regime for transport is managed by the ONR's Transport Competent Authority team and ensures that transport of goods is in accordance with The Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009. The carriage of Class 7 goods (radioactive material) within the UK is also therefore addressed as part of the Energy Act 2013. These regulations transpose into UK law the following international standards:

- Agreement concerning the International Carriage of Dangerous Goods by Road
- The Regulation concerning the International Carriage of Dangerous Goods by Rail
- European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways

5.8.42 These regimes follow the principles set out in IRR17 for the minimisation of dose to the public and the workforce. In addition, UKHSA regularly reviews the radiological impacts from the transport of radioactive materials within the UK for the ONR.

5.8.43 A 2017 study by PHE **[55]** investigating the estimated annual dose from transport of radioactive materials found that a typical member of the public would be exposed to less than 0.001 mSv annually. This dose is estimated using a worst-case scenario for exposure during typical transportation and is less than one one-thousandth of the legal limit for members of the public. The contribution from transport of spent fuel to exposure of the public was less than that of medical radioisotopes. In addition, the nuclear fuel activity the study analysed was the transport of material from a reprocessing facility, none of which now operate in the UK.

5.8.44 The World Nuclear Transport Institute ("WNTI") continues to distribute a study **[56]** of radiation doses from the transport of nuclear fuel cycle materials. A well as collating published sources, the study also draws upon information from WNTI member companies. This reports maximum public doses from transport of spent fuel of less than:

- 0.004 mSv via road transport;
- 0.006 mSv via rail; and
- 0.001 mSv via sea.

5.8.45 The level of radioactivity in new fuel and in solid radioactive waste is very much lower than in spent fuel so that the radiological impact from these types of transport would be even lower.

5.8.46 In proportion to the electricity generated, RR SMR uses smaller quantities of fuel and produces smaller quantities of operational solid wastes than the current UK nuclear fleet comprising mainly gas-cooled reactors. This is a consequence of the smaller amount of fuel required per unit of electricity generated and the generally more compact dimensions of SMR technologies.

5.8.47 The PHE study **[42]** also considered the impact on the workforce associated with the movement of radioactive materials. It found that the civil nuclear industry was generally responsible for far lower doses to workers than the radiopharmaceutical and industrial sectors, and in its summary stated that, of the workers in the report:

"The lowest doses are received by the operatives at Sellafield labelling nuclear fuel flasks and the highest doses are to the engineers involved in the movement of [radioactive cobalt] sources for the purpose of [sterilisation]. The drivers involved in transporting radiopharmaceuticals received the highest doses due to the large number of packages that are consigned each year compared to those consigned in the civil nuclear industry."

5.8.48 The WNTI study also reports maximum worker doses from transport of spent fuel of:

- Less than 1 mSv via road transport;
- 0.2 mSv via rail; and
- Less than 1 mSv via sea.

5.8.49 The same stringent regulatory principles would be applied to the transport of radioactive materials associated with the Proposed Practice and therefore should be expected to meet these same high standards of protection for workers and the public. This view is the same as that reached by the Government following its consultation on new nuclear power stations **[45]**:

"Having reviewed the arguments and evidence put forward, and given the safety record for the transport of nuclear materials and the strict safety and security regulatory framework in place, the Government believes that the risks of transporting nuclear materials are very small and there is an effective regulatory framework in place that ensures that these risks are minimised and sensibly managed by industry."

5.8.50 The Secretary of State, in his 2015 Justification Decision **[11]** relating to the UK ABWR™, has also stated the following:

"The Secretary of State also considers that radioactive waste and spent fuel arising from any UK ABWR™ built in the UK could be effectively managed to ensure that the potential risks or detriments from its handling, storage, transport or disposal are within acceptable limits."

5.8.51 Thus, the maximum potential radiological health detriment from the transport of radioactive materials carried out in support of the implementation of the Proposed Practice would be small, with the maximum individual annual dose to any member of the public being small (less than 0.020 mSv/y) and maximum worker doses (less than 1 mSv/y) well below annual dose limits.

Potential Transport Accidents – Impact on Public and Workers

5.8.52 The UK Regulatory Regime for transport is based on the IAEA Regulations for the Safe Transport of Radioactive Material **[57]** and European and UK legislation. Protection for the public and workers against the effects of accidents during transport is achieved by requiring:

"Containment of the radioactive contents; control of external radiation levels; prevention of criticality; and prevention of damage caused by heat." [130]

5.8.53 In addition, UKHSA publishes, as part of its regular review of the transport of radioactive materials within the UK, the radiological consequences resulting from any transport accidents in the UK.

5.8.54 A report **[58]** has been prepared covering the entirety of the data available in the Radioactive Materials Transport Event Database ("RAMTED") from 1958 up to and including 2004. This report shows that the most serious radiological consequences arising from accidents during transport have occurred as the result of improperly packaged radiography sources and that, as a result of better training, only two of these have occurred since the mid-1980s. Among the events whose

130] Regulations for the Safe Transport of radioactive Material - IAEA Specific Safety Requirements No. SSR-6 (Rev. 1) Page 2 www-pub.iaea.org/MTCD/Publications/PDF/PUB1798_web.pdf radiological implications were considered worthy of study, there was only one that related to transport associated with nuclear power. This event involved a worker mistakenly placing a component from the lid of a road transport flask in his cab for several hours which resulted in a small additional dose to him. No power station-related transport events were identified that could have resulted in doses to a member of the public. Incidents after 2005 comprise a small number (3) of accidents involving packages containing uranium ore concentrate, all of which were assessed as giving rise to a dose consequence of less than 1 mSv.

5.8.55 The transport packages with the greatest hazard potential under accident conditions would be those used to transport spent fuel from any nuclear power station. However, these packages would have to meet very stringent regulations that would make it extremely unlikely that any significant release of radioactivity could take place even under extreme accident conditions. For example, the IAEA specifies **[57]** that packages must be able to withstand a fully engulfing fire at 800 °C for at least 30 minutes; be capable of withstanding a 9 m drop (equivalent to a 250 km per hour impact with a concrete block); survive at 200 m depth in water for 1 hour; and at 15 m depth for 8 hours, without any rupture of the containment. There is a large body of evidence[131] to show that the current IAEA Type B[132] test requirements are sufficiently severe to cover all reasonably conceivable situations and cover all the situations which can be realistically envisaged in the transport of spent fuel, higher activity waste and other fuel cycle materials. This includes experimental evidence from the successful crash testing of IAEA packages in a range of situations. For example, the Central Electricity Generating Board programme of testing culminating in the 1984 demonstration of a train impacting an irradiated fuel transport flask and the tests in the US conducted at Sandia National Laboratory with various "missiles" impacting on fuel flasks.

5.8.56 With regard to the transport of un-irradiated fuel and solid waste materials, the hazard potential is much lower because these materials are much less radioactive. For a significant radiological health detriment to arise, members of the public would need to be exposed to any released materials over a prolonged period following any accident or for radioactive materials to be inhaled or ingested. Emergency arrangements that are required to be in place to respond to transport accidents would ensure these risks are reduced to very low levels.

5.8.57 In summary, the radioactive materials transport operations associated with this Proposed Practice would be no different in nature to those from the existing UK nuclear programme, and the arrangements to ensure high levels of safety would be similar. The risks from transport accidents linked to new nuclear power stations therefore remain low and would have very little potential to impact on public health.

Potential Reactor Accidents – Radiological Impact for Public and Workers

5.8.58 It is a fundamental principle of UK nuclear safety regulation[133] **[41]** that *"all reasonably practicable steps must be taken to prevent and mitigate nuclear or radiation accidents."* All licensed nuclear sites maintain and rehearse regularly their emergency arrangements which are provided to mitigate the consequences of an accident if it were ever to occur. These arrangements are a requirement of the Nuclear Site Licence and are subject to the Radiation (Emergency Preparedness and Public Information) Regulations 2019 **[59]**. Appropriate arrangements would have to be provided for any new facilities licensed as a result of the introduction of the Proposed Practice.

5.8.59 The UK approach to accident safety is enforced through the ONR as the independent nuclear safety regulator. The ONR has published its SAPs **[41]** which provide guidance to its inspectors on the assessment of the safety of nuclear installations against this (and other) requirements that affect the potential radiological detriment from accidents to nuclear installations licensed in the UK. This Application focuses on just one element of the ONR approach—the BSL and BSO for accidents.

5.8.60 These two concepts are explained in the paragraphs below. The criteria relating to these levels and objectives provide a basis for assessing the potential scale of radiological detriment from accidents ahead of the completion of the licensing process for a particular design.

5.8.61 Through their BSLs and BSOs, the ONR has set down two standards for determining whether the risk posed by accidents to the public is likely to be sufficiently low to be acceptable for a particular design of nuclear plant. This is just one of the tools used by ONR during the licensing process.

131] Examples of references where these types of tests are described can be found at: http://www.patram.org/PATRAM_FP_07.pdf. See also: http://www.patram.org/PATRAM_FP_07.pdf. http://www.tes.bam.de/de/umschliessungen/behaelter_radioaktive_stoffe/dokumente_veranstaltungen/patram_2010/Patram2010_Final%20Program.pdf.

132] Type B tests are outlined in IAEA-TECDOC-295 (1983) and require that packages can be demonstrated to perform adequately in normal operation of transport and withstand a range of challenges to represent accidents. The various tests are designed to confirm performance against water sprays, free drops, compression and penetration (normal operation), together with the demonstration of sufficient resilience against mechanical and thermal challenges, and water immersion (accidents).

133] Safety Assessment Principles for Nuclear Facilities, Revision 1 (January 2020) Fundamental Principles Prevention of accidents FP.6 pg 17.

5.8.62 The ONR's SAPs state:[134]

"It is ONR's policy that a new facility or activity should at least meet the BSLs."

5.8.63 They go on to explain:[135]

5.8.64 *"The BSOs form benchmarks that reflect modern nuclear safety standards and expectations."*

5.8.65 Thus; a BSL sets the minimum standard likely to be acceptable, with the BSO representing the more challenging safety expectation that nuclear plant would achieve an acceptably low level of risk.

5.8.66 The SAPs set out target BSLs to limit the total predicted frequencies of accidents on an individual facility, grouped in "bands" according to the scale of radiation dose that could arise if the accident were to occur (as shown in Table 10). The requirement is to demonstrate that a design has achieved a predicted frequency of accidents in each of these "bands" which falls below these BSLs. Put simply, the designer must convince the ONR that the likelihood of accidents occurring across all levels of severity is acceptably low.

5.8.67 Recognising that severe accidents could affect large numbers of people if they were ever to occur, the ONR's SAPs set down additional BSL and BSO criteria to limit their likelihood. These are framed in terms of the assessed probability per year of an accident that could give rise to certain threshold levels of radiation dose to a person off site. These doses, and their BSL and BSO likelihoods are shown Table 10. There is an additional target that accidents at a site which cause 100 immediate or eventual fatalities must be shown to occur with no more likelihood than a chance of one in one hundred thousand per year (at the BSL) and the benchmark for modern designs (i.e. the BSO) is a likelihood of no more than a chance of one in ten million per year of such a scale of accident.

Table 10: ONR target 8, frequency dose targets for accidents on an individual facility recieved by any person offsite

Predicted off site dose, mSv (i.e. a measure of severity of accident)	Predicted likelihood of accident occurring that could lead to this level of dose in any 1 year: (i.e. the maximum acceptable likelihood of accidents at this level of severity occurring)*	
	BSL	BSO
0.1 – 1	1	1 chance in 100
1 – 10	1 chance in 10	1 chance in 1,000
10 – 100	1 chance in 100	1 chance in 10,000
100 – 1000	1 chance in 1,000	1 chance in 100,000
>1000	1 chance in 10,000	1 chance in 1,000,000-

5.8.68 In the assessment of a modern reactor design against these BSOs, the ONR concluded in their assessment of the EPR™ reactor design (a Gen III PWR) under the GDA process **[60]** that the Probabilistic Safety Assessment ("PSA") results presented by EDF and AREVA meet the BSOs presented in Table 10. This is an example of how the ONR applies its expectations. We would expect other modern evolutionary type reactors such as the RR SMR (a Gen III+ PWR) to have a broadly similar risk profile, albeit with a significantly smaller source term.

5.8.69 Within its SAPs, the ONR included annex 2, which explains that the additional risk of death from accidents to a person just outside of the boundary of a plant which just met the BSL above would be "about 2 x 10^{-5}/y" (which means one chance in fifty thousand per year). Similarly, the additional risk from a plant which just met the BSO would be "about 2 x 10^{-7}/y" or one chance in 5 million per year.

134] Safety Assessment Principles for Nuclear Facilities, Revision 1 (January 2020) para 698

135] Safety Assessment Principles for Nuclear Facilities, Revision 1 (January 2020) para 701

5.8.70 The Sizewell B nuclear power station was licensed against a previous version (1992) of the ONR Safety Assessment Principles and thus also provides another illustration of the effect of this approach on the level of radiological health detriment from potential accidents. In his report following the Sizewell B Public Inquiry (which heard a large amount of detailed evidence on this subject), Sir Frank Layfield (the Inspector chairing the inquiry) concluded that the maximum risk of death to any member of the public from accidents at the station would be around 4.2×10^{-8} per year. In more everyday language, this means a risk of about one chance in twenty-five million per year that someone living close to the station could be killed as the result of an accident. Statistically, this means that the additional annual risk of death to those living closest to the power station is about the same as the average annual risk we all face of being killed by an aircraft falling on us. For people living further away, the risk is even lower. Whilst no one would claim that calculations like this provide a precise number for the frequency of such very unlikely events, the figure does give a reasonable indication of the very low level of risk posed. The same report concluded that the likelihood of accidents leading to one hundred or more additional deaths in society was around one in one hundred million per year—i.e. well within the BSO set down in the ONR's SAPs.

5.8.71 Modern nuclear reactor designs such as RR SMR have been developed to provide levels of safety comparable with or even higher than those described above. Thus, the risk of additional radiological health detriments from accidents at nuclear plants falling within the Proposed Practice should be very small, with a maximum risk of death to any member of the public of around 1×10^{-5}/y and most probably very much less than this. This conclusion is in line with that reached by the Government following its 2008 consultation.

Radiological Impacts of Severe Accidents and Consequences Worldwide

5.8.72 As in our 2013 Application, our view is that the risk of an accident involving the Proposed Practice in the UK resulting in significant detriments is low. This section identifies the principal reasons for this conclusion. Annex 5 sets out in more detail the reasons why this remains our view.

5.8.73 A modern reactor design has many measures to ensure both workers and the public are protected. An Operator of the Proposed Practice will be supported by a series of highly robust design features that are described in more detail in Annex 1. Annex 5 explains that these features give a great deal of confidence that the essential safety functions of long-term cooling and containment can be maintained even in the event of an extreme event or other accident. It should also be recognised that in the UK, all licensed nuclear sites maintain and rehearse their emergency arrangements which are provided to mitigate the consequences of an accident if it were ever to occur. Annex 5 also explains the robust regulatory regime and the safety culture that will be required of any UK Operator of the Proposed Practice to ensure that the risks of accidents are as low as reasonably practicable. Taking these factors into account, Annex 5 concludes that the risk of significant detriment following a severe accident from the deployment of the Proposed Practice is very low.

5.8.74 However, to ensure that this analysis is comprehensive, an overview of the radiological detriments that have resulted from severe reactor accidents is provided in Annex 5 (which describes the Windscale, Three Mile Island, Chernobyl and Fukushima accidents).

5.8.75 This is a brief summary of the more detailed overview available in Annex 5. Not all of the accidents described in Annex 5 resulted in a large release of radioactivity to the environment(for example, the accident at Three Mile Island). High doses of radiation may be received by workers and emergency personnel in their efforts to return the nuclear power plant to a stable condition after the onset of an accident, as was seen at Chernobyl and most recently at Fukushima. Radioactive contamination may be distributed over a wide area including neighbouring countries, however counter measures—such as sheltering, prohibition of certain food items or drinking water, and evacuation—should adequately manage the risk such that members of the public do not receive doses that exceed those from the natural background.

5.8.76 In the UK there are substantial provisions that ensure a high level of nuclear safety is maintained, including effective and independent regulation of any UK operator of the Proposed Practice. If an accident were to occur, its consequences would be mitigated.

5.8.77 In addition to the risk of an accident being low, the RR SMR described in the Proposed Practice has a reactor core inventory 40 % lower than Sizewell B. The postulated release during any accident is therefore lower than that from existing LWRs justified in GB. Coupled with advanced, passive features, the risk of release is also considered to be lower for the Proposed Practice than existing designs. Conservative values have been described in this document which will bound the final values once the design is complete.

5.8.78 The discharge of iodine in a postulated accident is lower for any event in the Proposed Practice than in existing LWRs justified in GB. Iodine is a product of the nuclear fission reaction and is particularly volatile. Uptake of iodine into the thyroid gland, where unmitigated, can lead to a disproportionate effect on children and nursing mothers. With a smaller source term and advanced, passive safety measures, the risk of release and quantity of release with respect to iodine is lower; reducing any potential impact on this vulnerable population.

Decommissioning – Routine Doses to Workers and the Public

5.8.79 The strategy for decommissioning any new nuclear power station(s) licensed in the UK would be examined by regulators at the site licensing stage—i.e. before the station was built. Regulators would need to be satisfied that the work is capable of being carried out in a way that would meet regulatory requirements. A detailed decommissioning plan must be maintained throughout the life of the plant and at the end of a station's operational life, a final decommissioning plan, safety case, and environmental impact assessment would also have to be approved by regulators before decommissioning work on the site could begin.

5.8.80 Workers involved in the decommissioning of nuclear power stations, like those at operating stations, are protected by the requirement for operators to comply with nuclear site licence conditions and the Ionising Radiation Regulations 2017, which require employers to put suitable arrangements in place for the radiological protection of their workers. As with normal power station generation, these Regulations also limit individual worker exposure to no more than 20 mSv in any single year without the explicit permission of the HSE. ONR's BSL for the average annual individual dose for workers at 10 mSv also applies. Evidence from stations currently undergoing decommissioning is that the doses achieved would be far below these levels.

5.8.81 The average annual dose to workers at reactors in the UK which are in decommissioning **[42]** was below 0.1 mSv every year between 2004-2010, with over 3,000 classified workers in this area. None had an exposure above 10 mSv from 2007-2010. These figures include the work being undertaken to decommission first generation Magnox reactors, as well as on the Sellafield site. In several respects, the decommissioning of modern reactor plant is more straightforward than it is for the range of plant within the responsibility of the Nuclear Decommissioning Authority ("NDA") group. Workers involved in decommissioning RR SMR plants would receive protection similar to that described above for decommissioning activities at existing UK nuclear sites, however they would be working on a less technically difficult decommissioning project. As a result, their doses would be at a similarly low, or lower, level. In the light of the evidence above, the average annual individual doses to workers should be well below the 10 mSv/y figure adopted in this Application.

5.8.82 There would be the potential for members of the public living near the station to receive very small additional exposure as a result of the discharge of very small quantities of radioactivity to the environment under permits granted by the relevant environmental agencies under the EPR 2016 **[39]** in England and Wales. As during normal operation, the permits should ensure discharges are such that dose levels pose no threat to the public.

5.8.83 The additional average individual dose to the UK population from the decommissioning of new nuclear facilities has not been directly assessed. However, given that decommissioning activities are already taking place in the UK, and noting that the average individual dose to a member of the public in the UK from all nuclear industry activities is estimated to be only around 0.0009 mSv/y, as shown in Table 7, it is clear that the contribution that decommissioning activities could make to radiation doses would not be significant.

Decommissioning Impact of Discharges and Accidents on Workers and the Public

5.8.84 The purpose of decommissioning is to progressively reduce the radiological hazard on site and the Decommissioning Plan, approved by the regulator, should ensure this. Following final shutdown of the reactor, short-lived nuclides decay quickly which reduces the inventory of radioactivity in the fuel and therefore the risks. The decay heat in the fuel falls initially quickly and then more slowly. Eventually the decay heat will have fallen to an appropriate level for the fuel to be removed from the reactor and placed in a spent fuel facility on site and then eventually removed from site. During decommissioning the inventory of radioactivity would also reduce as material was removed from site and sent for disposal.

5.8.85 In considering potential accident scenarios throughout the decommissioning process, the ONR would apply the same SAPs as those used for operating plant to ensure workers and the public are protected. In conclusion, the decommissioning of any new nuclear plants developed as part of the Proposed Practice would therefore pose a minimal risk of radiological health detriment, either through permitted discharges or through accidents which could result in radiological health impacts to workers or the public.

Spent Fuel Management and Radioactive Waste Disposal

5.8.86 The UK's classification of radioactive wastes is explained in Chapter 6. Most low-level waste from reactor operation is currently disposed of routinely in the LLW Repository (the national facility near Drigg, Cumbria), whereas higher activity waste and spent fuel is currently in interim storage either at the nuclear power stations or in licensed storage facilities pending development of a final deep geological disposal facility ("GDF"). Higher activity waste and spent fuel from the Proposed Practice would be expected to be stored onsite for the lifetime of the plant, until the GDF or another suitable facility is available. Most low-level waste would go to a national facility near Drigg.

5.8.87 The Government has begun the siting process for a GDF, after consultation with communities **[61]** and has laid out its long term strategy in a 2019 National Policy Statement **[62]**. As part of this, the Government concluded that:

"The development of geological disposal infrastructure is essential because it provides the best available practical means of ensuring the long term safety and security of higher activity radioactive waste"

5.8.88 Whilst not explicitly discussing RR SMR, the Policy Statement does include the spent fuel from up to 16 GW of nuclear new build as part of the future arising nuclear waste to be stored in a GDF.

5.8.89 More detailed information on RR SMR waste, as well as expected procedures and techniques for decommissioning, will be available to DESNZ throughout the licensing and environmental permitting processes for RR SMR. As part of this process, Rolls-Royce SMR Limited and Nuclear Waste Services ("NWS") will engage to produce a Disposability Assessment, which will ensure that the waste produced is acceptable for disposal, and that the long-term safety and environmental impact has been considered. NWS have prepared an initial Expert View **[63]** on the Disposability of Wastes and Spent Fuel arising from the Rolls-Royce SMR stating:

"In general terms, the nature of the wastes and spent fuel from the RR SMR are not significantly different to those with which we already have familiarity, giving confidence that a disposability case could be made."

5.8.90 The 2016 report from **[64]** Radioactive Waste Management ("RWM") (now called NWS) into high level requirements for a GDF discusses the use of generic waste containers, meaning that the design for the GDF can be waste agnostic. As further information becomes available, the specific design of waste containment can be matured. However, the existing government appetite for the use of GDF disposal for new build nuclear waste, and the decreased quantity of waste from modern reactor designs, suggests that the implications of nuclear new build will have little impact on the design and delivery of the GDF. This is reinforced by the Government statement **[65]** that:

"the total of the UK Derived Inventory should not be finalised before proceeding with the final NPS."

5.8.91 The repository would also be designed to incorporate features that ensure that the off-site dose would fall within the design targets. These could include the legal limit of 1 mSv for members of the public, RWM's (now NWS) source-related dose constraint of 0.15mSv, or the BSO of 0.02 mSv per year **[66]**.

5.8.92 Therefore, assuming these facilities were used, any radiological health impact from interim storage and disposal of new build waste, together with spent fuel from the Proposed Practice (whether or not as part of an overall nuclear new build programme involving other technologies such as the EPR™ at Hinkley Point C), would be a small increment to that which would arise from existing wastes, whether or not any new types of station are built.

5.8.93 Alternatively, if separate disposal facilities were constructed for the interim storage and disposal of higher-level waste and spent fuel from any new nuclear station(s) and engineered to meet the same levels of radiological protection, the additional doses to workers and to members of the public would be at a very low level.

5.8.94 It is therefore concluded that the potential additional health detriment associated with radioactive waste interim storage and disposal arising from the implementation of the Proposed Practice will be small. The additional radiation dose to the members of the public potentially most exposed would certainly be less than 0.3 mSv—indeed, as explained above, the design target for a UK waste repository is more than a factor of 10 lower than this.

5.8.95 Due to the lack of design maturity for a potential GDF (the project is still in the investigative phase of siting), there is not a published target for worker exposure during the course of managing higher activity waste and spent fuel. However, any design would aim to meet the ONR's BSO level of 1 mSv per year of exposure for employees working with ionising radiation. As the ONR would not license a site that had not reduced the dose to workers to be ALARP, the use of the BSO is a good guide for a possible future exposure level.

5.9 Summary of Results

Overall Level of Potential Health Detriment to Workers and the Public

5.9.1 Table 11 summarises the assessments reported above. This shows that all relevant processes required as an integral part of the Proposed Practice could be undertaken within relevant UK dose limits and constraints, or within the accident BSLs set out in assessment guidelines by the ONR. Maximum representative person doses to the public would all be below the 0.3 mSv/y constraint for new nuclear facilities, with negligible additional radiation doses to other individuals within the UK and wider population. Maximum radiation doses to workers would certainly be below the annual dose limits with average worker doses at least a factor of ten lower than this, and certainly below the 10 mSv/y figure adopted in this Application. These figures define an outer envelope for the level of radiological health detriment for the Proposed Practice.

5.9.2 The actual levels of radiological health detriment that would follow from the Proposed Practice would be determined by optimisation and would be below the bounding levels identified above as a consequence of the application of the requirements of the UK regulatory regime, which require doses to be reduced below limits and constraints to a level as low as is reasonably practicable, although the precise levels cannot be predicted at this early stage.

5.9.3 However, the evidence presented in this Application on how these regulations have affected other similar processes at existing nuclear sites assists by giving a broad indication of what optimisation will deliver.

5.9.4 The largest individual radiological health detriment quantified here for these existing activities is the average dose to workers involved in decommissioning facilities (which at <1 mSv/y is still below the basic safety level of 10 mSv/y).

5.9.5 For the public, the highest representative person dose identified (if relevant) arises from any UK located fuel manufacturing or enrichment facility (see below) on the conservative assumption that it is the same as currently assessed for the UK sites at Springfields and Capenhurst. Even for these, the largest potential contributors, representative person doses to the public are shown to be considerably below the 0.3 mSv/y level.

5.9.6 Table 11 summarises both the bounding value for a particular potential source of radiological exposure and the additional information provided in this Chapter on the impact that optimisation could have. For the purpose of Justification, it is not necessary or appropriate to prejudge what precise impact optimisation will have, but it would be misleading not to recognise the fact that it will certainly reduce doses and potential detriments further from the enveloping values quoted here. Finally, it should be noted that no member of the public is likely to be more than one type of representative person identified in Table 11, so it would not be correct to treat these maximum potential radiation doses from the various sources of exposure as additive. The UK's approach of using dose constraints would protect the public from excessive exposure as the result of several different facilities being located at the same site.

5.9.7 The risk of significant radiological health detriment from potential accidents has also been shown to be small. Conservatively assuming that any new facilities licensed in the UK as part of the Proposed Practice only just meet the ONR's BSL, the additional risk of death to a person just outside the plant boundary is about 2×10^{-5}—i.e. a chance of one in fifty thousand. Although it is not possible at this early justification stage to quote more precise numbers, modern designs including the RR SMR will be designed to achieve levels of accident safety well within the BSL so that the maximum risk will be significantly lower than this "bounding" value. RR SMR aims to achieve ONR BSO levels in radiological risk mitigation. Evidence presented in this Chapter indicates a more realistic level of risk of death to an individual member of the public close to the site boundary from accidents at a single reactor would be around a one chance in twenty five million per year.

Table 11: Dose limits and expected doses for workers and members of the public

Potential Source of additional Radiological Health Detriment as a result of the Proposed Practice	Relevant dose constraint for activity (mSv/y)	Further relevant information provided in Application on possible effect of optimisation
Maximum Additional Doses to the UK Public		
Dose from uranium fuel manufacture	Less than 0.3	0.032 mSv/year at Springfields, according to RIFE report
Dose from uranium enrichment	Less than 0.3	0.14 mSv/year at Capenhurst, according to RIFE report
Dose from normal operation of a modern evolutionary design water cooled reactor falling within the Proposed Practice	Less than 0.3	< 0.005 mSv/year at Sizewell B, according to RIFE report
Estimated max. dose to any member of public from transport of radioactive materials	No specified limit but protection provided by regulations limiting dose rates from transport packages	< 0.001 mSv/year according to PHE report
Dose to public from radioactive waste disposal (including at a future GDF)	Less than 0.3	<0.15 mSv/year design constraint from GRA,[136] <0.02 mSv/year ONR BSO
Average individual doses to workers (NB maximum doses always less than dose limit)		
Fuel enrichment	Less than 10	0.18 mSv/year at Urenco Capenhurst
Fuel manufacture	Less than 10	0.29 mSv/year at Westinghouse Springfields
Nuclear power station workers in normal operation	Less than 10	0.18 mSv/year average in the UK according to PHE
Workers in radioactive materials transport	Less than 10	<1 mSv/year according to PHE
Decommissioning	Less than 10	<1 mSv/year according to PHE
Waste disposal repository	Less than 10	<1 mSv/year, NWS target constraint

5.9.8 As is also illustrated, even with quite cautious assumptions, the radiological health impact for workers as a result of the Proposed Practice would also be small and well below regulatory limits. In every case, the average annual worker doses identified are lower than the 10 mSv/y figure adopted in this Application as a bounding level (and derived from the ONR's SAPs as the BSL for assessing new installations). Actual average levels of exposure would be much below this figure, as a result of the modern designs within the Proposed Practice and the application of the optimisation principle. Worker doses would be lower than those already accepted by employees such as aircrews or health workers in non-nuclear industries.

5.9.9 Table 12 in the conclusion section below compares the assessed radiological health detriments with figures from some other activities currently undertaken within the UK.

Conclusion on the Level of Potential Radiological Health Detriment

5.9.10 The objective of this Chapter has been to provide a high-level indicative assessment of the potential radiological health detriment that might be associated with the development of new nuclear power stations involving the Proposed Practice. The Chapter has also identified a maximum or bounding level of radiological health detriment for the Proposed Practice so as to enable the comparison with its benefits to be made with confidence.

5.9.11 For the Proposed Practice we are seeking to justify, we believe it is sufficient to state that maximum doses to individual members of the public from the practice will always be less than 0.3 mSv/y, and those to workers will always be well within limits and, on average, less than 10 mSv/y. The peak annual dose to a member of the public is calculated to be 12.3 μSv at the site fence.

5.9.12 This high-level assessment shows that the scale of potential health detriment from all potential activities associated with new nuclear stations is small, and there is no doubt that applicable

136] https://www.gov.uk/government/publications/near-surface-disposal-facilities-on-land-for-solid-radioactive-wastes regulatory dose limits and constraints could be met. This is the result of the mature status of the industry: modern nuclear power station design, and the efforts of both the national and international approaches to regulating this industry that have been refined over many years.

5.9.13 For those individual members of the general public who could be most affected, the maximum likely radiological dose from the deployment of the Proposed Practice is assessed to be of the same order as one additional return air flight from the UK to New York per year. Alternatively, the impact could be expressed as being about the same as the additional radiation dose that someone could receive by spending a week's holiday in Cornwall rather than remaining somewhere where natural background radiation is at the UK's average level. However, it would be wrong to suggest that, for the purposes of demonstrating justification (as opposed to optimisation), it is necessary to rely on these very low figures. Doses to workers as a result of the Proposed Practice would be low. They would be comparable with, or lower than, those to which workers in the rest of the nuclear power industry (and other industries which entail radiation exposure, such as the airline industry) are currently exposed.

5.9.14 The design of every facility (new or existing) required to implement this Proposed Practice will have to meet stringent safety and security requirements. These requirements will ensure that RR SMRs would have a low likelihood of accidents with risk levels demonstrated to be as low as reasonably practicable. The risk of significant radiological health detriment arising from accidents will thus be very small.

5.9.15 This Chapter provides an indication of the scale of potential radiological health detriment against which the potential benefits of energy generation from new UK nuclear station(s) should be weighed and this is summarised in Figure 4 and Figure 5.

Figure 4: Scale of Radiological Health Detriments (Workers)

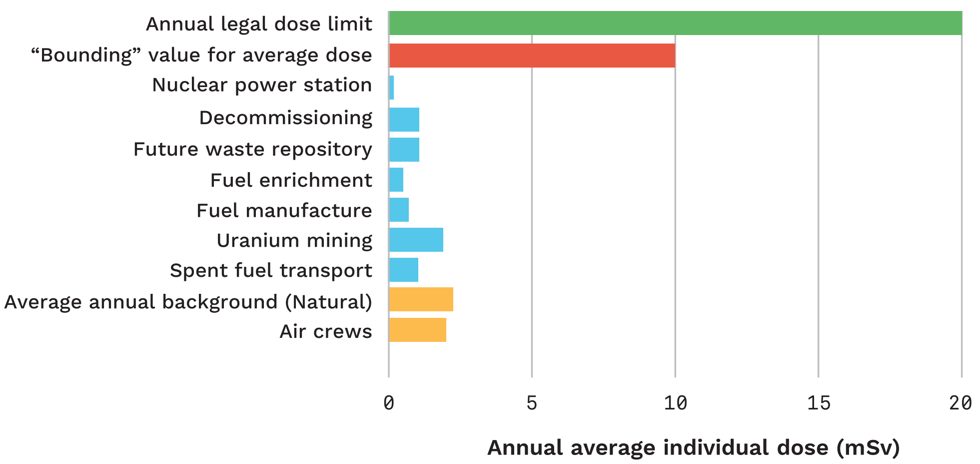


Figure 5: Scale of Radiological Health Detriments. Maximum Doses to the Public (for Representative Persons)

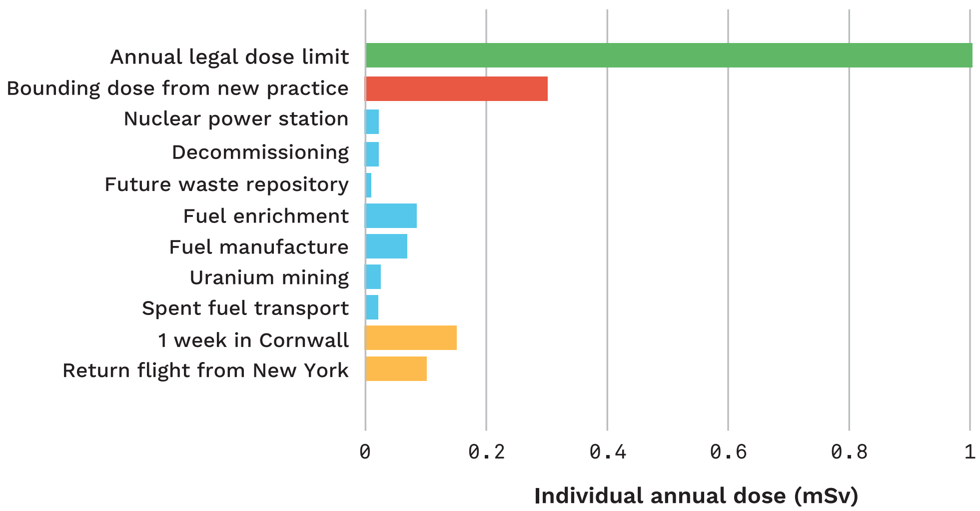


Table 12: Contributions to public and occupational dose in the UK

Source of Additional Exposure	Additional Dose
Public	Dose limit = 1 mSv per year
Bounding value for the purposes of justification of individual dose to any member of the public from introduction of the Proposed Practice	Less than 0.3 mSv per year
Evidence on the maximum level of dose to any member of the UK public that currently arises from any of the activities that could be required as part of the Proposed Practice (indicates the impact of "optimisation")	Less than 0.14 mSv per year (uranium enrichment)
Dose from one return flight a year from the UK to New York	Around 0.1 mSv per year
Dose to someone who spends 1 week a year in Cornwall (and comes from part of UK with typical natural background radiation level)	Around 0.15 mSv per year
Dose from one CT scan of abdomen per year	Around 10 mSv per year
Workers	Dose limit = 20 mSv per year
Bounding value for the average level of dose to any worker in the UK assessed to arise from the Proposed Practice	Less than 10 mSv per year
Maximum potential average individual worker dose identified in this Application	Less than 1 mSv per year
Average annual dose to classified workers within UK nuclear industry	Around 0.8 mSv per year
Average annual dose to member of typical UK air crew	Around 2 mSv per year

6: OTHER POTENTIAL DETRIMENTS - RADIOACTIVE WASTE AND DECOMMISSIONING

The operation and eventual decommissioning of a fleet of new RR SMRs would add a relatively small volume of radioactive waste to that which already requires management and disposal in the UK.

The types of waste created by the Proposed Practice would be similar to those which already exist, and for which management and interim storage arrangements for a prolonged period of time, decades if required, are currently in place. While not every aspect of radioactive waste disposal has yet been demonstrated, the UK Government remains firmly committed to deep geological disposal of nuclear waste within a Geological Disposal Facility ("GDF") and Nuclear Waste Services ("NWS") continues at pace to determine the most suitable site within the UK for this facility **[5]**.

The precise impact of higher activity waste and spent fuel on the UK GDF cannot be determined at this time, but before any site is commissioned there must be a Funded Decommissioning Programme ("FDP"), approved by the Secretary of State,[137] and disposability assessment in place **[67]**. These would ensure that the impact of the additional waste is managed within the construction, operation and closure of the GDF. Previously licenced designs, such as the one subject to our 2013 Application, were found to be compatible with the UK GDF programme **[68]**.

At the end of the life of the plant, there is a further requirement to decommission and remove waste from the site. The UK was the site of the first commercial- scale electricity-generating nuclear power plant at Calder Hall, and subsequently gas and sodium cooled reactors so it follows that the Nuclear Decommissioning Authority ("NDA") has extensive research in the decommissioning and restoration of nuclear sites. The most recent example of this is the Imperial Collage reactor site delicensing in 2024.[138]

Liabilities associated with nuclear power plants, including radioactive waste management and decommissioning, are the ultimate responsibility of the site licence holder and cannot be delegated or assigned to other parties **[69]** with the exception of agreements with the UK government regarding the ultimate disposal of higher activity waste and spent fuel.

There is also considerable operational experience from outside of the UK for the decommissioning of nuclear power plants and the storage and disposal of radioactive waste. The United States of America, Canada and France have also managed the decommissioning of early nuclear reactors, while Finland is leading with the construction of the world's first GDF that will accommodate spent nuclear fuel **[70]**. Rolls-Royce SMR Limited are incorporating best practice into their design to facilitate decommissioning and minimise waste. Further details on worldwide decommissioning are provided in Annex 3.

On this basis, it is concluded that the detriment associated with the need to manage radioactive waste and to decommission any new nuclear power station based on the Proposed Practice would be small in relation to the major benefits that the nuclear power station could provide to the UK.

6.1 Introduction

6.1.1 This Chapter addresses the impacts of radioactive waste management and decommissioning in relation to the Proposed Practice, but not potential radiological health detriments, which are discussed in Chapter 5. The issues covered in this Chapter are:

- The existing UK regulations and policies addressing radioactive waste;
- Discussion of how radioactive wastes are currently managed in the UK, as well as any relevant future plans for the management of radioactive waste and any current relevant experience regarding these plans;
- The level of confidence that radioactive waste created during the operation, and decommissioning of, a new RR SMR will be managed responsibly and without any meaningful associated detriment;
- The extent to which decommissioning and waste management liabilities and associated costs will be met without the need to place a an unacceptable burden on the UK taxpayer; and
- The main types and quantities of radioactive waste that would require management and disposal during the operational lifetime of a RR SMR plant as well as site administration after the plant had stopped generation.

137] https://www.gov.uk/government/organisations/nuclear-liabilities-financing-assurance-board/about

138] https://onr.org.uk/news/all-news/2024/02/onr-completes-first-ever-full-decommissioning-of-uk-reactor-site-under-modern-regulatory-controls/

6.1.2 On this basis, it is demonstrated that neither radioactive waste management and disposal, nor decommissioning of nuclear power stations based on the Proposed Practice, should result in a detriment to the UK that is not justified by the significant benefits of the Proposed Practice identified in earlier chapters.

Commentary on our 2013 application

6.1.3 Despite the obvious design differences between the Gigawatt-scale plants that were the topic of previous justification decisions and the RR SMR, all nuclear plants will generate similar types of radioactive wastes during both operation and decommissioning. The principles and technologies used in their designs are also not dissimilar, with the RR SMR aiming to learn from the operational experience of previous designs to reduce the radiological impacts of decommissioning even further.

6.2 The Regulatory Regime for Nuclear Waste

The Nuclear Installations Act 1965

6.2.1 The Nuclear Installations Act 1965 is the foundation for nuclear regulation. It lays the groundwork for the licence conditions under which any nuclear licensed site, including nuclear plants and, in the past, reprocessing sites, operate.[139] This includes the duty to minimise the production of radioactive waste and the quantity accumulated on site, as well as to record the waste accumulated. It also covers the process of delicensing after the decommissioning of a site.

Environmental Permitting Regulations 2016

6.2.2 The Environmental Permitting (England and Wales) Regulations 2016 sets out the requirements for all discharges and disposals into the environment to be permitted, including any discharge of radioactivity. In England the EA provide these permits, while NRW are the regulator for Wales. In Scotland, SEPA provide authorisation under the Environmental Authorisations (Scotland) Regulations 2018, which provide analogous restrictions on the discharge of radioactivity to the environment.

6.2.3 A key common feature in these permits and authorisations is the requirement to limit quantities of radioactivity released (with the limits depending on type) by using BAT. The ONR uses a similar term, requiring risks and detriments to be reduced to ALARP. These terms represent a common aim of making a judgement regarding how low the radiological and safety detriments can be reduced before further reductions would not give good value for the effort expended in making them. It is important to note that this philosophy places an onus on nuclear operators to not just meet regulatory limits, but have a duty to expend the time, money, and effort to improve on them where reasonably possible.

Energy Act 2023

6.2.4 One of the Energy Act 2023's key purposes is to facilitate long-term energy security in Britain and the UK's transition to a 'net zero' energy system. It also includes provisions relating to the regulation of sites for the disposal of certain radioactive wastes.

Radioactive Substance Regulation

6.2.5 The Environment Agency's Radioactive Substance Regulation ("RSR") framework is a set of principles and objectives provided by the Environment Agency to provide guidance about how they combine the application of the law, international best practice (via organisations such as the International Commission on Radiological Protection, see Chapter 5 for more information) and the UK permitting and BAT regime for the purposes of radiation protection for people and the environment **[71]**.

6.3 Categorisation of Radioactive Waste in the United Kingdom

6.3.1 In the UK, solid radioactive waste is classified firstly by the quantity of radioactivity it contains, then by whether additional handling requirements are required as a consequence of radioactive heat generation.

139] Currently nuclear waste repositories do not require a nuclear site licence under NIA65, this is being changed by amendment of the Nuclear Installations Regulations 1971 but it is not clear when this change will be made.

6.3.2 The five categories, and a brief explanation of their derivation, are set out below **[72]**:

High-Level Waste ("HLW")

6.3.3 Wastes in which the temperature of the waste may rise significantly as a result of their radioactivity, requiring specialist storage or disposal facilities to manage this.

6.3.4 This category of waste is dominated by reprocessing wastes. As of 2019, the NDA had inventory of 1,500 cubic metres of HLW, or 0.03% of waste volume, however it made up 76.1% of radioactivity.

6.3.5 In the event spent fuel is categorised as waste, it would likely be categorised as high-level waste.

Intermediate-Level Waste ("ILW")

6.3.6 Wastes that exceed radioactivity limits to be classed as low-level waste, but they do not produce enough heat for this to be considered in the design of storage or disposal facilities.

6.3.7 A large quantity of the UK ILW inventory is from gas cooled reactors, including structural steel, graphite, swarf from fuel rods and graphite blocks. Modern plants create ILW in their filters, ion exchange resins and chemical deposition in cooling pipes (often captured in filters). This ILW creation is an expected part of filtering gases and liquids to make them safe for release or reuse.

Low-Level Waste ("LLW")

6.3.8 Waste with less than 4 GBq/tonne of alpha radiation or less than 12 GBq/tonne of beta/gamma radiation is categorised as LLW. This category of waste is mainly building rubble, pipework or frame-work, and miscellaneous contaminated wastes such as used gowns, gloves, or cleaning cloths.

Very Low-Level Waste ("VLLW")

6.3.9 Waste with such low levels of radioactivity (less than 4 MBq/tonne, 1 one-thousandth of the limit for LLW) for bulk materials, or less than 400 kBq per 0.1 cubic meter, is categorised as VLLW.

6.3.10 These wastes can be disposed of like a normal waste stream, either as industrial waste or in specified landfills for bulk materials.

Higher Activity Waste

6.3.11 Higher activity radioactive waste is a broad term which includes all HLW and ILW, as well as certain wastes categorised as LLW but which are not currently suitable for disposal in existing LLW facilities.

6.4 Radioactive Waste and its Management During Plant Operation

6.4.1 While both fossil-fuelled and nuclear power plants generate energy through heating water to produce steam, nuclear fuel is not burned in the conventional sense. The difference is important to note, as the way in which waste products are managed are entirely different between the two processes.

6.4.2 When burning fossil fuels, the entirety of the fuel is consumed, converted to water (as steam) and Carbon Dioxide, and these gaseous waste products are simply released into the atmosphere, while any residual material is either re-used or deposited into landfill. The mass of waste generated and emitted by a fossil fuel plant is proportional to the mass of the input fuel which can be measured in millions of tonnes **[73]**.

6.4.3 In a nuclear power plant there is no emission of spent fuel. A fuel assembly is loaded into the plant, used until it is 'spent', and then unloaded. A comparison of a new and spent fuel assembly would show very little change in size, mass or appearance. If the assemblies were opened and the new and spent fuel itself compared, they would appear to be virtually identical uranium pellets. This is because the bulk of the waste products are individually transmuted atoms within the fuel.

6.4.4 The mass of uranium fuel needed to generate a given amount of electricity in a nuclear power plant is a tiny fraction of equivalent mass of fossil fuel. To produce the same amount of energy as 1 kg of enriched uranium (roughly the volume of an egg) would require 47,000 kg of natural gas (approximately the amount in a medium-size tanker) or 88,000 kg of coal **[74]**.

6.4.5 The spent fuel, approximately ten tonnes, of fuel assemblies, every 18 months, will be the source of the overwhelming majority of radioactivity produced during the operation of the RR SMR. However, there will also be less active radioactive waste streams, which will also need to be managed. These include materials around the core which become radioactive through neutron activation, and various materials and components that become contaminated with radioactive materials such as gloves, tools, or filters.

6.4.6 There will also be radiological wastes generated from decommissioning the plant, which are discussed later in this Chapter.

6.4.7 The RR SMR aims to minimise the generation of radioactive waste and activation of materials using inherent design features. These include the use of indirect steam generation to prevent the activation of turbine components, filters in coolant lines to remove radioactive particulates and a novel boron-free water chemistry that reduces the production of tritium, a radioactive waste product from activation of the coolant.

6.4.8 The primary remaining source of radioactivity that must be managed by plant operators is usually the filters that have been removed, which safely contain the small amounts of radioactive by-products produced in the plant.

6.5 Authorised Discharges of Radioactive Material

6.5.1 The principle of optimisation means that while modern reactor designs have nearly eliminated the requirement for radioactive discharge during operation, it may sometimes be the BAT to discharge very small amounts of nuclear material to the environment.

6.5.2 Before any nuclear power plant, including the RR SMR, would be permitted to carry out such a discharge, the operator would have to prove, prior to construction, that the emissions have been minimised by using BAT. It is not possible to know for certain the discharges of an operating plant (this would depend on, among other things, usage, age, and fuel burn profiles), however estimates can be made, and are shown in Table 13 and Table 14. Table 13 and Table 14 allow a comparison of expected discharges from RR SMR with the recorded radioactivity discharged from Sizewell B, the UK's only operating PWR, and the estimated discharges of the UK EPR, the reactor being constructed at Hinkley Point C. The figures in Table 13 and Table 14 have been normalised for the differing power outputs of the reactors, meaning the true discharge rates for RR SMR would be approximately half those shown here. It should also be noted that discharges are calculated based on very conservative values and actual discharges are likely to be considerably lower than the values presented.

Table 13: Comparison of normalised annual gaseous radioactivity discharge

Reactor	Tritium (TBq/GWe)	Carbon-14 (GBq/GWe)	Iodine-131 (MBq/GWe)	Noble Gases (TBq/GWe)	Other (MBq/GWe)
RR SMR	0.089	42.63	40.71	22.59	6.94
UK EPR	0.290	200	29.0	0.46	2.30
Sizewell B	0.521	250	24.0	2.59	4.84

Table 14: Comparison of normalised annual aqueous radioactivity discharge

Reactor	Tritium (TBq/GWe)	Carbon-14 (GBq/GWe)	Iodine-131 (MBq/GWe)	Noble Gases (GBq/GWe)	Other (MBq/GWe)
RR SMR	0.18	0.00002 (1.71 kBq/GWe)	0.0005 (0.496 kBq/GWe)	1.9	1.01
UK EPR	30.0	13.0	4.00	No Data	0.35
Sizewell B	21.7	No Data	No Data	0.405	5.09

6.5.3 These figures are provided for reference, to show how as reactor designs develop, further reductions in radioactive discharge are made. The large numbers involved mean that comparisons are difficult to contextualise, and the differing biological effects of each radionuclide means that dose is not proportional to radioactivity across isotopes. In addition, the RR SMR is continuing to optimise radioactive discharges to levels that are ALARP.

6.5.4 The measure of radioactivity above is in Becquerels to compare the total amount of radioactivity, rather than the amount of radioactive material. However, the concentration of a source is also extremely important. Tritium, unlike other radionuclides, is not easily filtered, absorbed, or otherwise abated, so dilution and release of tritium is currently standard practice in PWR plants. If the tritium were not discharged, it would build up to dangerous concentrations for plant workers during refuelling. This tritium would therefore be discharged over the course of operation, usually diluted in cooling water outflow.

6.5.5 The aim of RR SMR's boron free chemistry regime, is for no aqueous discharge of tritium. The value in Table 14 for aqueous tritium is included to cover the very rare event of fuel pin failure. Even in the worst-case scenario any discharge would account for less than one quarter of a milligram of tritium diluted in a year's worth of cooling water. This would still be within the legal limits for drinking water in the UK **[75]**.

6.6 Impact of Authorised Discharges of Radioactive Material

6.6.1 Despite the optimisation of radioactive discharges, if they are to be made as part of the operation of the nuclear power plant then it is important to discuss the UK regulatory regime which ensures the protection of people and the environment.

6.6.2 The RIFE reports are annual reports produced by the UK environmental and food standards agencies. They monitor all exposure pathways for the "representative person" and confirm they would receive an exposure below legal limits. The concept of the representative person is discussed in more depth in Chapter 5, however it simply represents the worst-case exposure for a member of the public. The most recent (2022) RIFE report found that the dose from any nuclear power plant in the UK was less than 2% of the required dose limits, taking into account all exposures from all factors, including radioactive discharge. This would represent an increase of no more than 0.5% from background exposures. It can therefore be concluded that radioactive discharge from nuclear power plants, including the proposed RR SMR, would pose no threat to the public.

6.6.3 In the past, studies have generally focused on the potential impact that radioactivity in the environment could have on human health (as covered in Chapter 5). The widely accepted view has been taken that if people are protected then other species in the environment will also be protected.

6.6.4 This approach, however, would not take account of the requirements of legislative measures for the protection of wildlife from radiation, the Conservation of Habitats and Species Regulations 2017 as amended, more commonly known as the Habitats Regulations. Under the Habitats Regulations, the devolved environmental regulators are required to review existing permits/authorisations to ensure they do not, directly or indirectly, adversely affect what were Natura 2000 habitat sites, but are now known as a national site following the UK's exit from the EU.

6.6.5 The environmental impacts of new nuclear power stations are discussed further in Chapter 7, however in summary, the RIFE report found the radiation doses from nuclear sites to the worst affected organism were below the agreed dose guidelines. These guidelines were set by the EA to ensure there would be no significant impact on national sites.

6.6.6 The environmental regulators continue to monitor the environmental impact of any permits or authorisations, and any new applications must contain an assessment of the radiological risk to species or habitats in the surrounding environment **[76]**.

6.7 Solid Radioactive Waste Management

6.7.1 The strategy for management of radioactive waste in the UK is undertaken according to the NDA's Radioactive Waste Strategy ("RWS") **[77]**. The RWS outlines the preferred routes for waste disposal within the NDA group and aims to improve implementation of the waste hierarchy to reduce the amount of radioactive waste for disposal. This is most relevant for VLLW and LLW, which are the safest forms of waste to work with and comprise the majority of the volume of radioactive waste produced in the UK, making them ideal candidates for waste treatment, re-use or volume reduction.

Very Low-Level Radioactive Waste

6.7.2 VLLW has been eligible to be disposed of in landfill for over 15 years, after the policy **[78]** was introduced in 2007. There is now a robust supply chain for the handling of VLLW in the UK, as well as the permitted disposal sites at East Northants Resource Management Facility ("ENRMF") Kings Cliff, and Lilyhall **[79]**. By diverting this waste away from the LLW Repository ("LLWR"), radioactive waste management can be easier and faster. This can also extend the life of the LLWR for materials that would benefit from the isolation it provides.

Low Level Radioactive Waste

6.7.3 While some LLW is disposed of locally at nuclear licensed sites (at Sellafield and Dounreay), most of the UK's LLW waste, including the waste created at currently operating nuclear power stations, is disposed of at LLWR near Drigg in Cumbria. At the LLWR, waste is volume reduced (if this has not already been done for transport), immobilised in steel containers with grout, and then placed into engineered concrete vaults that can then be capped **[80]**.

6.7.4 There is a small amount of LLW in the national inventory that is not suitable for disposal in the LLWR. No LLW of this type (mainly large graphite blocks from gas-cooled reactors) would be generated by the RR SMR.

6.7.5 The LLWR was previously used for all lower-activity waste arisings. However, the introduction of the LLW strategy in 2010 saw a large proportion of LLW diverted from the specialised and relatively costly LLW into permitted landfill sites and other diversion routes (such as metal recycling and permitted incinerators) Further application of the waste hierarchy, through reduction and prevention of waste generation, means that it is expected that the LLWR will be able to take the LLW from all NDA sites. The relatively small additional quantities of LLW from new nuclear power stations such as the proposed RR SMR would also be able to be disposed at the LLWR.

6.7.6 It is important to note that any new nuclear power station would be expected to have an Integrated Waste Strategy ("IWS") and Integrated Waste Implementation Plan in place before receiving a nuclear site licence from the ONR. The IWS must show that: a site will comply with all legal obligations; that the waste management hierarchy will be applied; and that all radioactive waste that will arise from the site has been identified and disposal or management routes assigned. In conjunction with the requirement for an FDP, the site must have plans in place for the disposal of all waste and set aside the money to cover any disposal costs to prevent a burden on the taxpayer.

6.7.7 In conclusion, there should be no significant detriment from the generation of these low-level wastes. The transport of the material offsite would have a negligible impact on road traffic, and practical, established disposal facilities are available for use to ensure the safe disposal of any LLW which cannot be otherwise diverted.

Intermediate Level Waste

6.7.8 The current policy in the UK is that ILW created by new nuclear power stations will be stored on site until disposal facilities are available **[81]**. The RR SMR will include interim storage facilities for this purpose within the site, able to safely manage ILW produced during operation and decommissioning.

6.7.9 This interim storage is usually done in stainless steel containers, such as drums or boxes, and guidance in provided by Nuclear Waste Services Limited ("NWS"), previously Radioactive Waste Management Limited), which is part of the NDA **[82]**. The high integrity, long-lived package designs make handling during storage and retrieval easier and safer for operators. Retrieval is an important part of interim storage—it is intended to be temporary and is designed with this in mind. ILW is sometimes stored in centralised interim storage facilities for multiple nuclear sites, as was the case of ILW from Magnox reactors **[77]**.

6.7.10 All ILW will have to be handled, packaged and stored in an optimised manner, as required by UK regulation. An optimised balance between volume reduction and increased handling will be identified, while ensuring the highest levels of safety. The way in which ILW arises may impact this. For example, if a deferred decommissioning strategy is used, there may be lower levels of radioactivity present, reducing the required shielding. The NDA also continues to develop new treatment routes that may become available through continued technology development.

6.7.11 The interim storage of ILW has, in some cases, meant that ILW previously being stored for long term disposal has been subject to substantive radioactive decay, decreasing its activity to the point it can be re-assessed as LLW. This was the case with some packaged Magnox ILW in 2022, which could then be diverted out of storage to the LLWR **[80]**.

6.7.12 There is currently no facility for the disposal of ILW in the UK. The government has, since the inception of the GDF programme, intended to enable dispose of ILW in a UK GDF. However, as part of a 2023 consultation, the government laid out plans for a possible near surface disposal facility. Such a facility might accommodate ILW with an activity close to the LLW/ILW definition border, such as certain graphite reactor wastes.

6.7.13 The proposal to allow for ILW disposal in near surface facilities has been informed by work carried out by the NDA, and based on existing schemes in Finland, France, Spain and Sweden. Not all ILW requires the level of isolation provided by a GDF, and so the NDA, following its mission to make nuclear waste permanently safe, sooner, has developed near surface ILW disposal proposals. This would allow for facilities which are much quicker to create to take ILW and aid the decommissioning of sites before the creation of the GDF. Some ILW, presenting the most significant disposal challenges and benefiting from the greatest isolation, would still be stored on-site pending disposal in the GDF.

6.7.14 The Government, via NWS, continues to work towards the development of a GDF, and re-started the work required for identifying a suitable site in 2020. It also re-iterated its policy that future waste, including that from any SMR programme, would be disposed of in a GDF if unsuitable for near surface disposal **[83]**.

Spent Fuel

6.7.15 Spent fuel is not considered declared waste in the UK. While the current policy is not to reprocess spent fuel, this is *"in the absence of reprocessing proposals from industry"* **[5]**, not a firm commitment to never again reprocess spent fuel. At this time, spent fuel is not considered a waste.

6.7.16 However, spent fuel would still have to be stored on site pending development of a GDF. The spent fuel storage facilities are described in Annex 3, and the radiological impact of transport of higher activity consignments to a GDF in the future is discussed in Annex 5.

6.7.17 While the precise amount of spent fuel created by RR SMR plants would be dependent on multiple factors (such as how many are built, fuel burn-up profiles, load factors and more) there will be arrangements in place for the storage of this fuel until it can be transferred to a GDF. Future wastes from prospective reactor designs are not currently accounted for in the UK waste inventory, but the Government has suggested that it can be taken that a GDF would take fuel[140] from any new nuclear programme.

6.7.18 Current estimates for the RR SMR spent fuel arisings (averaged over 60 years lifetime) are 2.79 tHM/TWh(e) or 1.22 m3/TWhe. Compared with an AP1000, this is roughly 6 % higher (on a mass basis) and 13 % higher (on a volumetric basis). This broadly similar result is expected since the RR-SMR, although classed as an SMR, has a relatively large core size meaning neutron leakage (as a result of size) should be similar. Note the RR SMR core size is almost identical to Ginna, USA. However, unlike an AP1000 and most PWR designs (other than VVER and EPR), the RR-SMR does utilise a heavy radial reflector that improves neutron economy and therefore spent fuel accumulation rates. However, as a result of operating boron-free and unlike a standard PWR that could operate with a low-leakage loading pattern, core safety (in particular the requirement to maintain adequate shutdown margin at cold-zero-power) necessitates a larger proportion of higher-reactive fuel to be loaded on the core periphery. Loading pattern changes and radial neutron reflector design tend to 'cancel out' resulting in similar spent fuel accumulation rates as shown in this calculation. The slightly higher volumes of spent fuel, can be safely managed both on site and eventually in a GDF. The RR SMR discharges virtually no tritium as a result of the boron free chemistry regime, this is a significant improvement over existing LWRs justified in GB.

6.7.19 It is likely that any spent fuel would be given sufficient time to decay before being disposed of, reducing both the decay heat generated and allowing for some radioactive decay. The transportation of spent fuel (discussed further in Chapter 5) would take place under the transport guidance and requirement of ONR and would not cause a significant quantity of traffic nor radiological health risk. It can therefore be said that the detriment of managing and disposing of spent fuel would not be significant.

6.8 Decommissioning

6.8.1 Like all power stations, at the end of its operational life a nuclear power plant must be decommissioned. This process is essentially dismantling and restoration of the site for further use. The presence of radiological material at nuclear power plants, and the accompanying oversight that comes with it, means that decommissioning is defined by the ONR as the actions taken to remove regulatory controls from a facility. This section details the additional radiological considerations that are nuclear power plants present during decommissioning.

The Regulatory Framework for Decommissioning

6.8.2 One of the conditions within all nuclear site licenses, which are required for the operation of any nuclear site, is the consideration of decommissioning. Licence condition 35 states: *"The licensee*

140] Civil nuclear; roadmap to 2050 Section 9 www.gov.uk/government/publications/civil-nuclear-roadmap-to-2050/civil-nuclear-roadmap-to-2050-accessible-webpage?trk=public_post_comment-text *shall make and implement adequate arrangements for the decommissioning of any plant or process which may affect safety."* The ONR also expects all plants to be designed with this process in mind. Safety Assessment Principle DC.1 states that *"Facilities should be designed and operated so that they can be safely decommissioned."* Decommissioning, therefore, is considered from the start of a modern nuclear power station and is a core tenet of the design requirements for RR SMR.

6.8.3 In addition, sites undergoing decommissioning are under the same regulatory controls as operating sites, as discussed elsewhere in this Application. This means they must have a nuclear site licence, must have radiation protection and incident planning, must receive permission or authorisation from the local devolved environmental regulator for any discharges to the environment, and must have planning permission if the decommissioning process may impact on transport or require new structures, such as new interim storage facilities. Even further to these, an operator must, under the Nuclear Reactors (Environmental Impact Assessment of Decommissioning) Regulations 1999 ("EIDAR"), perform an environmental impact assessment of the decommissioning process prior to commencing decommissioning, and mitigate any negative impacts as far as is practicable. Consideration of regulatory aspects relating to end states, such as the eventual release from permitting and the need to have associated plans and assessments in place as set out in Guidance on Requirements for Release from Radioactive Substances Regulation. **[84]**

6.8.4 There are also regulatory requirements to ensure the financial demands of decommissioning are met through an FDP, discussed later in this Chapter, to ensure a burden is not placed on the taxpayer.

Decommissioning Process

6.8.5 The decommissioning process is discussed in more depth in Annex 3, however the topic will be covered briefly here.

6.8.6 The basic objective of decommissioning is to ensure the long-term protection of the public and environment and involves clean out, dismantling and removal of plant, extensive decontamination of any remaining materials and the site (should this be necessary) so that they can be safely managed or re-used. Decommissioning often involves the dismantling of existing structures to allow for the re-use of the land they are on, however this is not required, if, for example, a similar development is proposed for the site.

6.8.7 The decommissioning process as described by the ONR, has 3 stages **[85]**:

- Post-operational clean out. This is where the majority of radioactive materials, such as used nuclear fuel, are removed from the facility.
- Dismantling. Stage 2 can be either deferred or prompt:

  (a) Deferred Dismantling involves making preparations through the removal of radioactive waste and plant items to place the facility into a pre-defined period of care and maintenance. This allows for the benefits of natural radioactive decay to reduce radioactivity prior to final dismantling.

  (b) Prompt dismantling is when the facility is immediately dismantled after clean out, accepting the higher radioactivity levels to benefit from making the site safer, sooner.

- Final site clean up, to a point where the site can be de-licenced by the ONR and released from permitting by the environmental regulators.

6.8.8 The choice between prompt and deferred dismantling is usually driven by the level of radioactivity on site, and the complexity of decommissioning. Deferred decommissioning is used mainly in the UK for older stations, such as the Magnox sites, which present complicating factors. Even these sites, following recent progress in decommissioning techniques, are becoming eligible for prompt decommissioning. It is expected that RR SMR plants will follow the prompt decommissioning route. It is envisaged their unique modular construction design will simplify decommissioning.

Waste and Discharges from Decommissioning

6.8.9 As part of the site-specific licensing requirements, an IWS and Waste Management Plan will be developed for any new nuclear power plant, including the RR SMR.

6.8.10 Generally, however, the waste created from decommissioning would be:

- ILW – Parts of the reactor core such as the reactor pressure vessel and fuel rod components. Primary coolant circuit pipework, valves or pumps may also be ILW depending on how effectively they can be decontaminated.

- LLW – Parts which have been lightly contaminated or activated during the operation or decommissioning of the plant, for example gloves, filters, and residues left from decontamination of steel and concrete.
- VLLW – Bulk materials which have made up the RR SMR site such as girders and concrete. These may be sent to landfill or could be re-used according to the requirements of the waste hierarchy.

6.8.11 While there would be larger quantities of waste created during the decommissioning of the plant than during its operation, the same principles of waste minimisation, categorisation, storage and compaction would be applied to ensure the radiological impact was limited and reduced through optimisation.

Potential Detriments from Decommissioning

6.8.12 Traditionally, the main volume of waste from the decommissioning of nuclear power plants has been large quantities of non-radioactive concrete and building rubble **[86]**. The low-concrete design of the RR SMR means that the predominant decommissioning wastes from this design are likely to be structural steel, which can be decontaminated and re-used in accordance with the waste hierarchy.

6.8.13 The radioactive waste, such as reactor components or primary cooling loop components, can either be decontaminated or disposed of. If decontaminated, then the existing effluent routes for wastewater from within the reactor can be used to limit the release of radioactivity, while components sent for disposal will follow similar procedures to those used for ILW created during the operation of the plant.

6.8.14 The main detriment from decommissioning is therefore likely to be non-radiological, and due instead to the volumes of traffic required to send scrap and refuse to be recycled or disposed of. A discussion of such detriments can be found in Chapter 7.

6.8.15 Other impacts of decommissioning have been shown to be minor. The UK has extensive experience of decommissioning from the Magnox power plants, for example the plant at Wylfa, **[21]** and the environmental management plan (as required by EIDAR) found that all negative impacts from decommissioning could be adequately mitigated to prevent detriment. The operating experience from these plants and the Imperial College[141] reactor further contributes to new best practices for the decommissioning of nuclear power plants, potentially making the process faster without reducing safety.

Funding Decommissioning

6.8.16 Under the provisions of the Energy Act 2008, operators of new nuclear power plants must make prudent provision for both the full cost of decommissioning their installations, and their fair share of the costs of safely and securely managing and disposing of their waste. In achieving these provisions, the risk of recourse to public funds should be remote. This is done through the creation of an FDP, which includes the establishment of an independent fund that would receive a portion of the revenue from the generating plant which is set aside to pay for decommissioning costs **[87]**.

6.8.17 The FDP must be agreed with the Secretary of State before an operator can begin construction work of nuclear safety significance (termed by the ONR as ‘first nuclear concrete’), and consists of:

- A Decommissioning and Waste Management Plan (“DWMP”), which estimates the likely incurred costs of the decommissioning programme. The DWMP must first describe the “technical matters”, a term defined in the Energy Act 2008 referring to the treatment, storage, transportation, and disposal of hazardous material on the site, as well as preparation for, and decommissioning of, the site and the associated clean-up activities. The DWMP must then estimate the costs of the so called “designated technical matters”, which will always be the decommissioning of the site, and may, by order of the Secretary of State, include the management of hazardous materials; and
- A Funding Arrangements Plan (“FAP”), which describes the arrangements in place to ensure that sufficient money is set aside during the operation of the plant, and placed into an independent fund to ensure the costs described in the DWMP can be met.

6.8.18 While it is the responsibility of any prospective operator to propose suitable arrangements as part of an FDP, the independent Nuclear Liabilities Financing Assurance Board (“NLFAB”) is responsible for scrutinising the submitted FAP and advising the Secretary of State on its suitability. The NLFAB will examine the FAP to ensure the fund is independent, sufficient, will be correctly used and will remain solvent, alongside ensuring the governance of the fund is suitable

141] ONR completes first ever full decommissioning of UK reactor site under modern regulatory controls www.onr.org.uk/news/all-news/2024/02/onr-completes-first-ever-full-decommissioning-of-uk-reactor-site-under-modern-regulatory-controls/

to meet its objectives. The NLFAB will also provide advice as to whether the FAP has robust cost estimates, to help prevent the fund being inadequate to meet decommissioning liabilities **[88]**.

6.8.19 The guidance for the FDP lays out the Government's expectations for how the fund should be managed during operation to ensure it can deliver its objective. This includes: a risk-based contingency to target the value of the fund above the expected cost of the DWMP; a detailed investment strategy to ensure the fund value is not eroded by inflation; and arrangements for the independence of the fund from the operator, to ensure that the fund is protected from creditors in the event of the operator's insolvency.

6.8.20 During the operating life of the nuclear power plant, as the FDP is being funded, annual and quinquennial reports must be compiled. The annual report would contain a transparent assessment of any changes to the cost estimates made for the decommissioning of the plant and analyse the current performance of the fund to ensure that these costs can be met. The quinquennial report would analyse the entirety of the DWMP to ensure that the actions and assumptions are still realistic, and that the disposal paths and decommissioning plans are still achievable. If necessary, a change to the FDP can then be made to ensure the core objective of the FDP—that the risk of recourse to public funds is remote—remains achievable.

6.8.21 The FDP must also make arrangements for the handling of ILW and spent fuel. The UK Government, as the operator for a future GDF, will provide a disposal route for any such higher activity waste arisings, and have published a waste transfer pricing methodology to provide certainty to operators as to the price an operator will have to pay for the disposal of its waste, which includes a small premium for risk management to prevent any burden on the taxpayer **[89]**.

6.8.22 After the completion of decommissioning, the FDP fund may disburse any surplus assets back to the operator. This helps to create a financial incentive for any operator to design for decommissioning and continue to apply new best practices and technologies during the operating life of the plant to aid in its swift and safe decommissioning.

6.8.23 In summary, the framework is in place to ensure that at the end of the operational life of any new nuclear power plant, including the RR SMR, the plant will be decommissioned safely and that, as far as practicable, the risk of detriment to the taxpayer is mitigated to remote levels.

6.9 Conclusion

6.9.1 This Chapter has considered the possible detriment from the operation and decommissioning of a nuclear power plant based on the Proposed Practice in the context of radioactive waste management and decommissioning. It can be concluded that while any new nuclear power plants based on the Proposed Practice will create new radioactive waste and spent fuel, the legal, economic and regulatory framework for the management of any new radioactive waste arisings, as well as the option for safe, long-term storage for any waste or spent fuel already exist and that any additional detriment caused caused by radioactive waste management and decommissioning will be low.

6.9.2 In addition, Government policy requires FDPs to be in place before nuclear construction commences. This reduces the risk of new nuclear power stations (including the RR SMR) creating a burden on the UK taxpayer in the form of future waste management and decommissioning liabilities.

7: OTHER POTENTIAL DETRIMENTS - ENVIRONMENTAL IMPACTS

All major infrastructure projects have impacts on the environment. In line with government guidance, these impacts are addressed at a generic level through a Strategic Environmental Assessment and Sustainability Appraisal, then at a site or project specific level through an Environmental Impact Assessment ("EIA") and Habitats Regulations Assessment **[90]**. There are also specific environmental permitting processes for individual sites **[91]**.

This Chapter previews those issues which are likely to be most relevant to the Proposed Practice, showing that:

- The overall environmental impacts from the Proposed Practice would be small.
- All environmental impacts would be properly mitigated and kept to a minimum.
- The Proposed Practice would meet all applicable standards and regulations.
- The environmental impacts would not be unique to the Proposed Practice and would be less than, those of other large scale electricity/energy generation due to the compact nature of the RR SMR and the off-site modular construction approach.

In terms of the environmental impacts of the Proposed Practice, the significant difference with the RR SMR is the use of off-site modular construction, resulting in fewer transport movements during construction and reduced build time. Subsequent to the 2013 Application there have been some significant changes to environmental, sustainability, and planning legislation following the Paris Climate Agreement and the UK's exit from the European Union, which are reflected in this Chapter.

7.1 Introduction

7.1.1 Major infrastructure projects (including nuclear power stations) inevitably have an impact on the environment. It is for this reason that a detailed environmental assessment is required as part of the application for a Development Consent Order under the Planning Act 2008, which must be decided in accord with the Overarching National Policy Statement for Energy (EN-1) **[92]** and the future National Policy Statement for Nuclear Power Generation (EN-7) which will apply to new nuclear power stations deployed after 2025. This Chapter provides a preview of the environmental impacts that would be addressed during any such consenting process within the UK to ensure that there are no unacceptable environmental impacts from the deployment of the Proposed Practice.

7.1.2 It is important to note that these likely environmental impacts are not a consequence of the use of ionising radiation, and are broadly similar to the nature of impacts that would result from the construction of other thermal generation projects. Nuclear power has a significantly higher energy density compared to other thermal generation plant. So a small modular design has relatively low impacts for high power output compared with other thermal generation.

7.1.3 Renewable generation also involves many of the construction-related impacts covered in this Chapter.

7.1.4 These impacts are therefore covered in this Application to provide a full picture of the detriments involved in the Proposed Practice, and to demonstrate that the detriments do not significantly erode the overall benefit.

7.1.5 The following sections consider the potential scale of environmental impacts during operation, the means by which they would be addressed and mitigated, and the regulatory regime in place to control them:

- Conventional waste management;
- Traffic and transport;
- Air quality;
- Aquatic environment;
- Cooling towers;
- Chemicals;
- Noise and vibration;
- Light; and
- Landscape and visual effects.

7.1.6 The key potential environmental impacts of construction are assessed below for completeness. The construction of a nuclear plant does not raise any unique environmental issues different to those of any infrastructure construction project. The construction of any new nuclear power station, like any other construction project, would be undertaken in compliance with all of the relevant legislative requirements. The following sections are addressed in this Application:

- Habitat and species protection;
- Traffic, transport and laydown;
- Noise;
- Air quality; and
- Conventional waste.

Plant decommissioning is also briefly considered for completeness.

7.2 Environmental Impacts During Operation

Conventional Waste Management

7.2.1 The requirements for managing conventional waste from the operational phase of the Proposed Practice are the same as for any other conventional waste producer. For nuclear power stations, the waste generated would typically include office paper, lubricating oil, cardboard, plastics and municipal wastes from staff services. This would be broadly similar to that expected from any power station or major technical enterprise.

7.2.2 Conventional waste would be segregated from radioactive materials so as to maximise the potential for reuse, recovery or recycling. Any hazardous conventional waste streams would be controlled rigorously.

7.2.3 It should be noted that the majority of waste production is governed less by the design of the plant than by the waste management system adopted by the operator. Appropriate mitigation measures will be applied in accordance with the waste hierarchy (reduce, re-use, recycle) as identified in relevant waste strategies including the strategy for England **[93]**. In this respect, the Proposed Practice is no different to other major industrial facilities, and no different from nuclear plants which are currently in operation, or the subject of the 2015 Justification Decision.

7.2.4 Conventional waste would be managed in accordance with best practice and in compliance with relevant regulations (such as the Hazardous Waste (England and Wales) Regulations 2005, the Waste (England and Wales) Regulations 2011 and the Environmental Permitting (England and Wales) Regulations 2016). As a result, any environmental impacts would be small and would be mitigated.

Traffic and Transport

7.2.5 The principal transport impacts resulting from the operational phase of the Proposed Practice would be increased road and rail movements.

7.2.6 The volumes of radioactive waste and spent fuel that would be generated by the Proposed Practice are described in Chapter 6. Given their relatively small scale, the number of any associated transport movements required would be very low.

7.2.7 With regard to operational transport requirements, there would be regular road deliveries to the site. However, there would be no need for the frequent delivery of large quantities of supplies (such as fuel) or the shipment off site of large waste volumes. As a result, there would be no major addition to existing commercial traffic. The resulting increase to local noise levels would consequently be small, and likely to be less than other baseload electricity-generating stations.

7.2.8 Most of the permanent workforce are likely to commute to the site using private vehicles. However, shift-working arrangements would result in the staggering of these movements, diminishing the impact. As necessary, travel plans could be established in order to minimise the impact on the environment of the journeys of employees and third parties. It should also be noted that any project would invariably undergo a design and access analysis which is likely to include a "travel plan" **[92]**, as part of the development consent process.[142]

142] Nuclear power plant projects require a "Development Consent Order", the application for which must comply with the Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009. Regulation 5(2)(q) requires this to include all documents "necessary to support the application" and the Planning Inspectorate's "Advice note six: Preparation and submission of application documents" provides a "design and access statement" as an example of such a document.

7.2.9 An additional itinerant workforce would be needed periodically (about every 18 months) for reactor outages (for approximately 1 month). This workforce would comprise around 1,000 staff, although the numbers would vary at different outages. Again, the effects of transport could be mitigated where possible, using experience from similar projects to ensure no significant impacts. These mitigation measures might include the site travel plan and the use of designated advisory routes.

Air Quality

7.2.10 Operation of the Proposed Practice would result in no significant effects on air quality. Unlike fossil fired plants, there would be no significant emissions of air pollutants such as CO_2, SOx, NOx or airborne particulate matter.

7.2.11 Whilst ancillary equipment such as auxiliary boilers and emergency combustion generators might lead to some minor emissions, they would generally be operated intermittently, and only then within the conditions of an Environmental Permit required under the Environmental Permitting (England and Wales) Regulations 2016. A requirement for the adoption of BAT would be applied to mitigate any potential impacts in accordance with this regime.

7.2.12 The main source of emissions is expected to be diesel generators for standby and alternate electrical power, which are only required to operate in certain very infrequent events, and auxiliary Mobile Fired Boilers ("MFBs"). Both systems would use Class A2 low-sulphur fuel oil, with a sulphur content less than 0.1 %.

7.2.13 As it is important the diesel generators operate reliably when needed, they are regularly tested by starting and running them for a short period, typically for around an hour. The auxiliary MFBs are operated during plant outage for approximately 5 days every 18 months to provide steam during plant start up.

7.2.14 For the RR SMR plant, it is expected that the diesel generators will be run for a total of 96 hours of routine testing per year, which would use 43,200 litres of fuel. The total volume of fuel oil used by the MFB during start-up would be approximately 152,400 litres, which would be needed every 18 months. This results in an annual usage of about 145,000 litres of fuel, or 123 tonnes.

7.2.15 The majority of pollutant emissions would come from the diesel generators, with the MFBs contributing mainly CO_2 to the total emissions. The total emissions would be around 330 tonnes of CO_2, 2.3 tonnes of NOx, 0.2 tonnes of CO, 0.14 tonnes of SO_2 and 0.07 tonnes of particulate matter.

7.2.16 As a comparison of light fuel oil consumption at nuclear power stations for the purposes of testing backup generators, the UK EPR®, which will be installed at Hinkley Point C and Sizewell C, is expected to use 145 tonnes (170,000 litres) of low sulphur fuel oil per year, running for around 100 hours of testing **[94]**.

7.2.17 Against this background, and based on prior experience with existing nuclear plants, there can be confidence that all of the necessary air quality standards would be met, and any environmental impacts would be small.

Aquatic Environment

7.2.18 This section discusses the impacts that may arise from the use of cooling water during the operation of the Proposed Practice.

7.2.19 Large volumes of water are already abstracted from UK rivers, as well as estuarial and coastal waters, for electricity generation purposes at existing thermal generating stations, whether nuclear or fossil fuelled. Rejection of waste heat to the environment is required as part of the thermodynamic cycle that uses steam to generate electricity **[95]**. The cooling water for the turbine generator can be cooled either via direct cooling or the use of cooling towers. To allow for flexible siting of the plant, the RR SMR uses mechanical draft cooling towers in its generic design, although could use direct cooling if there are site-specific circumstances[143] that mean direct cooling becomes the BAT.

7.2.20 However, the potential negative effects of the installation and use of cooling towers include:

- Plume effects:
  - Fog and ice;
  - Salt dispersal;[144]
  - The possibility of bacterial emission;

143] EA Evidence Cooling Water Options for the New Generation of Nuclear Power Stations in the UK www.assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291077/scho0610bsot-e-e.pdf

144] Salt dispersal is is the emission and deposition of dissolved salts and minerals present in the cooling water in the form of drift droplets from the cooling tower.

- Visual impact of the towers; and
- Noise from fan operation.

7.2.21 These effects will be discussed further in this Chapter, along with the separate impacts the use of direct cooling would have.

7.2.22 Regardless of the chosen cooling system, there may be a requirement for the installation of marine infrastructure, for the abstraction of cooling water. The installation of this equipment would have to be assessed and licensed under Part 4 of the Marine and Coastal Access Act 2009. Any potential environmental impacts would be evaluated before the granting of such a licence, with a duty to monitor and mitigate any impacts.

7.2.23 In addition to the use of water for cooling purposes, water might be abstracted for other purposes such as process water, potable water and to supply firefighting systems.

Thermal Effects

7.2.24 Many of the concerns around the thermal effects of power plant cooling are related to direct cooling use. While the generic RR SMR using cooling towers will have discharges of cooling water, these will primarily be for salinity control. It is possible that these discharges will be hotter than the ambient water, but by a negligible amount in comparison to direct cooling, which has been used as part of other power plants and justified practices for many years. However, a brief overview of thermal discharge is included for completeness.

7.2.25 Thermal discharges have a range of effects on the environment. Some direct effects include altering organisms' growth and breeding patterns, an alteration of dissolved oxygen concentrations, and even altering the mix of species in an area by driving out species that prefer colder water and attracting those that prefer warmer water. Indirectly, this can lead to altered biodiversity and microbial activity and eutrophication. However, these are extreme impacts which any power plant operator and the devolved environmental authority has a duty to prevent.

7.2.26 Unlike for other pollutants, heated discharge water does not have any statutory limits on quantity or temperature uplift requirements. However, following the requirements of the Water Environment Regulations 2017 (which transposed the consolidated EU Water Framework Directive into UK law), the EA targets for temperature uplift in the mixed seawater zone have become law. These targets, developed by the UK Technical Advisory Group ("UKTAG") in 2008 (and have not been updated since), are for an uplift of less than 3 °C in general, and less than 2 °C in sensitive areas **[96]**. In reality, the licencing requirements from the EA require thermal discharge to be kept as low and cool as possible, following BAT.

7.2.27 For the RR SMR, while the impact of cooling water return is site-specific, the use of indirect cooling means the actual temperature uplift caused by discharge would be well within these limits. To illustrate, Hinkley Point C will abstract and return around of 125 m^3s^{-1} seawater, which will be heated by 11 °C **[97]**. This will cause an increase in local sea water temperature within legal limits. RR SMR will abstract and return about 1.5 m^3s^{-1}, which will be returned 8 °C hotter. This will clearly cause a far smaller amount of water heating in the local marine areas.

7.2.28 If direct water cooling was required, arrangements deployed by the Proposed Practice would be similar to those of existing nuclear stations and those which are the subject of the 2010 Justification Decisions. As with existing nuclear stations, cooling water intake and discharge would be routinely monitored by plant staff to ensure that the discharge of cooling water was managed within the limits set by the EA/NRW in the Environmental Permit.

Chemicals and Chemical Effects

7.2.29 The Proposed Practice could result in chemical effects to the aquatic environment due to the need to dose the cooling water with a biocide to prevent the growth of marine organisms, such as mussels and algae, which might otherwise impede the operation of the cooling water system. Low level chlorination (by sodium hypochlorite injection) will be the method used in saltwater environments. This could lead to the discharge of chlorinated breakdown products, referred to as Total Residual Oxidant ("TRO"), in the marine environment. The chlorination regime and the discharge standards for TRO would be controlled in accordance with the conditions and limits set out in the operational Environmental Permit **[98]**. Therefore, it is not expected that there would be any significant environmental impact.

7.2.30 Whilst there would be a requirement to store and use various chemicals on-site for operational purposes, such as water treatment processes, these would not be released into any permitted discharges. In addition, any chemical handling would be undertaken in accordance with the Control of Substances Hazardous to Health ("CoSHH") Regulations 2002, thereby controlling exposure to chemicals and protecting workers' health.

7.2.31 Since any dosing regimen for new plant would be site specific, benefit from existing operational experience, and subject to the application of BAT, there should be no significant release of residual biocide within the cooling water discharges that would have a significant impact on the receiving waters.

Salinity

7.2.32 One of the key mechanisms for the removal of heat when using cooling towers is evaporation, a side effect of which is the increase in concentration of dissolved solids in the cooling water. To prevent the build-up of these solids, the cooling system constantly removes a volume of concentrated cooling water from the system, called blowdown. This blowdown is responsible for almost all of the abstracted water requirement and makes up the majority of the discharge from the power station. However, the returned water would have a higher salinity than the abstracted water.

7.2.33 The EA has stated that for indirect cooling using seawater, blowdown *"is unlikely to exceed double strength and, given the relatively small volume, it should not pose any regulatory problem"*, and *"the associated salinity change would be small and unlikely to be detectable beyond the mixing zone"* **[95]**. If direct cooling was used blowdown would not be required.

Effects on Marine Organisms

7.2.34 The two main effects of water abstraction on marine organisms are impingement and entrainment. Impingement is when organisms are drawn into the plant infrastructure and become impinged on filtering screens or bars. The second is entrainment, when the organism is small enough to enter the plant and some subsequent systems (usually those designed to remove entrained organisms) before being returned to the sea. The majority of these organisms are fish (and eels, in certain locations).

7.2.35 The abstracted water for a coastally situated plant is taken from a significant distance offshore and at depth, to avoid the area of the ocean where organisms are most plentiful. To further keep fish from being drawn into the intake, the RR SMR will make use of a low-velocity side entry intake, in line with current relevant good practice, which reduces inlet velocity and reducing overall marine impact. In addition, the low water abstraction requirements for indirect cooling of the RR SMR allow a larger intake than necessary to be constructed, further reducing inlet velocity. A wide range of methods are in common use for fish deterrents and fish screening, and the specific technologies employed are dependent on the marine habitats found local to each particular site. The choice of technology and design for new nuclear power stations would be based on the local environmental conditions, operating experience at existing power stations both in the UK and abroad, appropriate expertise in fish protection and the latest available regulatory guidance **[99]**. As a result, the impacts on fish and other marine fauna would be mitigated.

Cooling Towers

7.2.36 If cooling towers were used, there would be a potential environmental issue relating to the emission of bacteria within the plume from the tower. However, the mechanisms of bacteria growth in cooling tower systems are well understood, and methods for prevention of bacteria growth and dispersion are available. The decision to use cooling towers or not will be made on a site specific basis.

7.2.37 The design and operation of any cooling towers required for the Proposed Practice would be based on the lessons learned from past operating experience and would follow relevant good practice **[100]**. As a result, the environmental impacts would be mitigated or unlikely to occur. This could be achieved through the appropriate use of technology, such as mechanical draft cooling towers with plume abatement. Such impacts would be assessed and regulated as part of the development consent process.

Noise and Vibration

7.2.38 The design of the buildings and plant would ensure that the continuous operating noise from the Proposed Practice would be minimal and would represent only a small addition to the existing background level. The presence of the earth berm will also help to mitigate sound transmission from the plant.

Best Available Techniques have been incorporated throughout the RR SMR design leading to the decision to use indirect cooling, via mechanical draft cooling towers, for the generic design.

The wet closed induced draught cooling towers are specified to have ultra-quiet blades engineered to minimise noise from airflow and an ultra-quiet double-flow stainless steel wet coil, which reduces the sound produced by water splashing or trickling, as well as the airflow turbulence that occurs during the heat transfer process. The cooling towers are specified to have excess capacity at design conditions that allows it to meet thermal performance requirements with lower airflow and reduced fan speed, decreasing the noise generated by air movement and fan operation.

7.2.39 Whilst some additional noise might result from the intermittent operation of ancillary equipment, such as auxiliary diesel generators, these systems would only be operated infrequently for intermittent testing or during abnormal conditions. Noise control during the operation of the power station would be subject to conditions and limitations specified within the Environmental Permit. Acoustic enclosures could also be fitted around certain external plant if required to reduce noise.

7.2.40 As part of the development consent order process for any RR SMR build, a site-specific noise study would be carried out, and noise limits imposed on a site-by-site basis which the power plant would operate within.

Light

7.2.41 In addition to any street lighting, the outside perimeter of the plant site would require some security lighting. Environmental effects would be mitigated by ensuring that lighting was correctly positioned, directed downwards rather than upwards, and that no unnecessary lighting was used. As a result, environmental effects would be small.

Landscape and Visual Effects

7.2.42 The operational site of a RR SMR nuclear power plant is split into two broad categories: the plant itself, containing the reactor, turbine and supporting buildings, and balance of plant buildings; and the surrounding site, including access roads, car parks, cooling tower infrastructure (if applicable), water abstraction infrastructure and transmission lines. The latter infrastructure can be location agnostic, and so is less tightly integrated into a known layout.

7.2.43 The area of the plant is 10 hectares, roughly equivalent to the area of the Wembley Stadium complex in London. There will be an additional area required for the external infrastructure, however this will be a relatively sparsely built-up area.

7.2.44 Visual impacts are to be expected as part of any large generation facility, from the reactor buildings, power transmission lines and cooling towers. The visual impact of the reactor buildings will be moderated by the architecture of the plant, including the sloped roof structure and large earthwork berm that surrounds the site. The largest effects would be the cooling towers (if applicable) and transmission lines, which sit outside of the boundary of the berm.

7.2.45 Two potential concerns around the use of cooling towers are their large physical size and highly visible plume. A visible plume is caused when warm, saturated (air that cannot be made any more humid) exhaust air exits the tower and is cooled on contact with colder air. This causes the water in the air to condense into visible droplets, which form the plume.

7.2.46 The large cooling towers usually associated with thermal generating stations are natural draft cooling towers (“NDCTs”). These use the rising hot air from the coolant to drive the airflow within the tower, requiring a large amount of space (around 100 m in diameter and more than 100 m high) resulting in saturated hot air exhausts that form a significant visible plume. These concerns have been mitigated through the RR SMR use of mechanical draft cooling towers (“MDCT”) which are much smaller than NDCTs at around 16 m wide and 10 m high, with tens of units being used instead of 2-10 large towers. The RR SMR MDCTs will be provided with plume abatement systems, which allow additional dry air to be drawn into the exhaust flow of the towers, cooling and drying the exhaust before it can create a visible plume.

7.2.47 Since transmission lines would be required by all centralised generating plant, and would have a similar impact, they are not considered in this Application. If located at an existing power station site, a new nuclear power station using the Proposed Practice may not necessarily require new transmission lines. Installation of any new lines, where required, would be subject to approval under the requirements of the Planning Act 2008 for Nationally Significant Infrastructure Projects.

7.2.48 The landscape and visual effects of the Proposed Practice would be mitigated in light of experience from past projects. Visual impacts would be minimised, for example, by ensuring that the design followed the relevant guidelines **[101]**.

7.3 Environmental Impacts During Plant Construction

7.3.1 Construction of a large build nuclear power plant can take around a decade, with a large workforce and high quantity of raw material deliveries. A key differentiator of the Proposed Practice is the standardisation and modularisation of the build process. This allows for increased build certainty and speed and less transport movements to and from the site.

7.3.2 Construction of an RR SMR would be split into three main phases: advance work, site establishment, and main plaint assembly.

7.3.3 The first phase involves the work required to begin true construction, such as surveys, site clearance, early road construction, CCTV and perimeter establishment, and any other work required to operate a construction project on the site.

7.3.4 The second phase, site establishment, prepares the site for the installation of the modularized reactor, and includes the groundworks, foundations, site factory, cranes and further road construction among other activities. At this stage, the project is still non-nuclear, with the high-precision reactor construction being performed in off-site factories.

7.3.5 In the third and final phase, the modules are transported to site and installed inside the site factory, which will provide environmental protection and lighting for installation allowing construction to be performed around the clock, regardless of inclement weather conditions, until completion. The factory will then be removed, leaving the constructed SMR in place.

Habitat and species protection

7.3.6 Like many other large infrastructure projects, the development of a nuclear power plant could potentially impact on sensitive species and habitats.

7.3.7 The impacts on species and habitats from the Proposed Practice will depend primarily on the sites where new nuclear power plants are deployed. This potential impact was assessed in the Strategic Environmental Assessment undertaken during the preparation of the Nuclear National Policy Statement (EN-6) **[102]**.

7.3.8 The Conservation of Habitats and Species Regulations 2017 **[103]** require the decision-making authority to make an appropriate assessment of the likely significant effects on protected sites, in view of the site's conservation objectives, before deciding whether to authorise the development of a new nuclear power station. The developer is required to provide sufficient information (including in relation to impact avoidance and mitigation measures) to facilitate an appropriate assessment to be made.

Traffic transport and laydown

7.3.9 As part of all construction projects, people and materials must be brought onto the site, resulting in increased traffic to the power plant compared to when it is operational. There may also be additional space required to store the materials as they are delivered, called lay down areas.

7.3.10 The design of RR SMR includes the locations of laydown areas and roads, with a view to their construction, use and possible removal being standardised across plants. This allows for the optimisation of transport and laydown across all build programmes. RR SMR lay down areas will be inside the locations of the earthwork berm that will be created after construction, meaning that post-construction landscaping and restoration of these areas is planned for.

7.3.11 In relation to increased traffic quantities, early estimates are that approximately 50,000 deliveries of materials and modules would be required to the site. This is considerably lower than the number of transport movement required for larger nuclear projects.[145]

7.3.12 A transport assessment will be required for individual sites before construction can begin, but this could include mitigating the impact of transport for workers through bus services, walking and cycling plans, on-site accommodation or shift management. The site factory will aid the scheduling of shifts by providing a clean, dry, well-lit area for work to be carried out independently of weather and daylight conditions. It is expected that only around 1,000 workers will be required to be on site for the construction of the RR SMR, far fewer than for gigawatt-scale nuclear power plant construction **[104]**.

7.3.13 Regardless of the eventual deployment locations for the Proposed Practice, the consequences on traffic and transportation will be assessed during the planning process in the same way as for any other large construction project with the aim of minimising disruption caused.

145] Hickley Point C is predicting 290,000 HGV movements during construction.

Noise

7.3.14 Noise levels are described using decibels ("dB"). It should be noted that the decibel is a relative logarithmic unit, so there is not a linear relationship between sound levels—in general, an increase of 10 dB means a sound intensity 10 times higher, and a perceived loudness twice as loud. Examples of different noises and their intensity are listed in Table 15 **[105]**.

Table 15: Reference Sound Pressures

Noise Source	Sound Pressure level in dB
The quietest sound a healthy human ear can hear	0
A quiet library	40
Ordinary spoken conversation	60
A food blender	85
Heavy traffic	88
A pneumatic drill	91
An industrial fire alarm	97
A nightclub	100
A live gig or concert	110
An aeroplane taking off 100 m away	130

7.3.15 During the construction stages, there are different sources of noise, for example, power tools and heavy mobile equipment, including trucks, bulldozers and front-end loaders.

7.3.16 At this stage, it is not possible to state definitively what the noise impact from the construction of the proposed plant would be at residential locations, and it is anticipated that it would be managed under the 'prior consent process' under section 61 of the Control of Pollution Act 1974.

7.3.17 Construction noise on the RR SMR would be the subject of restrictions imposed through Development Consent Order conditions to the extent that this was identified as necessary by the relevant planning authorities. It is also important to note that the innovative use of a site factory for the RR SMR will reduce noise pollution, as much of the work will take place inside a built structure.

Air Quality

7.3.18 The impact of construction activities on air quality is dependent on numerous factors, many of which are specific to the site on which the RR SMR is built. Any effects on air quality would need to be assessed as part of the development consent order process for individual sites and included in the EIA.

7.3.19 Generally, air pollution during construction can come from many sources: emissions from plant, vehicles and equipment; dust and particulates created from excavation or processing; or odours from industrial processes and tools. The use of a site factory will help to contain any pollutants, allowing for filtration and mitigation of their impacts. In addition, as part of the global aims of net zero emissions, the availability of an electrically powered, zero emission plant is increasing. This is likely to allow for the minimisation of emissions by using Electric Vehicle or Hydrogen technologies on site.

Conventional Waste

7.3.20 Similarly to all industrial manufacturing and construction projects, there will be conventional waste arisings from the construction of the RR SMR. However, the plant is designed to follow the UK waste hierarchy, prioritising the reduction of waste created, re-using materials where appropriate, and prioritising recyclable materials to minimise the generation of non-recyclable waste.

7.3.21 Conventional waste created during construction will be minimised by using off-site factory assembled modules and earth excavated during construction will be reused to form the surrounding berm.

7.4 Environmental Impacts During Decommissioning

7.4.1 Decommissioning of a nuclear site refers to the process by which some or all regulatory control can be removed from a facility **[106]**. Usually in the case of a nuclear power plant the plant is shut down, disassembled, and removed, with all waste products and structures removed and the site returned to its original state. It is also possible some structures are completely decontaminated and re-purposed. Please note that this section only deals with environmental impacts and further information on decommissioning can be found in Chapter 6.

Regulation

7.4.2 In the UK, under the Nuclear Installations Act 1965, nuclear operators are responsible for the safety of a site until a site is either relicensed or the ONR gives notice that a site has been delicensed. For areas of a nuclear site which do not contain certain waste disposal installations, this requires the site to meet specified dose exclusion criteria. For areas of a nuclear site containing certain waste disposal installations, however, this requires that there has *"ceased to be any danger from ionising radiations from anything on the site or, as the case may be, on that part of it question"* **[107]**. When all radioactive substances activities have stopped and the site reference state has been reached, operators apply to surrender their environmental permit by following guidance on requirements for release[146] ("GRR"). The GRR focusses on the management of radioactive wastes arising from the final stages of decommissioning and preparations for permit surrender.

Environmental Impact Assessment

7.4.3 There are a wide range of regulatory requirements for the decommissioning of a nuclear site. Every nuclear site licence requires a site to have arrangements, plans and programmes to undertake decommissioning in place before they can begin to operate.

7.4.4 Prior to decommissioning the ONR must provide consent under the Nuclear Reactors (Environmental Impact Assessment for Decommissioning) Regulations 1999 ("EIADR") as amended.

7.4.5 Under EIADR, an EIA must be produced for the decommissioning activities, for consideration by the ONR, local planning authorities, the local environment regulator, and the public **[108]**. The decommissioning EIA will assess similar environmental impacts to the EIA prepared for construction of the plant, including air quality, noise and vibration, surface water impacts, traffic and transport, and radioactive discharges amongst other impacts.

Transport

7.4.6 A comparable number of transport movements would be expected for decommissioning a plant as the number to construct it. However, decommissioning could take place over the course of decades as part of the UK policy of deferred dismantling,[147] reducing the rate of traffic to the site considerably. There may be more vehicles moving to and from site during the period of fuel removal, and then again while demolition and dismantling occurs, however these would likely still be less busy periods than during construction. Additionally, the lower staff requirements for the decommissioning stage would further reduce traffic.

7.4.7 It can therefore be assumed that the environmental impact of transport during decommissioning will be lower than during operation most of the time, only being noticeable during the end stages of dismantling.

7.5 Conclusions

7.5.1 The analysis in this Chapter, undertaken on the basis of previous experience building and operating nuclear power plants, the application of updated standards and legal requirements, and current analysis from the design of the RR SMR, show the environmental impact of the Proposed Practice would be acceptably low. Impacts would be lower than large scale electricity/energy generation projects due to the compact nature of the RR SMR and the off-site modular construction approach and would be assessed and mitigated through the UK's existing, comprehensive, and well tested developmental and environmental regulatory regimes.

146] guidance on requirements for release

147] RR SMR presently intend to implement prompt decommissioning as detailed in Chapter 6.

8: OTHER POTENTIAL DETRIMENTS

Other Considerations

The wider impacts resulting from the adoption of the Proposed Practice would result in no significant detriments.

Existing, very small proliferation risks are reduced by inclusion of Safeguards by Design in to the RR SMR.

Station structural resilience, shielding and comprehensive security measures also ensure that the power station is at low risk from malicious and terrorist acts.

Stringent health and safety standards would continue to provide a safe workplace, and the risk of industrial accident would be very low.

Stations would be protected against the effects of climate change.

The risks of detriment from a severe accident, even following an extreme event, would be very low.

8.1 Introduction

8.1.1 This Chapter considers other potential detriments that might result from adoption of the Proposed Practice involving the RR SMR. The following detriments are examined in the sections below:

- Non-Proliferation;
- Security;
- Industrial Safety;
- Climate Change Impacts; and
- Extreme Events and Severe Accidents.

8.1.2 The principal changes since our 2013 Application are:

- The addition of consideration of the factors that lead us to conclude that the risk of significant detriment from extreme events remains low.
- A general update of the information provided in relation to the other detriments that we consider in this Chapter.

8.2 Non-Proliferation

8.2.1 The potential for the proliferation of nuclear weapons from the deployment of civil nuclear power stations arises from the fact that certain materials used in, or arising from, nuclear power could, if diverted from peaceful use, be processed for use in the manufacture of nuclear weapons. However, an effective regulatory framework is already in place to prevent any such diversion from the UKs existing nuclear fleet, and a new programme of nuclear power stations including the Proposed Practice would not materially change the existing, very low, proliferation risk. There would be major technical difficulties involved in obtaining weapons-grade material from RR SMR irradiated fuel. In 2021 the World Nuclear Association stated **[109]**: *"Civil nuclear power has not been the cause of or route to nuclear weapons in any country that has nuclear weapons, and no uranium traded for electricity production has ever been diverted for military use."*

8.2.2 The cornerstone of international efforts to prevent the spread of nuclear weapons is the Nuclear Non-Proliferation Treaty ("NPT") **[110]** and the associated safeguards provided by the verification regime of the IAEA.

8.2.3 The NPT's main objective is that states have a right of access to the peaceful use of nuclear power in return for accepting that they will not use such programmes to work towards developing nuclear weapons. Nuclear safeguards are measures to verify that countries comply with international obligations not to use nuclear materials from civil nuclear programmes for non-peaceful purposes.

8.2.4 The UK is a Depository Power for the NPT, it has IAEA safeguards on its civil facilities and has implemented additional IAEA safeguards measures via the Nuclear Safeguards Act 2000. This treaty also includes independent verification measures to ensure that nuclear material is not diverted from peaceful use.

8.2.5 Any new nuclear power stations built in the UK, including any using the Proposed Practice, would be subject to these IAEA and national safeguards measures, which have been effective internationally in verifying a wide range of reactors and associated fuel cycle plants over many years. Nuclear new build based on the introduction of modern designed, light water-cooled reactors (including the Proposed Practice) would present no new issues of principle.

8.2.6 Any new nuclear power station would provide interim facilities for spent fuel to be stored. The on-site fuel storage facility associated with the Proposed Practice would not present any technological challenge to safeguards verification.

8.2.7 Plutonium or highly enriched uranium is required to construct nuclear weapons. Extracting plutonium from irradiated fuel from nuclear power plants is difficult, and the fuel elements used in modern commercial light water reactors would not be a good source of material for a weapons-related enrichment facility. The reactors use low enriched fuel and are operated to maximise the value of the nuclear fuel. It is physically impossible to create a nuclear explosion from fissile material of such low enrichment; neither new nor irradiated fuel is weapons-grade material.

8.2.8 The Government's continued commitment to this effective regulatory framework was confirmed in its January 2024 Civil Nuclear: Roadmap to 2050 **[5]**: *"Our mission is to ensure the safe and responsible deployment of civil nuclear globally; to uphold and protect the global non-proliferation regime, and ensure the UK honours its obligations in that; and to work with our allies and partners in areas of shared mutual interest to deliver resilient and secure nuclear supply chains."*

8.2.9 The paragraphs above show that any additional risks of proliferation resulting from the Proposed Practice are very small. Any associated detriment is therefore also very small. The Government stated in its 2008 White Paper on Nuclear Power **[111]** that: *"The Government continues to believe that new nuclear power stations would pose very small risks to safety, security, health and proliferation. We also believe that the UK has an effective regulatory framework that ensures that these risks are minimised and sensibly managed by industry."*

8.3 Security

8.3.1 New nuclear power stations, like the UK's existing nuclear fleet and other major infrastructure installations, could be potential targets for terrorist attacks or other malicious acts because of the perceived impacts on health and the economy, and the publicity such an act may attract. The following sections consider the security measures in place to minimise this risk and describe the inherent design features of a nuclear power plant that would mitigate the consequences were an attack to take place. They demonstrate that the potential security-related detriment from the Proposed Practice is very small.

Security Measures and Regulatory Framework

8.3.2 Security measures for nuclear power plants in the UK are regulated under the Nuclear Industries Security Regulations 2003. These regulations apply to all 'nuclear premises' (including nuclear power stations and make provision for the protection of nuclear material and other radiological material, both on sites and in transit, against the risks of theft and sabotage, and for the protection of sensitive nuclear information, such as site security arrangements and sensitive areas of plant. Consequently, each site licensee is required to develop and implement a Nuclear Site Security Plan to ensure the security of its site.

8.3.3 These plans are subject to the scrutiny and approval of an independent security regulator, the Office for Nuclear Regulation - Civil Nuclear Security and Safeguards ("CNSS"), which is part of the ONR.

8.3.4 The comprehensive measures required include not just the physical aspects of the security regime (access control, alarms, monitoring, etc.) but armed response requirements and processes to ensure the reliability of staff and contractors to protect against the possibility of 'insider threat' and the security of computer systems. All are subject to prior approval, independent review and audit by ONR-CNSS.

8.3.5 All staff and contractors with access to nuclear sites are required to undergo security checks to a level which is dependent on the nature of their work. The assessment of individuals' reliability is an ongoing process. This assists in the provision of a level of protection against infiltration threats and insider threats.

8.3.6 Nuclear site licensees are under a legal requirement to undertake emergency exercises that demonstrate their ability to implement satisfactory contingency plans. Licensees must also exercise their security and counter-terrorist arrangements to the satisfaction of ONR-CNSS. More generally, operators and the regulator review security measures in line with current threat assessments, and the ONR-CNSS regularly inspects sites to ensure that the security arrangements detailed in security plans are being followed.

8.3.7 The UK Government invited nuclear security experts from the IAEA International Physical Protection Advisory Service mission to assess civil nuclear security arrangements in the UK. The mission visit took place in October 2011, with a follow up mission occurring in 2016. Its objectives included assessment of the UK's legal and regulatory framework on the physical protection of nuclear material and nuclear facilities and its compliance with IAEA guidelines. The IAEA concluded the state of civil nuclear security is sufficiently robust, including the legal and regulatory framework **[112]**.

8.3.8 Additionally, the Government has enacted legislation to provide additional protection beyond the substantial provisions described above. The Terrorism Act 2006 contains provisions which enable the UK to ratify the UN Convention for the Suppression of Acts of Nuclear Terrorism, which the UK signed in September 2005. The Terrorism Act 2006 makes it an offence to utilise radioactive materials or facilities for terrorist purposes. The Anti-Terrorism, Crime and Security Act 2001 provides for sanctions against the unauthorised disclosure of sensitive information on the security of nuclear sites, nuclear material and proliferation-sensitive nuclear technology.

8.3.9 The UK security regulatory framework has progressed towards a goal setting, outcomes based and performance measurement approach over the last decade. With regulatory guidance in the form of Security Assessment Principles ("SyAPs") being issued in 2017 and updated in 2021 **[113]**. SyAPs place greater onus on operators to propose and justify security arrangements that meet ONR defined security objectives.

Physical Protection and Design Features

8.3.10 The potential vulnerability of nuclear power stations to terrorists or other malicious threats is further reduced by the same design features that provide high levels of protection against the effects of postulated incidents and accidents. The same features that safeguard people and the environment from a radiation release also help to defend the nuclear power station from malicious threats.

8.3.11 Modern reactors are protected by large structures and are designed to safely withstand extreme events, both natural and man-made. Their structural resilience to earthquakes and the thickness of their shielding makes them extremely robust. Details of structural resilience for the RR SMR are identified in Annex 1.

8.3.12 Reactor fuel is made of ceramic pellets that are difficult to fragment and require strong nitric acid to dissolve. The pellets are highly durable, neither explosive nor volatile and are not easily broken up into breathable particles. They are enclosed in metal casings that are necessarily extremely strong and corrosion resistant to survive intact in the high temperatures and pressures of a reactor core. The reactor core, with its extensive steel and concrete shields, further protects the fuel.

8.3.13 Once removed from the reactor, the highly radioactive nature of the spent fuel means that specialised handling equipment is required. Outside the reactor buildings, this necessitates the transport of the fuel in very robust containers weighing over 100 tonnes. Accordingly, the risks of theft of spent fuel are very low.

8.3.14 In addition to their physical robustness, nuclear reactors are protected by extensive safety systems. The "Defence in Depth" concept applied to the design of safety systems means that it is unrealistic to be able to defeat or damage sufficient systems to bring about a significant release of radioactivity. Nonetheless, emergency arrangements are in place, and exercised, to make dynamic decisions if it is appropriate and safe to do so in relation to the immediate shut down of reactors in the event of a heightened terrorist threat against them.

Dirty Bombs

8.3.15 A "dirty bomb" is a mix of conventional explosives with radioactive powder or pellets. When the explosives are detonated, the blast carries radioactive material into the surrounding area. In order to construct and detonate a dirty bomb, radioactive material must first be acquired. Such radioactive material could come from the radioactive sources used worldwide for medical purposes and in research applications, and material held within secure nuclear power stations within spent fuel or intermediate level waste does not add significantly to this risk. The same design features and security measures that protect a nuclear power plant also ensure the security of radioactive materials from theft.

Conclusion

8.3.16 Accordingly, it is concluded that there are effective security provisions in place to protect against terrorism and other malicious acts and that therefore any potential detriment associated with security risks is low.

8.4 Industrial Safety

8.4.1 The nuclear industry applies high standards to all aspects of worker health and safety, both in relation to radiation exposures and general industrial safety. In 2016 the IAEA established requirements **[114]** that support establishing, sustaining and continuously improving leadership and management for safety and an integrated management system, in addition the World Association of Nuclear Operators ("WANO") annually report worldwide trends in the nuclear power station industrial safety record. These trends show steadily improving industrial safety performance that compares well to other industries **[115]**. Against this background, the potential industrial safety detriments relating to the Proposed Practice would be very low, and similar to or lower than those resulting from other major industrial infrastructure projects.

8.5 Impacts of Climate Change

8.5.1 The siting of new nuclear power stations takes into account the implications of climate change, including the possibility of more severe weather patterns and rising sea levels in costal locations.

8.5.2 Nuclear National Policy Statement (EN-6, Volume I) confirms that a flood risk assessment was undertaken as part of the Strategic Siting Assessment which identified the nuclear sites listed in EN-6 as potentially suitable for new nuclear development **[116]**. The climate change risk assessment concluded that they *"have the potential to be protected from the risks of flooding over their operational lifetime."* Any proposed development incorporating the Proposed Practice will need to incorporate climate change adaptation measures[148] to take account of the effects of climate change, including: coastal erosion and increased likelihood of storm surge and rising sea levels; effects of higher temperatures; and increased risk of drought, which could lead to a lack of available process water. This section provides further discussion of RR SMR capability.

Increases in Severe Weather Conditions

8.5.3 The RR SMR design is highly robust, with substantial capability to withstand extreme events such as high temperature, and so scope for any detriment to arise from more intense weather patterns is very small. This will be further confirmed for the RR SMR initially through the GDA process[149] and then for site specific projects as part of permissioning under the nuclear site licence.

8.5.4 Regarding the impact of more severe weather predicted to occur in the UK, the range of effects of such weather is already within the range sustained by nuclear power stations elsewhere in the world.

Flooding

8.5.5 Developers of new nuclear power station projects in the UK are required to demonstrate that projects are consistent with both general flood risk policies applicable to energy projects in Section 5.8 **[117]** of the Overarching National Policy Statement for Energy (EN-1), as well as the more conservative requirements for nuclear projects as set out in Section 3.6 of the Nuclear National Policy Statement (EN-6, Volume I) in order to be granted development consent. These require that adaptation to potential increases in flooding in the future may be required.

8.5.6 The approach that would likely be taken by a nuclear operator when preparing an application for a Development Consent Order can be broadly summarised as follows:[150]

- The first step is to quantify the flood risk over the expected construction, operation and decommissioning period of the power station. Quantification is based on a conservative assessment.
- The second step is to ensure that the nuclear power station is properly protected. There are two approaches to providing flood risk protection. Either the power station is sited above the highest predicted water level or it is provided with purpose-built sea defences and other flood defences that are designed to resist predicted extreme water levels. Flood defences are not necessarily confined to engineered structures but may also include "soft" measures such as vegetated embankments as part of the local shoreline management plan.

148] It is expected that when published EN-7 will empowering developers to select sites for nuclear development, rather than use those listed in EN-6. It will therefore be for implementing developers to ensure that their proposed site is acceptable against the criteria set out in the national policy statement. https://assets.publishing.service.gov.uk/media/659fa3313308d2000d1fbe04/nps-new-nuclear-siting-consultation.pdf

149] EN-6 confirms in Section 3.6 that "The GDA process looks at the capability of the power station's generic design features to take into account the effects of climate change".

150] An example of the considerations taken by the nuclear regulators (both environmental and nuclear safety) in assessment of the approach for Hinkley Point C, can be seen in "External Hazards Assessment to Inform Nuclear Site Licensing of Hinkley Point C", Office for Nuclear Regulation, Assessment Report: ONR-CNRP-AR-12-107, Revision 1, 14 December 2012. https://www.hse.gov.uk/nuclear/hinkley-point-c/assessment-reports.htm.

8.5.7 Any RR SMR will include robust flood defence provisions as outlined above. These would ensure that any new power stations involving the Proposed Practice would be protected from any increase in flooding risks due to climate change. A RR SMR power station would therefore be no more prone to flooding risk than an operating or another new build reactor.

Regulatory Requirements

8.5.8 The UK has robust regulatory requirements to ensure that climate change impacts are considered and adequate provisions are made to assure the safety of nuclear power plant, including those in the relevant National Policy Statements, as set out above.

8.5.9 Nuclear operators are responsible for funding their own flood risk management and coastal protection defences and for ensuring they are compatible with other defences in the area. This obligation remains in force until operation has ceased, and waste in interim storage has been removed from the site. As part of this, nuclear operators must cooperate with the relevant environmental regulators who have responsibility for flood risk management.

Predictions

8.5.10 A consistent understanding of potential climate change impacts for the UK is provided by UK Climate Projections **[118]**. Their projections are based on a methodology designed by the Met Office and reflect scientists' best understanding of how the climate system operates, it might change in the future, and allow a measure of the uncertainty in future climate projections to be included. UK Climate Projections is funded by Government (including the devolved administrations).

8.5.11 Demonstrating that the design can withstand external hazards and adapt to potential climate change is a key focus of the RR SMR. For the generic design, a Generic Site Envelope ("GSE") has been produced, which identifies all hazards, including those judged to be impacted by climate change and provides Climate Change Adjustment Factor ("CCAF") for those hazards (where applicable and suitably conservative) based on the UK Climate Projections 2018 ("UKCP18"). Use of UKCP18 is conservative and selection of the Representative Concentration Pathways ("RCPs") and percentiles is endorsed by UK regulatory authorities, which state that the medium emissions scenario at the 84th percentile is adequately conservative for defining a design basis. RR SMR Limited are following this guidance in selection of RCPs and percentiles. UKCP18 projections are aligned with the Inter-governmental Panel on Climate Change ("IPCC") but provide climate projections specific to the UK.

The Rolls-Royce SMR is designed to meet conservative external hazards requirements from the existing nuclear sites in Great Britain, more detailed hazard characterisation assessments accounting for climate change will be undertaken once a site is selected. RR SMR will develop a climate adaptation strategy for the site-specific plant to ensure the plant is resilient and the final site-specific design will allow the operator to develop and maintain climate change resilience through the lifetime of the power station. Having adaptation plans in place will ensure the plant can make any required changes in a timely manner. Re-characterisation of hazards incorporating a climate change allowance will be carried out periodically for the foreseeable lifetime of the plant based on the latest observations, RGP and most recent recommended projections, to determine whether the adaptation plans will be triggered.

Examples of hazards that are affected by climate change and the climate change values calculated using the UKCP18 RCPs to develop climate change projections are detailed in the GSE. The GSE presents the maximum and minimum dry bulb temperatures, (a CCAF has not been incorporated into the design for minimum dry bulb air temperature this would make the value higher and therefore less conservative). Additionally, heatwaves are discussed, and air temperature affected by climate change has been considered in the derivation of these values.

Table 16 is an extract from the GSE and shows examples of external hazards affected by climate change and the bounding values calculated. Not all the hazards in Table 1 are covered by UKCP18, and where this is the case the GSE has used other best available data. Flooding is not captured in the table as the values are site-specific.

Some simple examples of how the design is including climate change adaptations include sizing the Heating, Ventilation and Air Conditioning Systems ("HVAC"), which is generally sized to a relative humidity and wet bulb temperature. HVAC is being designed to accommodate the design basis value which includes a climate change adjustment factor. The Essential Services Water System ("ESWS") and structures like surface water drains are being designed to accommodate for climate change, and structures like door thresholds are being raised.

Table 16: Example external hazards impacted by climate change and bounding values used to support design

External Hazard	Parameter	GSE Value	Commentary
Air Temperature	Maximum dry bulb air temperature (hourly)	49.0 °C	Maximum air temp (not accounting for climate change) is 42 °C at Oldbury. A CCAF of +7 °C was determined from RCP 6.0 emissions scenario for a 90 % probability level to the year 2100
	Maximum wet bulb air temperature (hourly)	32.3 °C	Uses a relative humidity of 32 % and dry bulb temperature of 49.0 °C, with enthalpy of 111.4 kJ.kg-1. Proposed value bounds previous GDA assessments and European Utility Requirements (EUR)
	Minimum dry bulb air temperature	-35.0 °C	Corroborates and is bounding of available data (consistent with UK EPR)
Rainfall	15-minute rainfall depth	203.1 mm	Present day value taken as the bounding 15-minute and 1-hour depth from the UK EOR GDA of 145.1 mm and 163.7 mm respectively. Incorporates a CCAF which corresponds to a 40 % enhancement from the present day
	1 hour rainfall depth	229.2 mm	
	24-hour rainfall depth	400 mm	Proposed value from EUR. Found to be bounding of the largest present-day value with addition of a CCAF
Cooling Water Temperature	Maximum Sea Water Temperature	32.3 °C	Present day value bounding of available data (consistent with UK HPR1000 GDA Submission and Sizewell B stress test at 28 °C)

Development Consent

8.5.12 The Nuclear National Policy Statement (EN-7) and the Overarching National Policy Statement for Energy (EN-1) will provide the primary basis for development consent decisions taken by the Secretary of State (advised by the Planning Inspectorate) on applications it receives for nuclear power stations based on the Proposed Practice. As detailed above, these National Policy Statements explicitly require that an application for a Development Consent Order must include information as to how the development incorporates adaptation measures to take account of the effects of climate change. In assessing any proposed development, the Planning Inspectorate would be advised as to the adequacy of the applicant's proposed measures by the relevant environmental regulator (the EA in England or NRW in Wales) and the ONR.

8.5.13 Accordingly, there are robust processes in place to ensure that any proposal to deploy the Proposed Practice would only proceed if the ability to safely withstand the impacts of climate change were demonstrated.

Nuclear Safety

8.5.14 The ONR expects operators to provide a high standard of protection against flood risk and other external hazards, to ensure that facilities can withstand predicted sea level rises and increased storm surges. Operators are required to review the level of protection required against all external hazards every ten years as part of the facility's Periodic Safety Review required pursuant to standard nuclear site licence conditions. Each review will take the most recent climate change projections into account. It provides the basis for any necessary enhancements to plant provisions and operating arrangements to be identified and implemented to maintain the safety of the plant to the end of its life. This regular scrutiny and review ensures that any changes in external hazards are identified, and any necessary further measures are implemented.

Conclusion

8.5.15 As demonstrated above, the Proposed Practice presents no material climate change risks, and so will not affect the overall level of very low risk associated with the RR SMR. Accordingly, any potential detriment associated with the effects of climate change is very low.

8.6 Considerations of Extreme Events and Severe Accidents

8.6.1 Since our 2013 Application, the war in Ukraine has shown how nuclear power stations can be affected by extreme events.

8.6.2 Additionally, the 2011 Fukushima accident in Japan, resulting from a massive earthquake and tsunami, highlighted the potential for multi-unit nuclear power stations to be affected by extreme natural disasters and for a severe accident to adversely impact cooling and long-term electrical power supplies.

8.6.3 Annex 5 provides more detailed information underlying our unchanged conclusion that the risk of significant detriments from extreme events and severe accidents is low. The Annex provides a discussion of the factors underlying this conclusion, which are:

- The capability and resilience of UK plants that is being further enhanced in the light of lessons from Fukushima;
- The commitment of UK operators to nuclear safety;
- Stress tests conducted on EU nuclear installations in response to Fukushima to ensure that any further improvements to the resilience of plants were identified for implementation; and
- The robustness of the regulatory regime and the independence and effectiveness of the UK nuclear regulator in promoting and overseeing high levels of governance in the nuclear industry.

8.6.4 Annex 5 also reviews previous reactor accidents and concludes that the measures described in this Application in Annexes 1 and 5 ensure that the risk of a severe accident involving the Proposed Practice and the resulting detriments are very low.

8.7 Overall Conclusion

8.7.1 The considerations in this Chapter lead the applicant to conclude that:

- There would be little change to the existing, very small, proliferation risks.
- Security measures would provide protection against terrorism and other malicious acts.
- Stringent health and safety standards would provide a safe workplace.
- Stations would be protected against the effects of climate change.
- The risks of detriment from a severe accident, even following an extreme event, would be very low.

8.7.2 For these reasons, the wider impacts resulting from adoption of the Proposed Practice would result in no significant detriments.

9: SUMMARY OF BENEFITS AGAINST RADIOLOGICAL HEALTH DETRIMENTS

9.1.1 This Application has described the benefits and detriments to the UK associated with implementing the Proposed Practice, together with its potential radiological health detriments. This final Chapter 9 draws these benefits and detriments together and concludes that the individual and societal benefits net of all non-radiological detriments of the Proposed Practice significantly outweigh the potential radiological health detriments that it may cause.

9.1.2 Our approach here is to assess the broad scale of the individual and societal benefits resulting from the Proposed Practice, and to compare this with the scale of the potential radiological health detriments it may cause. As we judge the benefits relating to security of supply and carbon reduction to be so significant, we have not attempted in this Application to detail or rely on any other potential benefits that might also arise. We have, however, sought to consider the full range of potential detriments that could in theory counter the significant benefits of the Proposed Practice.

Security of Supply Benefits

9.1.3 By providing an SMR for firm, dispatchable energy generation, RR SMR plants would help to achieve the diverse generation mix sought by the Government which will increase the resilience of the UK's energy system.

9.1.4 Sufficient uranium is available to fuel existing and potential new power stations. The relatively small volume of nuclear fuel required for electricity generation means that nuclear fuel can be stockpiled if future supply becomes uncertain.

9.1.5 For these reasons, the Proposed Practice would contribute significantly to the UK's energy security, representing a major benefit of the Proposed Practice.

Carbon Reduction Benefits

9.1.6 There is a scientific consensus that human activities are causing global climate change by adding greenhouse gases to the atmosphere. The UK has established legally binding climate change targets requiring that the net UK carbon account for the year 2050 is at least 100% lower than the 1990 baseline. This will require the UK to significantly reduce its dependence on fossil fuels.

9.1.7 Nuclear power is a low carbon-generating technology, with emissions across the entire life cycle of a nuclear plant comparable to those from renewable resources. Over the past 50 years, the use of nuclear power has reduced CO_2 emissions by over 60 gigatonnes[151]—nearly two years' worth of global energy-related emissions.

9.1.8 For these reasons, the Proposed Practice would contribute significantly towards meeting the UK's carbon reduction obligations, representing a further major benefit from the Proposed Practice.

Consideration of Potential Detriments

9.1.9 We now consider whether there are any detriments that are significant enough to counter the major benefits that have been identified above. Our Application sets out the extensive regulatory provisions and high levels of governance that are in place to ensure that the detriments we describe will be managed to the levels that we describe.

Economic Assessment

9.1.10 When data relating to the costs of nuclear energy is compared with data relating to the costs of other generation technology, it can be seen that SMRs are expected to remain a competitive form of generation, particularly when compared against other low carbon technologies.

9.1.11 Furthermore, the introduction of the Nuclear Regulated Asset Base model by the Nuclear Energy (Financing) Act 2022 provides a mechanism for the Government to determine, through its negotiations with individual nuclear developers, whether it considers that an individual project will represent value for money and be a cost-effective addition to the UK generation mix.

9.1.12 As the risk of a nuclear accident in the UK is very low, the risk of detriment to the UK economy arising from the economic costs associated with a nuclear accident is correspondingly low.

151] https://www.iea.org/reports/nuclear-power-in-a-clean-energy-system

9.1.13 For these reasons, the risk of a significant detriment to the UK economy from the Proposed Practice is very low. When security of supply and carbon reduction benefits are taken into account, adoption of the Proposed Practice is likely to be beneficial for the UK economy.

Radioactive Waste, Spent Fuel and Decommissioning

9.1.14 New nuclear power stations in the UK would create a manageable amount of additional radioactive waste. The types of waste and spent fuel created would be similar to the types of waste that are produced by existing nuclear power stations, and for which management and interim storage solutions currently exist. The Government is firmly committed to geological disposal and is confident that the 'Implementing Geological Disposal' **[119]** framework will be implemented. Outside the UK, there is also considerable and growing international experience in managing nuclear waste.

9.1.15 The HLW and spent fuel arising from the Proposed Practice could be disposed of within a GDF and this could be safely stored until this repository becomes available. Any additional excavation within the repository that would be required to accommodate the additional waste material would not represent a significant detriment to the UK.

9.1.16 The process of decommissioning nuclear facilities is now well understood and there is extensive and growing international experience in this regard.

9.1.17 Nuclear liabilities associated with radioactive waste management and decommissioning are the ultimate responsibility of the site licence holder. The Government has legislation in place which requires the Operator to have an approved FDP before plant construction can begin. The FDP helps the Government ensure that secure financing arrangements are in place to meet the full cost of waste management and decommissioning without recourse to public funds.

9.1.18 For these reasons, there can be confidence that the overall detriment from radioactive waste, spent fuel and decommissioning associated with the Proposed Practice would be small.

Wider Environmental Impacts

9.1.19 Other environmental impacts would be lower than those associated with other large-scale electricity generation. They would be properly addressed and mitigated. The RR SMR would meet all applicable standards and regulations.

9.1.20 For these reasons, the overall environmental impacts, and the associated detriment from the Proposed Practice in this area, would be low.

Other Considerations

9.1.21 There would be little change to the existing small risks associated with proliferation.

9.1.22 There are effective security provisions and regulations in place to protect against terrorism and other malicious acts and therefore any potential detriment associated with security risks would be low. Similarly, nuclear power stations are protected against the effects of climate change by the current regulatory framework.

9.1.23 Existing stringent health and safety standards would provide for a safe workplace in nuclear power stations, and the risk of accidents would be very low.

9.1.24 For these reasons, there are no other considerations which suggest that the adoption of the Proposed Practice would result in a significant detriment to the UK.

Summary of "Net Benefit"

9.1.25 Having considered all of the above potential detriments, none have been identified which could, either alone or when combined with other non-radiological detriments, be of sufficient scale to detract significantly from the major benefits to the UK that the Proposed Practice would bring.

Scale of Potential Radiological Health Effects

9.1.26 RR SMR power stations and their associated processes would be capable of meeting all applicable radiation dose limits and constraints. The regulatory system governing the Proposed Practice would ensure, following optimisation, that doses fall further below these limits. We estimate that the additional annual dose to a member of the public most affected would be very low and of the same order as for a person taking one additional annual return air flight from the UK to New York.

9.1.27 Doses to workers as a result of the Proposed Practice would be low. They would be comparable with, or lower than, those to which workers in the nuclear power industry (and other industries which entail radiation exposure, such as the airline industry) are currently exposed.

9.1.28 Stringent safety and security requirements would ensure that the likelihood of an accident leading to a significant release of radioactive material would be very remote. RR SMRs would have a very low risk of accidents with risk levels demonstrated to be as low as reasonably practicable. For these reasons, the overall radiological health detriment of the Proposed Practice would be very low.

Overall Conclusion

9.1.29 The security of supply and low carbon benefits for the UK from the Proposed Practice are very significant. Consideration of a wide range of potential detriments has confirmed that, even without relying on the full effects of optimisation, the potential health and other detriments associated with the Proposed Practice are low and significantly outweighed by the associated benefits.

9.1.30 The Applicant therefore concludes that the Proposed Practice should be justified.

10: ANNEX 1 - DESCRIPTION OF THE ROLLS ROYCE SMR

10.1 Introduction

RR SMR Overview

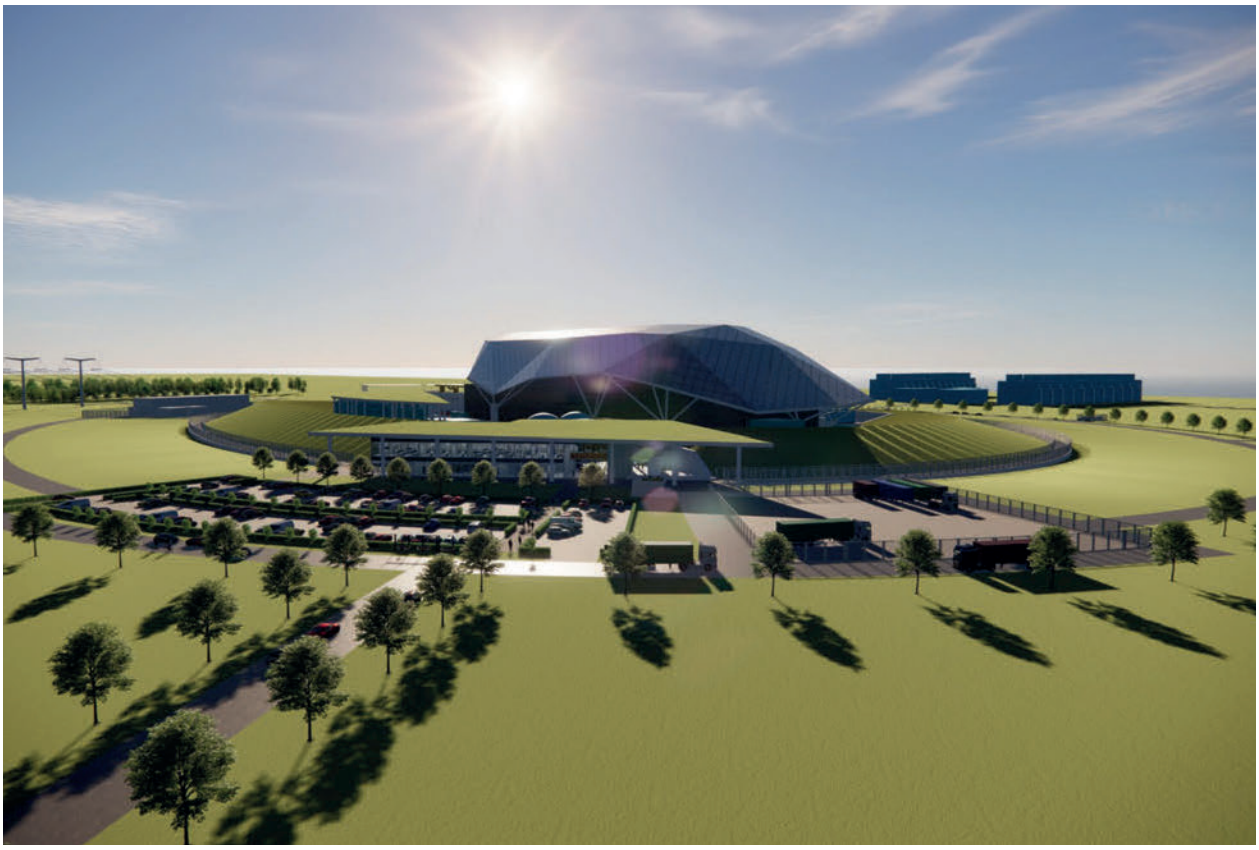
10.1.1 The RR SMR is an investable and globally scalable SMR power plant that leverages proven PWR technology and innovation in delivery to provide a deliverable and low-cost power solution. The RR SMR has been designed to maximise constructability, operability and resistance to natural and man-made hazards, whilst maintaining a compact primary power plant site footprint.

10.1.2 The RR SMR comprises a single unit, three-loop PWR which provides a nominal power output of 470 MWe per unit using industry standard 4.95% enriched Uranium dioxide (UO_2) fuel. The design includes multiple active and passive safety systems, each with substantial internal redundancy.

10.1.3 Each RR SMR power plant consists of the following key areas, with Civil Structures and Control and Instrumentation systems being distributed across the following main process areas:

- **Reactor Island –** includes the Structures, Systems and Components ("SSCs") that form the reactor, transfer and storage of new and used fuel, and any associated nuclear auxiliary systems. The purpose of the Reactor Island (RI) is to use the heat from a controlled nuclear fission reaction to generate steam, which is then passed to the Turbine Island.
- **Turbine Island –** provides the link with RI where steam is generated. The primary equipment in the Turbine Island is the Main Steam Turbine Generator and ancillary systems. The RI feeds steam to a single turbine train comprising one high pressure stage and two low pressure stages.
- **Cooling Water Island –** provides the primary means of removing heat from the power station. The generic (baseline) design uses indirect cooling: the system uses the atmosphere as its heat sink using evaporative cooling towers. The RR SMR can be provided with other direct cooling solutions to meet the site-specific conditions.
- **Electrical Systems –** includes systems relating to grid connection and intra-site electrical distribution, including emergency power supplies.
- **Balance of Plant –** provides a range of ancillary functions to support the ongoing availability of the power station and provide functions such as supply of demineralised water and chemicals.

Figure 6: Site Vision Image



10.1.4 The RR SMR in totality is a First of a Fleet design and not based on a currently operating reference plant. The design is however fundamentally based on proven PWR technology, using industry standard uranium fuel. The RR SMR programme commenced in 2016, with key design principles established early that were driven by market requirements and lessons learnt from previous nuclear power plant programmes. This led to 20 key design objectives being established for RR SMR, which have been consistently applied as the basis for design optioneering.

10.1.5 The whole power station is constructed using around 1,500 standard transportable modules manufactured and tested in off-site factories to minimise activity on site. The modules will fall within three categories or 'types': heavy pressure vessels, mechanical electrical and plumbing and civil engineering. The modules will be assembled on location within a compact site footprint. Each RR SMR unit will fit within a site 'canopy' measuring 21,500 m² or 5.3 acres.

Figure 7: Example of Module Clusters

10.1.6 The main innovations for RR SMR are in the fabrication and construction of the modular nuclear plant, incorporating use of proven techniques and relevant good practice ("RGP") from other industries. In comparison to existing PWR power stations, the RR SMR incorporates notable innovations that provide benefits with respect to safety, including:

- Passive and diverse heat removal systems (the Emergency Core Cooling System ("ECCS") and Passive Decay Heat Removal ("PDHR")) to provide decay heat removal in response to fault conditions, each with significant internal redundancy, and with no reliance on essential services supplied from onsite mobile equipment for 72 hours or from off site for 7 days.
- Boron-free chemistry, with full shutdown margin provided by the control rods alone, which allows for a simplified design with a reduction in human error induced faults, and eliminates risks associated with boric acid, boron dilution faults, and the environmental impact of boron discharge. It also enables the use of potassium hydroxide as the pH raiser, rather than lithium hydroxide that is used in conjunction with boric acid in traditional PWRs, offering potential benefits such as mitigation of fuel cladding corrosion and reduction in the tritium source term.
- A base isolation system, which reduces the seismic hazard for the RI and adjacent safety significant structures. By means of an aseismic bearing, the base isolation provides attenuation of the horizontal seismic ground motion to limit the peak acceleration transmitted to the structures located above it.
- A forced draught cooling system, which is adaptable to different cooling water constraints such that the RR SMR is deployable across a wide range of sites.
- Emergency blowdown relies on a mechanical valve design that provides reactor coolant relief in conditions where ECCS is demanded. The design of this valve practically eliminates a spurious opening of the blowdown line fault and minimises the safety requirements placed onto the Control and Instrumentation systems.

10.1.7 Additionally, the RR SMR will incorporate new features to deliver a higher level of protection against severe external hazards beyond the design basis as described in this document. This includes post-Fukushima countermeasures from the lessons learned and aircraft crash countermeasures.

10.1.8 The RR SMR is now being assessed under the GDA process. It is expected that the regulators' (ONR, EA and NRW) GDA Step 1 and 2 assessment reports will be available to inform the Secretary of State's decision on the RR SMR Regulatory Justification Application.

10.1.9 Key Technical Parameters for RR SMR are presented in Table 17.

Table 17: Key Technical Parameters of RR SMR

Parameter	Value
Reactor type	Pressurised water reactor - 3-loop compact PWR based on proven technology. Boron-free design to reduce environmental impact.
Electrical capacity (MWe)	470
Thermal capacity (MWth)	1358
Expected capacity factor (%)	>92.5
Design life (years)	60
Power conversion process	Rankine cycle
Cogeneration capability	Possible configuration
Passive safety features	Yes
Active safety features	Yes
Fuel type / assembly array	Industry standard UO_2, 4.95 % maximum enrichment in 17x17 array
Fuel cycle (months)	18-24
Emergency safety systems	Passive and Active
Refuelling outage (days)	20

10.2 About Rolls-Royce SMR Limited

10.2.1 Rolls-Royce SMR Limited has been established as an independent company, drawing on decades of Rolls-Royce experience in nuclear design and engineering, while capturing industry leading expertise, support from the UK Government and investment from world class companies. Investors in Rolls-Royce SMR Limited are:

- Rolls Royce plc: one of the world's leading industrial technology companies. It has led the design, development, and the investment programme to secure equity for Rolls-Royce SMR Limited. Rolls-Royce plc remains the majority shareholder.
- BNF Resources Limited forms part of a family office with extensive investments in the energy space. The company is represented and advised by BNF Capital Limited, an FCA regulated investment advisory business based in the UK.
- Constellation is the United States' largest producer of carbon-free energy and the leading competitive retail supplier of power and energy products and services for homes and businesses across the United States. Headquartered in Baltimore, its generation fleet powers more than 20 million homes and businesses and is helping to accelerate the nation's transition to clean energy with more than 32,400 megawatts of capacity and annual output that is 90 percent carbon-free. Constellation has set a goal to eliminate 100 percent of its greenhouse gas emissions by leveraging innovative technology and enhancing its diverse mix of hydro, wind and solar resources paired with the nation's largest carbon-free nuclear fleet. Constellation's family of retail businesses serves approximately 2 million residential, public sector and business customers, including three quarters of the Fortune 100.

- Qatar Investment Authority ("QIA") is the sovereign wealth fund of the State of Qatar. QIA invests across a wide range of asset classes and regions as well as in partnership with leading institutions around the world to build a global and diversified investment portfolio with a long-term perspective that can deliver sustainable returns and contribute to the prosperity of the State of Qatar.
- UKRI Innovate UK is a non-departmental public body sponsored by the Department for Science, Innovation and Technology. UKRI Innovate UK is the UK's largest public funder of research and innovation. UKRI Innovate UK supported Phase I of the RR SMR development through a match fund provision of £18 million and will provide up to £215 million in match funding to support research and development aspects of the GDA process in Phase II.

10.2.2 Rolls-Royce SMR Limited are the vendor of the integrated nuclear power station. Rolls-Royce SMR Limited are also the Requesting Party for the technology that is submitted into the GDA process.

10.3 Plant Design

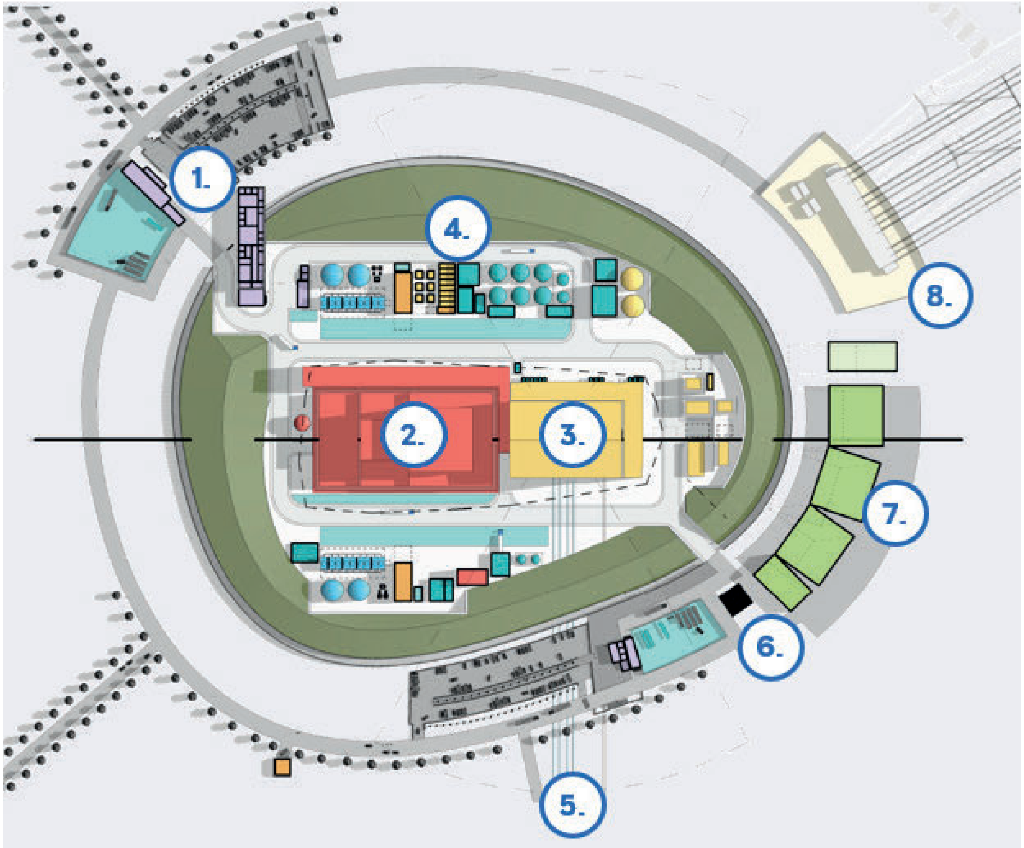
Plant Layout

10.3.1 The Generic Site layout of a RR SMR is illustrated in Figure 8, which shows the major facilities comprising the RI, Turbine Island and Balance of Plant ("BOP"). All facilities containing radioactive substances have been designed with physical robustness and provided with shielding to minimise radiation exposure.

Figure 8: Layout of RR SMR

Key

1. Main Entrance & Admin Building
2. Reactor Island (RI)
3. Turbine Island & Main Electrical Buildings
4. Balance of Plant
5. Cooling Water Island
6. Alternative Entrance
7. Dry Cask Stores
8. External Grid Connection

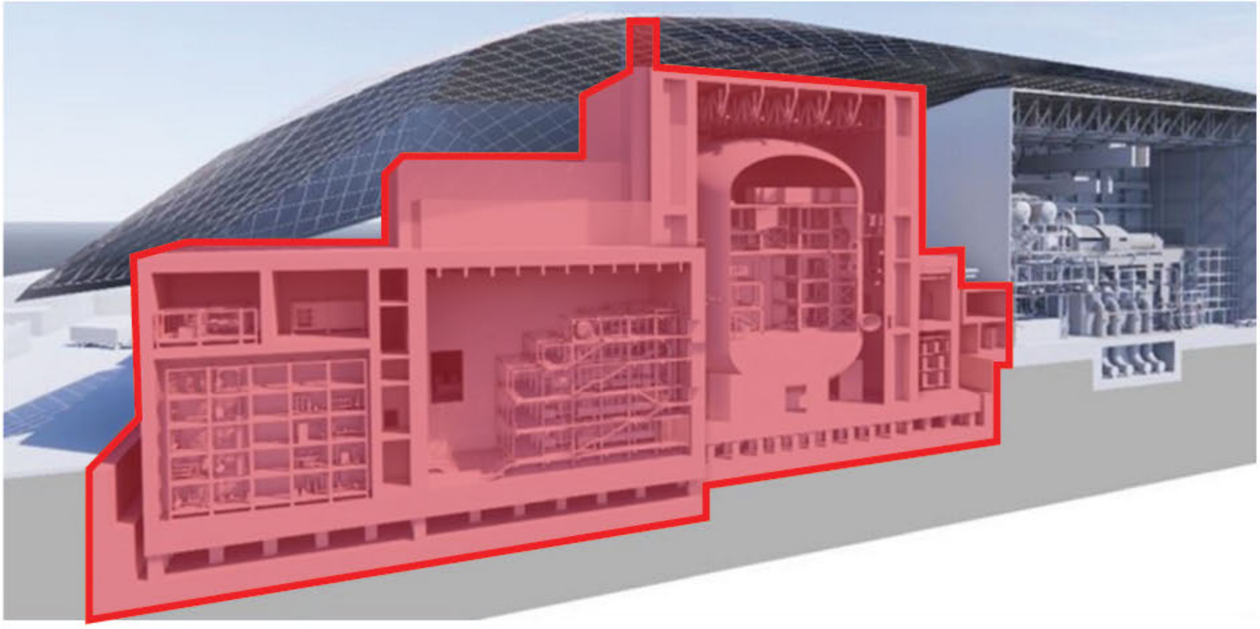


Reactor Island

10.3.2 The RI comprises a number of concrete structures providing support, and protection, to mechanical and electrical services housed within an arrangement of steel support modules.

10.3.3 The RI is approximately 90 m long, 75 m wide, and extends 40m above ground level. A section through RI is illustrated in Figure 9.

Figure 9: Cross-Section through Reactor Island



10.3.4 Principal RI structures are described within this Annex 1, namely:

- Reactor Assembly;
- Reactor Coolant System;
- The Containment Vessel;
- The Hazard Shield; and
- Seismic Isolation System.

10.3.5 Other systems within Reactor Island include:

- Waste Processing Block;
- Access Block;
- Outage Block;
- Auxiliary Block;
- Safety Fluid Systems;
- Fuelling Block; and
- Electrical, Control and Instrumentation systems including the Main Control Room ("MCR").

Reactor Assembly

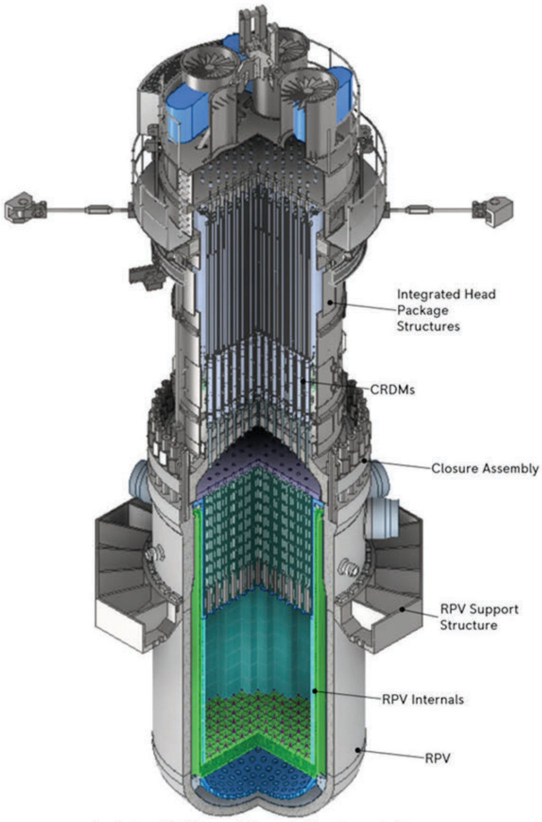
10.3.6 The Reactor Pressure Vessel ("RPV") body forms the external vessel for housing the RPV internals, containing the Reactor Core and interfacing with the Reactor Coolant System ("RCS") loops, thereby allowing cold coolant to flow into the core and hot coolant to flow out to the Steam Generators ("SGs").

10.3.7 The RPV body forms the main mechanical support structure for the RPV internals, RPV closure head and Integrated Head Package ("IHP"), together forming the reactor assembly.

10.3.8 The RPV is a Very High Reliability ("VHR") component designed and constructed in accordance with the requirements of the American Society of Mechanical Engineers ("ASME") Boiler Pressure Vessel Code Section III Subsection NB, plus the additional controls necessary for a VHR component.

10.3.9 To allow for core load, the RPV requires includes a removable Closure Head. When in place, the Closure Head completes the pressure boundary for the Reactor System. The Closure Head is part of the IHP which performs several functions including housing the Control Rod Drive Mechanisms ("CRDMs") and passing services to the top of the RPV. Figure 10 presents the key features of the RPV and IHP.

Figure 10: Cross-Section of Reactor Assembly



Reactor Coolant System

10.3.10 The RR SMR Reactor Coolant System consists of three vertical u-tube Steam Generators ("SGs") with associated pipework loops and a single pump in each loop, mounted directly to the SG outlet nozzle. The configuration of the SG, pipework and pump layout in each loop ensures a robust thermal driving head for natural circulation flow in faulted operation. In addition, the system includes a pressurising system, and associated overpressure protection equipment. The design includes multiple active and passive safety systems, each with substantial internal redundancy.

10.3.11 The Reactor Core produces 1358 MWth and has been sized to maximise power output within an RPV that is road transportable. A further 9 MWth is produced by the operation of the Reactor Coolant Pumps ("RCPs"). Heated coolant is transferred to three vertical u-tube SGs, each rated to remove approximately 456 MWth during normal power operation. The configuration of the RCS is illustrated in Figure 11. The arrangement selected is beneficial as it minimises containment size and reduces the water volume required for the purposes of plant protection, providing reductions in plant cost.

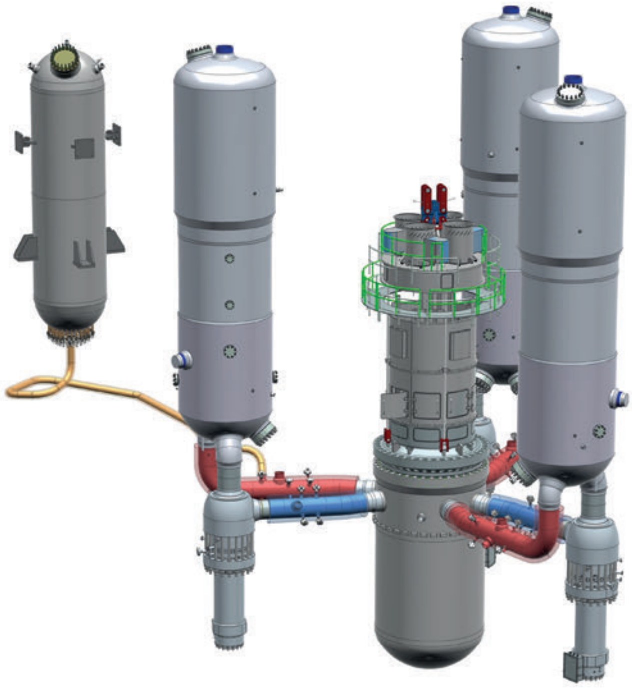
10.3.12 The RCS has been designed in accordance with ASME Boiler and Pressure Vessel Code Section III – Rules for Construction of Nuclear Facility Components **[120]**, which provides the minimum requirements for assurance of integrity of the reactor coolant pressure boundary; this governs the design analysis, materials, fabrication, examination, pressure testing and overpressure protection of the reactor circuit. In addition, there are certain components which have failure modes that may preclude the successful operation of safety systems e.g. catastrophic failure of the RPV. For these components, there are additional requirements on the structural integrity case which include more stringent controls in manufacture, additional fracture mechanics assessment and rigorous qualification of the manufacturing inspections.

10.3.13 The pressuriser is a vertical cylindrical vessel with hemispherical ends, which operates with a mixture of steam and water in equilibrium to provide the necessary overpressure to prevent boiling of the fluid in the RCS. To increase plant pressure, steam is generated by electrical heaters contained within the lower section of the vessel.

10.3.14 To reduce plant pressure, the Reactor Coolant Pressurising System uses a pump induced spray system; when demanded by the RI Control and Protection System, a spray initiation valve in the spray line opens, which allows coolant to enter the top of the pressuriser via a single spray nozzle to condense steam in the vessel, reducing pressure to the required level. The system design contains two main spray lines, each fed from separate RCS loops via the Chemistry Volume Control System. The spray line which is aligned to the pressuriser is alternated following each maintenance period to minimise thermal fatigue and to meet the 60-year design life requirement of the power plant.

10.3.15 As well as providing RCS over pressure, fluctuations in reactor coolant volume resulting from power changes or routine make-up and let-down are accommodated. Contractions in reactor coolant volume are accommodated through the supply of coolant from the Pressuriser to the RCS Pipework via the Surge Line (and vice versa for reactor coolant expansion). The Pressuriser is sized to provide robust and passive fault response for bounding faults, with accidents causing either rapid and significant cooldown or heat-up accommodated.

Figure 11: Overview of the RCS



Containment Vessel

10.3.16 The principal component of the Containment System is the Containment Vessel ("CV") which is a large free standing steel pressure vessel, with a cylindrical shell and two semi-ellipsoidal domes.

10.3.17 Containment access and egress is provided by two personnel airlocks and a main equipment access hatch.

10.3.18 The Fuel Transfer Channel ("FTC") passes through the lower dome and is embedded in the Containment Internal Structures. The FTC facilitates the transfer of Fuel Assemblies and other equipment by providing leak-tight passage between the Refuelling Pool (inside containment) and the Spent Fuel Pool ("SFP") (outside containment). Piping penetrations and electrical penetration assemblies provide leak-tight passage for fluid system piping and electrical systems across the containment boundary.

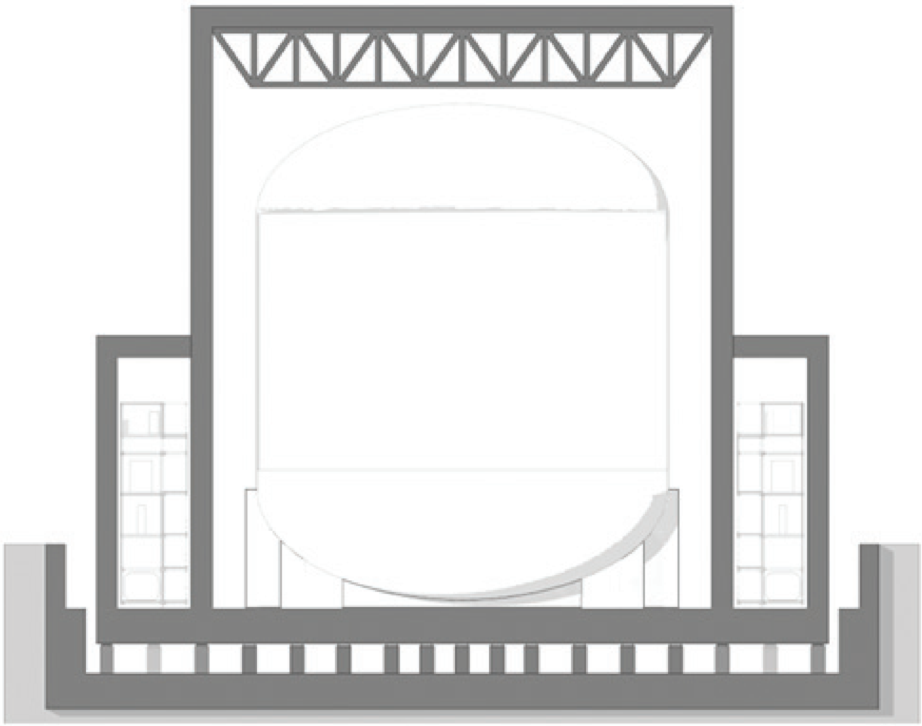
10.3.19 The CV has been designed to minimise penetrations and all penetrations meet the same design requirements for leak tightness and structural integrity as the containment structure itself.

10.3.20 Internally the Containment Vessel lower dome contains reinforced concrete civil works that form the reactor cavity, refuelling pool and main containment sumps. The primary function of the containment structure is to support and house the RPV and RCS and provide a load path for mechanical, electrical and plumbing module stacks and other SSCs in containment to the RI raft foundation. Vertical and horizontal loads acting on the CV are transferred to the CV support structure via shear studs, bearing faces and friction. This means that the lower dome of the Containment Vessel and part of the lower cylindrical shell is embedded in concrete internally and externally. The aseismic bearings beneath attenuate accelerations in the horizontal plane which makes the design less site dependent.

10.3.21 The main function of the Containment Support Structure ("CSS") is to support the CV and Containment Internal Structures, under all load cases, in all plant operating, fault and accident states. The CSS sits on the Basemat and is comprised of a central plinth of reinforced concrete with three outer plinths of reinforced concrete.

10.3.22 The division of the CSS into the central support and outer supports provides space for lifting, temporary support levelling, and welding of the CV lower dome (which is installed in two parts) and access through-life for inspection and maintenance. A section showing the CSS is shown in Figure 12.

Figure 12: Containment Support Structure section



10.3.23 The construction of the CSS is sequenced to align with the CV installation and welding. The CSS is partly constructed prior to lifting the first part of the vessel lower dome. The final construction phase of the CSS follows the welding of the CV lower dome parts and the first cylindrical section. This final step of concrete pours and grouting completes the embedment of the vessel into the plinths. Modular prefabrication of reinforcement will be used to reduce the duration of these activities on site.

10.3.24 The Reactor and reactor coolant systems are contained within the CV.

Hazard Shield

10.3.25 The Hazard Shield is a large, reinforced concrete structure that has the primary function of protecting safety critical SSCs from external hazards and providing protection against accidental and malicious aircraft impact. The Hazard Shield is founded on the Basemat.

10.3.26 The Hazard Shield is approximately 88 m (E-W) by 65 m (N-S) and extends 45 m above ground level as shown in Figure 13. The Hazard Shield is 1.8 m thick and comprises reinforced concrete walls supporting reinforced concrete roof slabs. The roof slab over the CV is further supported on a series of steel trusses which are designed to act compositely with the slab.

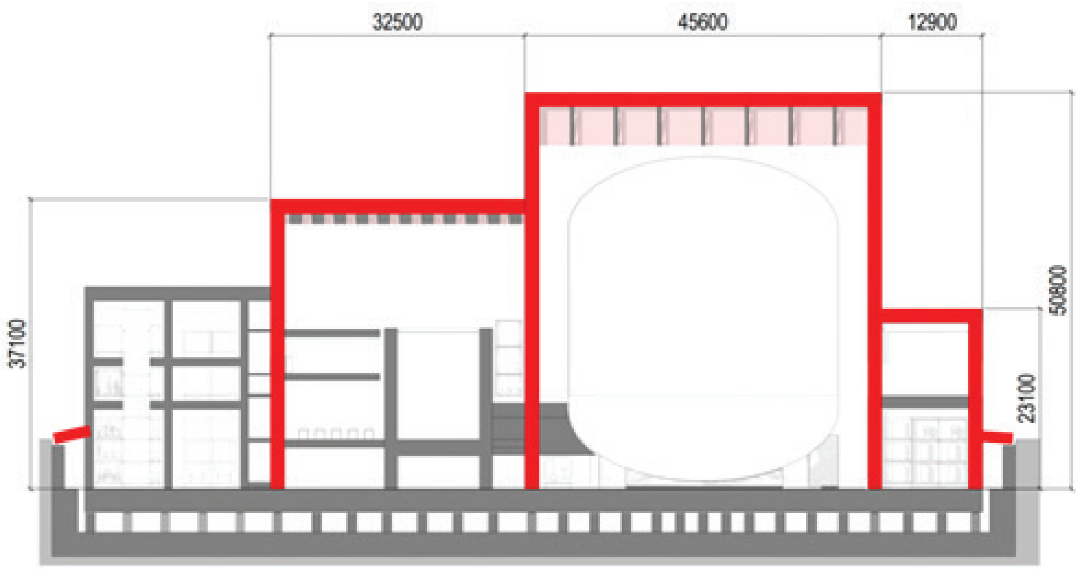
10.3.27 A series of internal walls divides the Hazard Shield into blocks and provide structural support to the exterior wall panels. To further improve the design efficiency of the Hazard Shield walls around Containment, buttresses have been provided as shown in Figure 14. The buttresses fulfil the dual-purpose of offering structural support to the Hazard Shield roof spans as well as providing inherent separation and segregation between SSCs located within them.

10.3.28 The extent of the Hazard Shield also includes impact protection structures that are found on the external boundary of the Hazard Shield. The function of these structures is to prevent physical debris and fuel ingress past the Hazard Shield boundary through any openings following external hazards including explosions or missile impact e.g. aircraft impact.

10.3.29 Extending horizontally from the external Hazard Shield walls at ground level is a skirting structure that will span over the gap between the Hazard Shield and the top of retaining wall. This will protect the Aseismic Bearing gallery beneath the Basemat from weather, detritus, and ingress of flammable liquids.

10.3.30 Finally, an effluent stack structure extends vertically from its base supported off the Hazard Shield roof to a sufficient height which allows gaseous discharges containing a suitably low concentration of radioactive material to be dispersed.

Figure 13: Hazard Shield Section

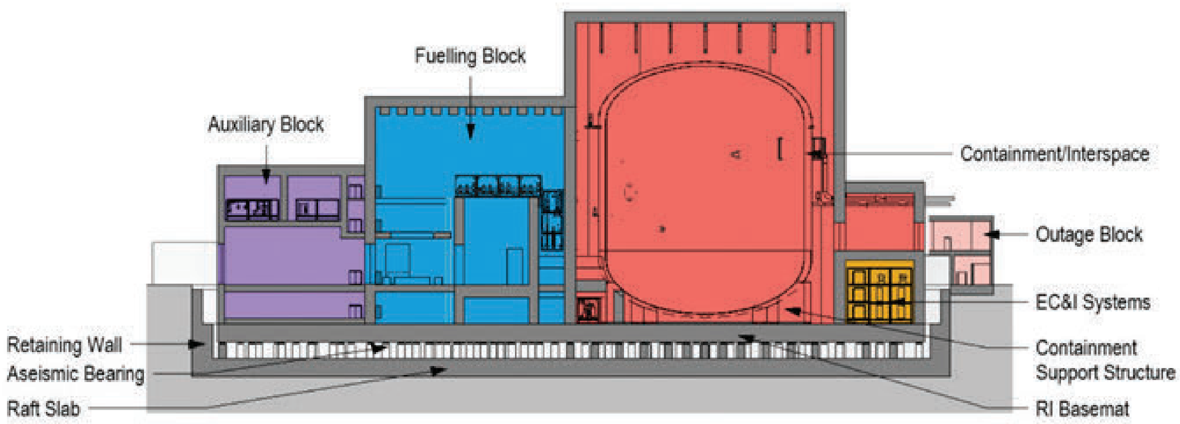


Seismic Isolation System

10.3.31 The Seismic Isolation System ("SIS") is a RI structure which protects SSCs required for the fulfilment of Fundamental Safety Functions ("FSFs") from horizontal accelerations during a Design Basis Earthquake. The inclusion of the SIS in the RR SMR design is intended to remove a significant amount of site dependency from the plant and layout design.

10.3.32 The SIS is supported from the reinforced concrete raft foundation and is comprised of a series of pedestals and aseismic bearings, which support the Basemat. The Basemat in turn supports the Hazard Shield and the contents of the Hazard Shield as illustrated in Figure 9.

Figure 14: Cross-Section through Reactor Island Structures



Fuelling Block

10.3.33 The Fuelling Block is located within the Hazard Shield of the RI, west of the CV and the Interspace. The Safety Fluid Systems—Train 1 and Train 2—are segregated north and south of the Fuelling Block respectively, in line with internal and external hazards principles.

10.3.34 The Fuelling Block contains several safety systems that perform functions associated with Reactor Plant, Handling of Nuclear Equipment and Nuclear Auxiliary Systems.

Main Control Room

10.3.35 The MCR is specifically designed to be operable and habitable under external and internal hazards with an endurance period for up to 7 days of habitability under accident conditions. Located within the Hazard Shield the MCR is capable of accommodating personnel through a number of design basis and severe accident scenarios including, for example, seismic events, radiation releases, tornadic missiles, jet impact, fire and explosions and provides provision for bringing the power station to a safe state.

10.3.36 The design of the control room is based on international standards, ONR Safety Assessment Principles, British Standards and RGP. The Control Room includes consideration of a wide range of possible operator characteristics and is laid out to ensure visibility of critical information and prevent. The control rooms are designed to have diverse access and egress routes and are secured against unauthorised access.

Turbine Island

10.3.37 The Main Steam System ("MSS") for the RI runs from the outlet of the SGs to a combined steam header within the Turbine Island. For each RR SMR, the steam raised in each of the three SGs is transported via a common header by the MSS to a single Main Turbine Generator System.

10.3.38 The RR SMR employs a full-speed wet Steam Turbine to generate electricity at 50 Hz. During normal operation, steam is sent to the High Pressure ("HP") Turbine where the energy within the steam is converted to mechanical rotational energy of the Turbine shaft.

10.3.39 Steam from the SGs passes through the double-flow HP Turbine and into the Moisture Separator and Dual-Stage Reheater. The steam is superheated before entering a further two parallel double-flow Low Pressure ("LP") Turbines connected to the HP Turbine rotor shaft.

10.3.40 As energy is removed from the steam in the Turbine, the thermodynamic conditions change where the pressure is reduced, and the moisture content is increased. As the HP Turbine exhaust conditions are no longer desirable for the LP Turbine, the steam is directed to the Moisture Separator Reheater through the Cold Reheat pipework, where excess moisture is removed, and the temperature is increased to a superheated state. Removing the excess moisture before the LP Turbine improves the life of the LP Turbine and reduces the severity of blade erosion.

10.3.41 Steam leaves the MSR through the Hot Reheat ("HRH") pipework where it is distributed to two LP Turbine sections and the energy within the steam is converted to rotational energy. The LP Turbines exhaust into the Main Condensers where the remaining energy is transferred to the Main Circulating Water System. The pressure within the Main Condensers is maintained as low as practicable to ensure that the LP Turbines extract the maximum energy from the steam. This also ensures maximum cycle efficiency is achieved.

10.3.42 During normal operation, steam is taken from the HRH pipework and used within the Deaerators as a means of raising the feedwater temperature to saturation and removing dissolved oxygen. During start-up, this is facilitated by the Auxiliary Steam System in the first instance, then the main steam once steam conditions are adequate.

10.3.43 Further details of the Steam and Power Conversion Systems are presented later in this Annex.

Cooling Water Island

10.3.44 The main cooling water system is a site-specific design. That is the RR SMR is designed to accommodate differences in siting constraints and apply the BAT in the context of a given site. The solution presented for the Generic Site is an indirect cooling solution based on Mechanical Draft Cooling Towers.

10.3.45 The Main Cooling Waster System ("MCWS") for the generic design is a closed loop system in which water is circulated between the condenser and a suite of Mechanical Draft Cooling Towers. The cooling towers spray the water against a parallel forced air draft in the opposite direction to the spray, this results in a proportion of the circulating water evaporating into the air stream, cooling the falling water by extracting the energy of evaporation for the remainder of the stream. As a consequence of the evaporation, impurities in the circulating water are concentrated.

10.3.46 To manage water quality some of the circulating water needs to discharge as Blowdown, this concentrated water is discharged back to the water source from which it was extracted. To compensate for blowdown and evaporation in the system, make-up water must be extracted from the water source and delivered to the Main circulating Water system, this is delivered by Auxiliary Cooling and Make-Up water system.

10.3.47 The MCWS includes intake and outfall heads, tunnels and the structures and sub-systems that are required for abstracting and returning cooling water to and from the heat sink, the MCWS also includes filtration, pumping and piping systems required to distribute cooling water to turbine island condensers.

Balance of Plant

10.3.48 The BOP comprises of all remaining buildings and SSCs including, but not limited to:

- Back-up Generators
- Workshops
- Chemistry Stores
- Water storage tanks
- Fire Protection
- Waste Treatment
- Meteorology Station
- Interim waste storage
- Gas Supply

10.4 Steam and Power Conversion Systems

10.4.1 Steam and Power Conversion systems include the:

- Reactor Pressure Vessel (detailed in section 10.3.6)
- Reactor Coolant System (detailed in section 10.3.10)
- Feedwater System
- Main Steam System (detailed in section 10.3.37)
- Condensing System
- Steam Turbine Bypass System and
- Generator System, as well as associated sub-systems.

Feedwater System

10.4.2 The primary function of the Feedwater System is to provide secondary circuit cooling to the SG for removal of heat from the Reactor Core. The equipment contained within the Feedwater System allows for the conditioning of the water supply to ensure that the feedwater is in line with SG requirements.

10.4.3 The baseline architecture for the Feedwater System consists of a Deaerator and feedwater storage vessels, main feed pumps, booster feed pumps, start-up feed pumps, feedwater header and two stages of high-pressure feed heaters set out in two trains. The Deaerators receive heated water from the condensate system and heat the water further to remove dissolved gasses. Steam is supplied to the Deaerator as the heating medium which also provides a constant flow path to remove dissolved gasses.

Condensing System

10.4.4 There are two separate multi-pressure shell condensers in the Condensing System, one per LP Turbine, which has reduced the overall Cooling Water mass flow and therefore reduced the Cooling Water Island footprint. This decision can be revisited on a site-specific basis depending on the availability of cooling water.

10.4.5 Each condenser houses the first LP Feedwater Heater in its condenser neck in the steam space between the LP Turbine outlet and condenser water box. The first LP Feedwater Heater Station is split into two parallel and equal extractions and heaters, one per condenser. The extraction, LP Feedwater Heater and associated pipework are all contained within the condenser neck and drain directly into the condenser.

10.4.6 The cooling water supply from the MCWS for the two condensers is arranged in series. The first condenser receives cooling water at conditions equal to the cooling water source. The cooling water passes through the first condenser and is subsequently heated before passing through the second condenser at a higher inlet temperature. The result is that the second condenser of the series operates at a slightly higher pressure. The condensate system forms part of the main water return system of the secondary circuit and comprises of the systems and sub-systems associated with the management of condensate extracted from the main condenser and delivered to the Feedwater System to the SGs.

Steam Turbine Bypass System

10.4.7 In operating conditions where steam from the SGs does not need to pass through the turbine train, for example during decay heat removal, the steam is routed through the bypass lines. This facilitates full load rejection in the event of a turbine trip as the reactor steam output can be temporarily routed to the condenser to avoid reactor trips in the event of a grid disconnection event. The Turbine Bypass System is currently sized to accommodate 70 % thermal load of the reactor whilst the Atmospheric Steam Dump System accommodates 40 % of reactor thermal load.

10.4.8 In this operational condition the steam inlet valves to the turbine are closed and the steam bypass valves are opened to allow steam flow to be routed directly to the condensers. A condensate spray extracted from after the condensate extraction pumps is used to reduce the steam temperature prior to entering the condenser.

Generator System

10.4.9 The Generator System forms part of the electrical generation system of the Turbine Island whose primary function is the conversion of mechanical rotational energy to electrical energy in the form of high voltage, three-phase AC electricity. The baseline architecture comprises a full speed 2-pole generator in single axis tandem compound configuration with the Steam Turbine. A hydrogen generator cooling system coupled with static excitation with brushes has been selected.

10.4.10 The Generator System is connected to the shaft of the high pressure and low pressure turbines in the Steam Turbine System to receive rotational mechanical energy. The Generator System supplies the converted electrical energy to the Transmission System for the main purpose of exporting to the grid.

10.5 Auxiliary Systems

10.5.1 Auxiliary Systems are included within the design of RR SMR to allow safe operation of the power station, they include, but are not limited to:

- Fuel Storage and Handling Systems
- Refuelling Systems
- Water Systems
- Waste Management Systems
- Air and Gas Systems
- Heating, Ventilation and Air Conditioning ("HVAC") Systems
- Fire Protection Systems
- Overhead Lifting Equipment.

Fuel Storage and Handling Systems

10.5.2 Fresh Fuel Storage and Handling Systems comprise of the New Fuel Receipt and Inspection Area, a section of the Fuelling Block used for the receipt, inspection, and storage of new fuel before it is moved into the SFP and Lifting Equipment. They are located outside Containment but within the Hazard Shield.

10.5.3 The Storage of Spent/Irradiated Fuel Assemblies and Other Radioactive Parts System is a pool used for interim storage of fuel, fuel inspection, fuel repair and cask loading, ensuring the FSFs of Control of Reactivity ("CoR"), Control of Fuel Temperature ("CoFT"), and Control of Radioactive Material ("CoRM") are maintained. It is divided into the following areas:

- SFP, where the fuel is stored in fuel storage racks. This region contains Post Irradiation Examination Equipment and fuel cleaning equipment
- Cask Preparation and Loading Pit, where the fuel is loaded into casks, which are then welded shut, drained of water and filled with helium. The upender and fuel transfer system are also located within this pit.

10.5.4 A Fuel Handling Machine is used to move the fuel between the upender, fuel racks, and other equipment. Jib cranes are used for the movement of items like fuel racks, the cask lid, and Post Irradiation Examination Equipment.

10.5.5 The SFP cooling and clean-up systems support achievement of the FSFs of CoR, CoFT, and CoRM during normal operation and fault conditions. It is comprised of:

- Fuel Pool Cooling System ("FPCS")
- Fuel Pool Purification System ("FPPS")
- Fuel Pool Supply System ("FPSS")

10.5.6 The primary function of the FPCS is to remove heat from the SFP to maintain SFP temperature below 50 °C. The primary function of the FPPS is to remove impurities from the SFP to maintain

SFP chemistry to within specification. The primary function of the FPSS is to supply water to the SFP to replace evaporative losses.

10.5.7 The FPCS and FPSS also provide the motive force to support the transfer of water between the SFPs during refuelling operations and contains the Refuelling Water Storage Tank. The FPPS also provides a connection location for the infrequent dosing of chemicals to the SFPs in the event of a chemical or biological excursion in the coolant.

10.5.8 The FTC is used to transfer new and spent fuel, as well as other Reactor Core components, between the Cask Preparation and Loading Pit and the RPV, which supports achievement of the FSFs of CoFT and CoRM during normal operation and fault conditions.

10.5.9 The FTC is a metal tube containing the fuel transfer system. The metal tube provides containment of the water, which is required to keep the fuel submerged during transfer for heat removal, containment and shielding. The fuel transfer system is a set of rails along which a basket containing the fuel runs, and a Serapid Rollbeam system to move the basket back and forth. A sealing system will be incorporated at both ends of the metal tube.

Refuelling Systems

10.5.10 The RR SMR refuelling systems comprise the refuelling cavity, the SFP and Cask Preparation and Loading Pit.

10.5.11 The SFP and Cask Preparation and Loading Pit are used to store partially spent fuel, RPV upper and lower internals, and RPV in-core instrumentation during refuelling. The SFP is also used as a water store for Emergency Core Cooling. It supports achievement of the FSFs of CoR, CoFT and CoRM during normal operation and fault conditions.

10.5.12 The Refuelling Cavity is a pool located above the RPV, which is flooded up during refuelling to facilitate the movement of the fuel and other nuclear equipment from the RPV. It supports achievement of the FSFs of CoR, CoFT and CoRM during normal operation and fault conditions.

Water Systems

Main Cooling Water System

10.5.13 The MCWS transfers heat from the Turbine Condenser to the heat sink (the atmosphere). It is required for optimum operation of the steam turbine and hence electricity generation.

10.5.14 The baseline design for the MCWS is indirect cooling using low noise induced draft towers with plume abatement (mechanical draught cooling towers). The MCWS supports duty heat removal during normal operations.

Component Cooling System

10.5.15 The Component Cooling System (“CCS”) transfers heat from the reactor systems and components to the Essential Service Water System (“ESWS”), supporting achievement of the FSFs of CoFT and CoRM during normal operation.

Essential Service Water System

10.5.16 The ESWS transfers heat from CCS to the ultimate heat sink (“UHS”), the environment, supporting achievement of the FSFs of CoFT and CoRM during normal operation.

10.5.17 ESWS will use indirect cooling with MDCT during normal operation (separate to those for the MCWS). The MDCTs will recirculate the coolant, with a bleed that will be collected and transferred for treatment in the wastewater drainage and treatment systems. From there the treated effluent will be re-used as ESWS make-up water.

Auxiliary Cooling and Make-Up System

10.5.18 The Auxiliary Cooling and Make-Up System (“ACMS”) provides and removes cooling water to the Turbine Island Closed Cooling Water System heat exchangers, supplies make-up water to the MCWS cooling towers and transfers wastewater to the sea. The ACMS supports the MCWS in delivering duty heat removal during normal operations.

10.6 Core and Fuel Design

Core Design

10.6.1 The Reactor Core of RR SMR is configured as an upright cylinder containing 121 Fuel Assemblies located within the RPV. The main core components are the Reactor Vessel internals, Fuel Assemblies, the neutron absorbing control rods and neutron sources.

10.6.2 Power in the reactor is controlled routinely using neutron absorbing control rods. Unlike other PWRs, the RR SMR does not use boron for routine reactivity control, simplifying operations and reducing waste.

10.6.3 Control rods are withdrawn to start the nuclear fission chain reaction. As a result of fission in the fuel, heat is produced which is used to heat the surrounding water in the reactor pressure vessel. This raises the temperature in the reactor coolant circuit (also known as the primary circuit) to around 300 °C.

10.6.4 To stop the water boiling, the pressure in the primary circuit is maintained using a pressuriser which keeps the pressure at approximately 15.5 MPa. The pressuriser works by allowing a little water to boil inside creating a steam bubble which exerts pressure on the rest of the water in the primary circuit much like a piston would. The water is circulated around the Reactor Core and into one of three loops using reactor coolant pumps. These pumps pump the hot water from the reactor into one of three SGs.

Fuel Design

10.6.5 Each fuel assembly consists of a fuel bundle, which contains the fuel rods. The fuel rods are tubes with a cladding made of zircaloy into which UO_2 fuel pellets are loaded and plugged at both ends. Each fuel assembly is surrounded by a zircaloy channel box. The channel box directs the flow of coolant through the fuel bundle and guides the control rods. The latest fuel assembly design contains a 17x17 array of fuel rods and the hardware necessary to support and maintain the space between fuel rods.

Table 18: RR SMR Fuel Parameters

Parameter	Value
Fuel Bundle Length	2800 mm
Approximate Overall Mass	500 kg
Approximate Heavy Metal Mass	350 kg
Approximate Mass of UO_2	400 kg
Average Fuel burn-up	47 GWd/tHM
Total Number of Fuel Assemblies Discharged over 60 years	**1696-1976**

10.6.6 The core and fuel design methods employed for design analyses and calculations have been verified by comparison with data from operating plants, test data and detailed computer calculations. Throughout the history of the PWR, designers have continually implemented advanced core and fuel design technology, such as control cell core, spectral shift operation, axially varying gadolinia and enrichment zoning, fuel cladding with improved corrosion resistance and part length fuel rods. As these technological improvements are added, the core and fuel design parameters are optimised to achieve better fuel cycle economics, while improving fuel integrity and reliability and while maintaining overall reactor safety.

10.6.7 Thus, there is confidence that a low proportion of fuel failures will continue to be observed (as on current operating plants). Recent world PWR experience indicates a failure rate (between 2006 and 2022) in the range of 0.1 to 6 leaking Fuel Assemblies per thousand. Even in the event of failure, the fuel remains in the fuel rod and thus radioactivity largely remains trapped in the fuel rod.

10.6.8 The average bundle enrichments and batch sizes are a function of the desired cycle length. The RR SMR core uses fuel with a range of enrichments less than 5 %.

10.6.9 The low enriched uranium and fuel manufacture can be sourced through current established nuclear fuel suppliers.

10.7 Control and Instrumentation

10.7.1 Control and Instrumentation ("C&I") systems control and protect the plant in both normal operations and faulted conditions. These systems are designed in line with recognised and endorsed best practices, such as provision of adequate and reliable engineering solutions, defence in depth, minimisation of design complexity, provision of diversity and redundancy, etc.

10.7.2 The RR SMR C&I safety systems are being designed at the outset to comply with current International Atomic Energy Agency (IAEA) Safety Guidelines and Standards, as well as prevailing IEC standards (principally IEC 61513 and the SC45 series of sub-standards) and the SAPs by ONR.

10.7.3 Cyber Security of C&I systems has been considered from the first design principles and is part of functional & standardisation requirements.

10.7.4 The C&I systems incorporate a Diverse Protection System ("DPS"), a Reactor Protection System ("RPS") and Accident Management Systems ("AMS"), details of these systems are provided later in this Annex.

10.8 Electrical Power

10.8.1 The grid interface of the RR SMR will be tailored to meet local requirements and avoid significant infrastructure development where possible. The interface with grid includes one or more main connections for power export; and an auxiliary connection. The main power export connections should be at 400 kV (or similar) to minimise transmission losses and fault levels. The auxiliary connection may be at the same voltage or at a lower voltage e.g. 132 kV. The ratings, reactance and earthing arrangements of grid-interfacing generators and transformers will be specified in a future design phase, with due consideration of short circuit levels.

10.8.2 The RR SMR will be fully compliant with the UK Grid Code. These requirements are being included in the design at an early stage.

10.8.3 Power from the Main Generator is supplied to the Grid via isolated phase busbar to the Generator Circuit Breaker and the Generator Transformer. Power for the normal supply of auxiliaries is taken off between the Generator Circuit Breaker and Generator Transformer.

10.8.4 Power is provided to auxiliaries via a single Unit Transformer, supplied from the Main Generator or the Main Grid Connection.

10.8.5 A single Station Transformer provides an alternative grid supply via the Auxiliary Grid Connection in case of unavailability of the main connection. The RR SMR's passive fault protection philosophy means that grid supplies are not required to deliver headline safety measure functionality.

10.9 Nuclear Safety and Licensing

Safety Design

10.9.1 The RR SMR has been developed through a combined systems-engineering and safety assessment approach. Defence in depth is provided through the provision of robust safety measures, designed against conservative conditions, which meet the guidelines from the deterministic analysis. The RR SMR is designed so that defence in depth against postulated initiating events is achieved by the provision of multiple independent barriers to fault progression.

10.9.2 The RR SMR is being developed to meet the ALARP criterion using a systematic design optioneering process. Confidence in the design is further garnered owing to the fact that it is based on proven Pressurised Water Reactors with novel features being introduced only where they add to the safety and passivity of plant.

10.9.3 Safety functions that play a role in delivering defence in depth are categorised. Functions are categorised based on; the consequence of failing to deliver the safety function, the likelihood that the function will be called upon and the extent to which the function is required, either directly or indirectly, to prevent, protect against or mitigate the consequences of initiating faults.

10.9.4 All SSCs that are required to fulfil a categorised safety function are subsequently classified. The classification of an SSC is linked to the categorisation of the function it is required to fulfil. The classifications inform the level of importance of the SSCs and the level of detailed attention to be attached to its design, manufacture, installation, commissioning and eventual operation and maintenance regime. This Method draws on relevant good practice to assign categorisations and classifications in line with IAEA SSG-30, the EUR, ONR TAG-094 and BS EN 61226.

10.9.5 The safety case is being developed using a systematic approach which uses recognised methods and processes to ensure that all types of hazards (loss of coolant accidents, intact circuit faults, internal hazards and external hazards) have been identified and that sufficient safety measures are in place to ensure that the people and the environment are protected. The safety case commences with a series of hazard identification studies which identify all the potential hazards on the plant with the undefended unmitigated potential to cause harm.

10.9.6 Design basis internal and external hazards have been identified for the RR SMR. The design will be tolerant to the design basis events including internal fires and external floods. Separation and segregation assessment has been undertaken on the plant layout which shows that the RR SMR is tolerant to internal hazards.

10.9.7 Initial dose assessments to workers and the public have been performed showing that the Rolls-Royce SMR meets required dose limits and further work is being undertaken to demonstrate that the design reduces doses to ALARP.

10.9.8 The safety measures and safety features are typical of Generation III+ PWRs and innovation has only been introduced where this improves passivity or safety performance.

Control of Reactivity

10.9.9 The primary safety measures implemented on the Rolls-Royce SMR for the fundamental control of reactivity safety function are;

- SCRAM; and
- Alternative Shutdown Function.

SCRAM

10.9.10 During powered operations, the Control Rods are vertically positioned by the CRDMs, by way of a drive rod which connects the two. The CRDM actuators are positioned on the top of the Reactor Pressure Vessel Head and their pressure boundary extends at sufficient height to allow the drive rod and Control Rods to be fully withdrawn from the Fuel Assemblies. The RPV internals ensure alignment of the Control Rods within the RPV. The CRDMs, Fuel Assemblies and RPV internals sit within the Reactor Core System, which in turn sits within the Reactor System.

10.9.11 The SCRAM Safety Measure is triggered when relevant trip conditions are detected by instrumentation in duty systems or through manual initiation by the operator. In response to this trigger, the Reactor Control and Protection Systems open reactor trip breakers to cut power to the CRDMs which release the Control Rods. Loss of electrical supply to the CRDMs will also release the Control rods. The Control Rods will fall under gravity and are guided by the RPV internals into the Fuel Assemblies to provide complete Shut-Down Margin.

10.9.12 In typical established operating PWRs, Control Rod shutdown does not provide full shutdown margin. In those designs, Control Rods provide an intermediate controlled state that arrests the transient yet requires further operations to provide full shutdown and achieve a stable, safe state. This further action is typically active supply of soluble boric acid over the course of several hours while the plant is transitioned from this controlled state to the stable, safe state. The possibility of re-criticality exists in this intervening period if the increasing boron concentration is not properly matched to provide adequate shutdown margin during the cooldown operation.

10.9.13 In the RR SMR, full Shut-Down Margin is provided by the Control Rods alone, this postulated re-criticality accident condition is eliminated, thus improving safety and eliminating a degree of complexity in the delivery of shut-down margin.

Alternative Shutdown Function ("ASF")

10.9.14 The objective of the ASF is to provide a secondary diverse means of Control of Reactivity by inserting liquid neutron absorbers into the core coolant at an appropriate concentration to maintain the core sub-critical. In the event that Scram is not successful, then ASF is demanded.

10.9.15 ASF boron delivery is split into two phases:

- Phase 1: Where enriched boron-10 potassium tetraborate solution is delivered to the Direct Vessel Injection ("DVI") nozzles of the RPV with a quantity sufficient to borate the entire RCS with an overall concentration no less than 499 ppm. During the delivery of this enriched boron-10 potassium tetraborate to the DVI nozzles, this solution is also delivered and mixed with the Refuelling Pool water to create an overall concentration no less than 499 ppm to support phase 2 operation.
- Phase 2: Where a pre-mixed potassium tetraborate solution >= 499 ppm is delivered from the Refuelling pool to the DVI nozzles of the RPV.

Control of Fuel Temperature ("CoFT")

10.9.16 A number of distinct measures are included to support the CoFT safety function during shutdown and faulted operations:

- High-Temperature Heat Removal ("HTHR")
- Low Temperature Decay Heat Removal
- Passive Decay Heat Removal
- Emergency Core Cooling

High-Temperature Heat Removal ("HTHR")

10.9.17 The HTHR safety measure provides a means of providing Control of Fuel Temperature following the majority of reactor faults; HTHR is the preferred heat removal measure following a fault that causes the reactor to shut down. HTHR is also used to maintain the reactor critical in some Loss of Offsite Power and Turbine Trip scenarios, preventing reactor shutdown where practicable.

10.9.18 There are two main routes through which HTHR removes heat from the reactor plant to atmosphere: Condenser Decay Heat Removal ("CDHR") and Atmospheric Steam Dump ("ASD").

10.9.19 CDHR uses the RCS, including the Reactor Vessel, SGs and RCPs, to remove heat from the core to the Main Steam System. The heat is then rejected to the Main Condensers, via a Turbine Bypass System, and then to the natural environment by the main cooling water system. The main feed and auxiliary feed pumps are available to provide feed to the SGs. CDHR can provide long-term cooling.

10.9.20 ASD can be used where CDHR is unavailable e.g. loss of Main Cooling Water System and involves the use of power operated steam relief valves in the ASD system to reject steam from the SGs to atmosphere. The auxiliary feed pumps provide feedwater to the SG from condensate storage tanks within Turbine Island. Once the feed water stores are exhausted, Passive Decay Heat Removal will be initiated to provide long-term cooling.

Low Temperature Decay Heat Removal ("LTDHR")

10.9.21 The primary function of the LTDHR safety measure is to remove decay heat from the core during where the plant is at low temperatures and as such heat removal via the SGs (either using PDHR or HTHR) is no longer available.

10.9.22 Reactor coolant is circulated between the RCS and the CSCS, which transfers decay heat to the CCS; subsequently, coolant is transferred to the ESWS, which rejects decay heat to the atmosphere via the ESWS cooling towers.

Passive Decay Heat Removal ("PDHR")

10.9.23 PDHR primarily removes decay heat from the Reactor Core during faulted operation and transfers the heat to atmosphere. It is the preferred means of providing CoFT following design basis faults that render HTHR unavailable and yet the RCS structural integrity is maintained. In the event of failure of PDHR, ECC is capable of providing an independent means of decay heat removal.

10.9.24 PDHR heat transfer from Reactor System to atmosphere is provided by three independent cooling trains each aligned to a separate RCS cooling loop. Each cooling train is sized to provide heat removal with 1oo3 redundancy. Each Local UHS train has sufficient stored water to provide 24 hours of heat removal; 2oo3 trains are sufficient to provide 72 hours of heat removal and 3oo3 trains are sufficient to provide at least 120 hours of heat removal.

Emergency Core Cooling System ("ECCS")

10.9.25 ECCS is designed to provide Decay Heat Removal ("DHR") without reliance on the structural integrity of the RCS. It is the principal means of controlling core temperature following intermediate and large Loss of Coolant Accident events, where rejection of heat using the SGs is unavailable.

10.9.26 In the event of an accident where the RCS is depressurised, coolant is injected into the core via the Low-Pressure Injection System ("LPIS"). The LPIS operates in three phases: an initial phase where coolant is driven by compressed gas into the RPV from the accumulators, a second phase where coolant is driven by gravity flow from the Refuelling Pool into the RPV, and a third phase where coolant is recirculated between the RPV and the Containment Sump. Together, the three phases ensure rapid initial injection followed by continuous recirculation of coolant. The Local UHS removes heat from the containment atmosphere using a heat exchanger. The condensed steam drains to the sump screens, to the core, to provide continued cooling for the duration of the 72 hours.

10.9.27 The Local UHS consists of three identical interconnected trains, each comprising a large, elevated tank containing demineralised water, as well as various supporting sub-systems. Heat is transferred to the coolant in the tank via the set of heat exchangers; the coolant subsequently boils, transferring decay heat to the environment. 2 out of 3 trains are sufficient to provide 72 hours of cooling without operator intervention.

Confinement of Radioactive Material ("CoRM")

10.9.28 The Containment System is the primary measure that confines radioactive material during all operational states and accident conditions, supporting the CoRM fundamental safety function. The Containment System incorporates features to minimise and mitigate postulated severe accident phenomena.

10.9.29 The principal component of the Containment System is the CV, which is a large steel pressure vessel, with a cylindrical shell and ellipsoidal dome profiles. The CV forms a leak tight pressure retaining structure surrounding the Reactor Coolant System and the Reactor System. The CV is considered the final barrier to confine radioactive material, after the fuel pellet, the fuel cladding tubes and the Reactor Coolant System. The design of the CV is optimised to minimise leakage. This is described in greater detail in section 10.3.16.

10.10 Defence in Depth

10.10.1 The RR SMR is being designed to achieve Defence in Depth ("DiD") against Postulated Initiating Events ("PIEs") through the provision of consecutive and practicably independent measures over five DiD levels, which would have to fail before harmful effects could be caused to people or to the environment.

10.10.2 The DiD levels are summarised in Table 19, including alignment to plant states, the objective of each level, the definition of the type of measure associated with the level of DiD, an estimate of the PIE frequency for which that level is generally applicable, and success criteria that measures associated with a level must achieve.

10.10.3 The RR SMR approach for DiD also covers United Kingdom RGP for Design Basis Conditions ("DBC") frequent and infrequent faults, defined as:

- Frequent faults: PIEs with an Initiating Event Frequency ("IEF") exceeding 1 x 10-3/yr, and unmitigated consequences exceeding Basic Safety Level ("BSLs"). A minimum of two practicably independent and diverse measures are provided to deliver the success criteria.
- Infrequent faults: PIEs with an IEF between 1 x 10-3/yr and 1 x 10 5/yr, and unmitigated consequences exceeding BSLs. A minimum of one measure is provided to deliver the success criteria.

10.10.4 The DiD approach also covers UK RGP for consideration of postulated frequent faults with failure of the first protective measure, which are considered within the design.

10.10.5 For the RR SMR, beyond design basis faults are covered by Design Extension Conditions ("DECs"), defined as:

- DEC-A: PIEs and complex sequences without fuel melt with an IEF <1E-05/year, and unmitigated consequences exceeding BSLs.
- DEC-B: Severe accident conditions postulated from the inherent hazard potential and from sequences arising from failures of duty, preventive, and protective measures.

Table 19: Defence in Depth Levels for RR SMR

DiD Level	Plant State	Plant State ID	Objective	Measure		Postulated Frequency (pa)		Success Criteria
1	Design Basis Conditions (normal operation: desired conditions)	DBC-1	Prevention of abnormal operation and failures by design	Duty	Desired operating conditions	>1E-02		<1m Sv pa on-site radiation worker <0.1m Sv pa on-site non-radiation worker <0.02 mSv pa off-site No physical barriers breached where reasonably practicable
2	Design Basis Conditions (normal operation: abnormal conditions)	DBC-2i	Prevention of fault conditions and control of abnormal operation	Preventive	Minor deviation from desired operating conditions	>1E-02	Note 1	<1m Sv pa on-site radiation worker <0.1m Sv pa on-site non-radiation worker <0.02 mSv pa off-site No physical barriers breached where reasonably practicable
3	Design Basis Conditions (fault conditions)	DBC-2ii	Control of fault conditions within the design basis	Preventive	Frequent fault	>1E-02	Note 1	<20 mSv on-site <1m Sv off-site No physical barriers breached where reasonably practicable
3	Design Basis Conditions (fault conditions)	DBC-3i	Control of fault conditions within the design basis	Protective	Frequent fault	1E-02 to 1E-03		<20 mSv on-site <1m Sv off-site No physical barriers breached where reasonably practicable
3	Design Basis Conditions (fault conditions)	DBC-3ii	Control of fault conditions within the design basis	Protective	Infrequent fault	1E-03 to 1E-04		<200 mSv on-site <10 mSv off-site No more than limited relocation of radioactive material confined by at least one physical barrier
3	Design Basis Conditions (fault conditions)	DBC-4	Control of fault conditions within the design basis	Protective	Infrequent fault Frequent fault and failure of the first protective measure	1E-04 to 1E-05 <1E-05	Note 1	<500 mSv on-site <100 mSv off-site No more than limited relocation of radioactive material confined by at least one physical barrier
4	Design Extension Conditions (fault conditions)	DEC-A	Control of fault conditions beyond the design basis	Protective	Beyond design basis	<1E-05		<500 mSv on-site <100 mSv off-site No more than limited relocation of radioactive material confined by at least one physical barrier
4	Design Extension Conditions (accident conditions)	DEC-B	Control of severe accidents	Mitigating			Note 1	<100 mSv off-site At least one physical barrier intact confining any substantial relocation of radioactive material
5	N/A	N/A	Mitigation of radiological consequences of significant releases of radioactive material	Mitigating			Note 1	N/A

10.10.6 An important aspect of the implementation of DiD is the provision of multiple, and as far as practicable independent, physical barriers between radioactive material and the environment. The physical barriers for the radioactive material in the Reactor Core include:

- Fuel matrix and fuel cladding
- Reactor circuit
- Containment and associated systems

Diverse Protection System (“DPS”)

10.10.7 The primary role of the DPS is to implement all automatic Category A functions responding to Design Basis Faults. All Category A functions are assigned to both the RPS and the DPS with one means of detection assigned to the RPS, while another is assigned to the DPS (as far as is practicable) to ensure signal diversity between RPS and DPS. The DPS forms part of the DiD layer 3 along with the RPS.

10.10.8 A secondary role of the DPS is to respond to Design Basis Faults which occur simultaneously with a common cause failure (“CCF”) of the RPS. The intent is for the DPS to be sufficiently diverse and independent from the RPS that the same CCF would not defeat both the RPS and the DPS. The DPS reacts later in the accident progression than the RPS and thus successful RPS functioning will not require DPS functioning.

10.10.9 In response to the requirements for diversity between the RPS and the DPS, and with the RPS utilising a software-based platform, the DPS shall be implemented in a hardwired technology, with no programmable devices in the path of the safety function.

Reactor Protection System (“RPS”)

10.10.10 The RPS fulfils two main roles:

- Is a secondary means of implementing all Category A functions alongside the DPS to provide signal diversity between RPS and DPS.
- Provides implementation of DiD level 3 Category B functions.

10.10.11 The first role is fulfilled by the RPS 1 Individual C&I System and the second role by the RPS 2 Individual C&I System.

10.10.12 The DPS being a hardwired system allows the RPS to use programmable logic as a diverse technology system. This allows complex functionality to be more easily implemented in the RPS.

Accident Management Systems (“AMS”)

10.10.13 The AMS systems support on-site staff in making decisions for the management of Design Basis Accidents (“DBAs”), Design Extension Conditions (“DEC”), and Severe Accidents (“SAs”). The role of the AMS is to provide monitoring instrumentation and systems for preventive and mitigative accident management. The AMS is made up of two systems, namely, Post Accident Management System (“PAMS”) and Severe Accident Management System (“SAMS”).

10.10.14 The SAMS is provided for DECs and SAs. The SAMS shall display information which allows the operator to control severe accident conditions and allows initiation of severe accident safety systems enabling a severe accident safe state to be maintained or the reduction of radiological consequences through implementation of emergency response actions.

10.10.15 In the event of a serious incident, onsite and offsite Emergency Control Centres are also available to enable management of an emergency response, including coordination of on-site and off-site emergency response teams, and these facilities are also provided with information displays to monitor accidents.

10.11 Safety Analysis

10.11.1 Safety analysis informs the design and provides assurance of the DiD approach outlined above. Key analysis techniques and approaches are summarised within this Annex.

Deterministic Safety Analysis

10.11.2 Hazards for the RR SMR are identified using a variety of well-established techniques, such as hazard and operability (“HAZOP”) studies, failure mode, effects and criticality analysis, and human factors task analysis, from which the hazards are grouped and sentenced into PIEs for assessment in the fault schedule based on frequency of occurrence and unmitigated consequences. This bottom-up approach is complimented by a top-down examination of generic lists of initiating events for PWRs and how/if they may arise in the RR SMR design **[121]**.

10.11.3 The outputs of the hazard identification studies are collated in a Hazard Log, which screens the hazards for further assessment, as inputs to the fault schedule for deterministic analysis (or the

Probabilistic Safety Analysis ("PSA") model for probabilistic analysis). The sentencing process is based on the severity of their unmitigated consequences or their frequency of occurrence.

10.11.4 When determining if an initiating event is within the design basis, consequences are calculated on a conservative basis using best available relevant data, and IEFs are calculated on a best estimate basis, except for natural hazards for which a conservative approach is adopted. If a frequency is close to the boundary that defines the design basis, with data uncertainty or cliff-edge effects capable of having a significant impact on overall plant risk, then an initiating event is assumed to be within the design basis.

10.11.5 The fault schedule is a focal point of the deterministic safety case and provides an entry point for exploration of the PIEs and the associated safety functions and safety measures. Fault sequences are developed and evaluated in the fault schedule to understand the chronological response for each PIE through each level of DiD to deliver a High-Level Safety Function, characterising the demand on preventive, protective, and mitigation safety measures in the design.

10.11.6 Safety measures are defined as an SSC, or a combination of procedures, operator actions and SSCs, that deliver a High-Level Safety Function to defend against a radiological consequence. Through specification of safety measures, the fault schedule provides a key interface between the safety analysis and the safety categorised functional requirements placed on the design.

10.11.7 Performance analysis is used to assess fault sequences in the fault schedule to provide high confidence that safety measures can achieve their safety functions. Sequences are modelled using validated computational codes on a best-estimate basis combined with conservative assumptions (such as application of single failure criterion or failure of non-qualified equipment) and judged against acceptance criteria to provide a suitable safety margin, including radiological dose targets and criteria such as Departure from Nuclear Boiling Ratio and peak fuel clad temperature for the reactor.

10.11.8 The plant state defines the success criteria that must be met at each level of DiD for protection against each fault, noting more stringent acceptance criteria are generally specified for DBC-2ii and DBC-3i frequent faults than DBC-3ii and DBC-4 infrequent faults and DEC-A/DEC-B accident conditions. Only safety measures that deliver Category A and Category B functionality are credited with reducing sequence frequency required for moving through the DBC-2ii, DBC-3i, DBC-3ii and DBC-4 plant states.

10.11.9 The scope of the performance analysis includes all plant states to ensure the absence of "cliff-edge" effects for beyond design basis events. The timespan of the performance analysis extends to the point that the plant has achieved a stable, safe shutdown state.

10.11.10 The initial conditions and key parameters used in the performance analysis will also support definition and substantiation of Operational Limits and Conditions ("OLCs"), and performance analysis for DECs will support definition of accident management strategies and emergency procedures.

Probabilistic Safety Analysis

10.11.11 PSA studies combine IEF information with Safety Measure failure probability information, to evaluate the design against numerical targets including:

- Comparison against the Core Damage Frequency target through a level 1 PSA.
- Comparison against the Large Release Frequency through a Level 1 and level 2 PSA.
- Comparison against the targets related to doses and numbers of fatalities through a level 1, 2 and 3 PSA.

10.11.12 The PSA models are constructed and iterated throughout the RR SMR design process, with the objective to:

- Study the benefits and detriments of various design options in support of risk minimization.
- Evaluate risks to demonstrate they are below the numerical targets and are ALARP.
- Achieve a balanced and optimised design, so that no class of accident or feature of the design makes a disproportionate contribution to the overall risk.
- Input to standalone ALARP assessments outside of the design optioneering process, with quantitative assessment to support justifications.

10.11.13 Other PSA applications will be realised as the RR SMR progresses throughout the plant lifecycle, such as the use of PSA to risk inform examination, maintenance, inspection and testing activities or OLCs.

Severe Accident Analysis

10.11.14 SAs have the potential to involve phenomena which pose both immediate and delayed threats to the FSF of CoRM, resulting in major consequences to the public and environment. Severe accident analysis ("SAA") is undertaken for the RR SMR design to assess a representative range of postulated severe accident progression behaviours, with the aim to avoid, so far as is reasonably practicable ("SFAIRP"), the loss of CoRM in the short term, and to preserve, SFAIRP, the CoRM in the long term.

10.11.15 SAA is performed on a best estimate basis, with realistic underpinning data and assumptions, transient analysis, accident progression and estimation of source terms. Accident progression behaviours are predominantly modelled using validated computer codes. As part of the deterministic analysis, severe accident SSCs are modelled to demonstrate containment conditions in DEC-B severe accidents can achieve relevant acceptance criteria, such as containment integrity.

10.11.16 The aims of the SAA are to support demonstration of 'practical elimination' of large or early releases through the design, or that design measures can mitigate the accident progression and radiological consequences. It also supports the demonstration that there are no 'cliff-edge' effects in the safety analysis through the levels of DiD and supports equipment qualification through definition of the safe operating envelope under severe accident conditions.

10.11.17 SAA interfaces closely with PSA, with the Plant Damage States developed in the level 1 PSA providing the starting point to generate a set of severe accident progression behaviours that are analysed to study the impact of success and failure of associated systems. This analysis is in turn used as input to the level 2 PSA whereby postulated accident scenarios are mapped according to the success or failure of the base events.

10.11.18 Other SAA applications will be realised as the RR SMR progresses throughout the plant lifecycle, such development of SA management strategies, guidelines and procedures, and offsite emergency planning activities.

Internal Hazards

10.11.19 In addition to plant faults, the design of the RR SMR considers evaluation of internal hazards, i.e., hazards arising from within the bounds of the power station that are considered as PIEs that could challenge the delivery of the safety function. Where practicable, the aim of the RR SMR is to ensure an inherently safe design, or where this is not achievable, to demonstrate tolerance to hazards to ensure a safe state can be reached and the risk is reduced to ALARP. Environment, Safety, Security and Safeguards ("E3S") design principles and requirements relevant to internal hazards have been identified to inform the layout during the concept design stage, with internal hazards specialist support provided to layout and design teams, to eliminate or minimise the impact of internal hazards.

10.11.20 The assessment and protection measures for internal hazards for RR SMR takes cognisance of RGP and guidance from the ONR and other international nuclear regulatory bodies. The internal hazards approach for RR SMR is largely built upon the concept of segregation of SSCs within the design through physical distance (separation) or physical barriers to ensure that individual losses of equipment can be tolerated within the safety case due to redundant equipment remaining available. The role of operators will also be considered and the need for access and egress, as well as impacts on barriers and SSC.

10.11.21 The identification of internal hazards includes a consideration of the initial conditions, the magnitude and the likelihood of the hazards, the locations of the sources of the hazards, the resulting environmental conditions, and the possible impacts on SSCs important to safety or on other SSCs. Assessment considers whether a PIE occurs due to a hazard, and whether the hazard can damage the safety measures for that PIE.

10.11.22 The assessment process also considers potential hazard combinations, including consequential hazards whereby a primary hazard initiates a secondary hazard that becomes the PIE, correlated hazards whereby more than one hazard is initiated by the same cause, independent hazards whereby there is no causal relationship between the combinations, and external-internal hazard combinations. Screening is applied to aid rationalisation of combinations to ensure the focus of assessment remains on those combinations that pose a foreseeable threat to SSCs and barriers.

10.11.23 The internal hazards sequences are included in the fault schedule, with deterministic assessment used to define hazard protection requirements, such as divisional barriers or pipe whip constraints. Safety categorised functional requirements are defined, and hazard protection measures are classified.

External Hazards

10.11.24 In addition to plant faults, the RR SMR evaluates external hazards, including combinations of external hazards, in the context of nuclear safety, i.e., hazards arising from outside the bounds of the power station that are considered as PIEs that could challenge the delivery of safety functions.

10.11.25 For hazards that can be characterised with non-discrete frequency of exceedance hazard curves, the design basis is set based on:

- Naturally occurring external events with frequency ≥1E-04 per year, as calculated on a conservative basis.
- Manmade external hazards and internal hazard events with frequency ≥1E 05 per year, as calculated on a best estimate basis.

10.11.26 For aircraft impact, the RR SMR layout will provide sufficient separation of safety systems to ensure availability of cooling to prevent core damage.

Post-Fukushima enhancements

10.11.27 Countermeasures from the lessons learned against Station Blackout and Loss of UHS caused by severe external hazards beyond the design basis are under evaluation. Nevertheless, the RR SMR will include enhancements such as the following:

- Alternative heat removal systems to ensure an UHS.
- Enhancement of building structures and layout to secure components and power panels in the event of severe external hazards such us flooding.

10.11.28 The RR SMR uses an Ice Store for Reactor Island Chilled Water System—The Low Temperature Chilled Water systems operate at temperatures below freezing (0 °C) using a glycol/water mix, and charge/discharge ice stores which can be used to provide cooling to key safety systems during an endurance period in which power is not available.

10.11.29 Most nuclear power stations, utilise diesel generator backed cooling trains for endurance cooling. Several incident reports are identified from the IAEA Incident Reporting System of diesel generators failing to start when required or failing during operation. The use of ice chillers provides a more compact and more easily protected solution.

10.12 Dose Targets and Limits

10.12.1 For each new generation of nuclear power station, the goal has been to simplify the design and improve operations compared to predecessors, including improvements in workers and public's safety.

10.12.2 Radiation protection policies and design guidance for the RR SMR are developed based on RGP and Operating Experience ("OPEX"). These are embedded into the optioneering and design development processes to ensure appropriate design features are incorporated into the design through the application of the hierarchy of controls to minimise dose to ALARP, and ensure the design facilitates compliance with Ionising Radiations Regulations 2017 ("IRR17").

10.12.3 The demonstration of ALARP is supported by the assessment of dose to workers and the public, with comparison against BSLs and BSOs providing confidence that the design of the RR SMR can achieve the numerical targets defined for the RR SMR, and through further design provisions and assessment can be demonstrated in all cases to reduce doses to ALARP.

On-site Dose

Normal Operation

10.12.4 The RR SMR combines advanced facility design features and administrative procedures conceived to keep the occupational radiation exposure to personnel ALARP. During the design phase, the designs of layout, shielding, ventilation and monitoring instrumentation are integrated with traffic, security and access control and plant operation models. Moreover, clean and controlled access areas are separated. Reduction of plant personnel's radiation exposure is principally achieved by: Reducing the source of radiation, increasing the distance between operators and the radiation source, decreasing the exposure time, and shielding the radiation source.

10.12.5 Good practice in radiation protection during the design stage is captured and applied during the design of the RR SMR in line with the requirements of IRR17, covering (but not limited to):

- Water chemistry and material selection optimisation to reduce radiation levels;
- Shielding design, such as:
  - Design of penetrations through shielded structures (pipework, HVAC ducts etc.) to reduce shine or scatter;
  - Use of labyrinths in rooms containing very active sources where personnel access is required in preference to a heavy, shielded door, where reasonably practicable;
- Containment and segregation of radioactive material, such as:
  - Features to ensure containment of radioactive contamination as close to source as possible;
  - Segregation of active systems from non-active systems, and high dose systems from low dose systems;
  - Segregation of pipework used to transfer high dose effluents and waste that may result in regular transient high dose rates;
- Radiation and contamination zoning schemes to support design and layout, including room placement and ventilation configuration (airflow cascades in controlled areas from areas of lower contamination to those of higher contamination);
- Design of SSCs to facilitate decontamination and flushing to reduce maintenance doses, and isolation to reduce the risk of spread of contamination;
- Design of HVAC systems to consider airflows, adequate air changes, and risks of iodine and degassing phenomena;
- Equipment and pipework design to minimise deposition of activity, through use of gradients and elimination of dead legs;
- Building and room layout to ensure personnel are kept away from radiation sources unless required and reduce the time spent near them to a minimum, and provision of locations within the building layout for Personal Protective Equipment ("PPE"), Respiratory Protective Equipment, a radioactive source store, a health physics counting laboratory, a Radiation Protection Control Centre, storge for health physics equipment including portable instrumentation, and dosimetry services
- Control of access and egress to radiation-controlled areas, contamination-controlled areas, and high dose rate areas;
- Provision of installed monitoring equipment for radiation protection, as well as portable instrumentation; and
- Enabling innovative and emerging technologies that can be of benefit to radiation protection, such as remote monitoring and communications or robotics and drones.

10.12.6 The RR SMR is a modern plant design that will incorporate improvements and optimisations over older PWR designs, based on RGP and OPEX. It is expected that the average dose to employees working with ionising radiation will be below the basic safety objective, set out by the ONR, and will at least be in line with the recent data presented by the US NRC, which gives an average measurable dose per individual of 0.7 mSv in 2020.

10.12.7 The assessment of dose rates associated has identified the need to incorporate additional primary shielding at the top of the RPV to reduce dose rates in the interspace area around primary containment. Furthermore, assessment has identified the need for secondary shielding around the primary circuit, including the SGs.

10.12.8 The RR SMR has been designed to minimise tritium production in the coolant. The concentration of tritium in the primary coolant is considered to reach steady state during the routine power operation. However, tritium may accumulate in the primary coolant due to releases from the fuel in the event of fuel pin failures. Such accumulation can be managed safely through treatment and controlled reactor bleeds in the Liquid Radioactive Effluent Processing System.

Accident Conditions

10.12.9 The RR SMR is designed to facilitate effective emergency preparedness and response to accidents that may result in a radioactive release.

10.12.10 Emergency response and control facilities for the RR SMR include the MCR, Secondary Control Room ("SCR"), Emergency Response Centre ("ERC"), Technical Support Centre ("TSC"), operational support centre, access control point, offsite ERC and offsite TSC. These facilities are being designed to facilitate post-accident emergency response in accordance with RGP and OPEX, to ensure they remain habitable and dose to responders is minimised to ALARP.

10.12.11 Many of the functions of these facilities relate specifically to the ability of the Control Room to perform its functions in accident conditions, including design basis accident conditions and severe accident conditions. The MCR is being designed to maintain habitability and tenability, with the ability to transfer control between the MCR and SCR, and to maintain communication links between the facilities and the plant.

10.12.12 Specific requirements are also placed onto the MCR for post-accident scenarios, including (but not limited to) design to ensure individual personnel doses remain below numerical targets (<20 mSv) through shielding and HVAC design, provision of diverse routes for access and egress, and provision of PPE.

10.12.13 Due to the passive safety features employed in RR SMR the only accident scenarios where pre identified operator actions will have to be undertaken are associated with Local Ultimate Heat Sink, Spent Fuel Pool and Essential Services Water Supply top up. These scenarios will require operator action after the first 24 hours of an accident scenario. These activities are carried out at all PWRs and the exposures from RR SMR will be no worse than at other PWRs, it is envisaged that they would, in fact, be lower due to the smaller reactor size (source term) of RR SMR. The reactor of the RR SMR contains 40% of the inventory of Sizewell B and on a per unit basis would be expected to have a significantly smaller radiological impact during normal operation and in the event of any incident or severe accident.

Off-site Dose

Normal Operation

10.12.14 Off-site dose reduction is primarily achieved by minimising gaseous and liquid emissions.

10.12.15 The primary function of Liquid Waste Treatment System is to collect and treat radioactive liquid effluents to be suitable to recycle or discharge. The baseline architecture consists of storage tanks for collection of liquid effluent, with a combination of filtration, Reverse Osmosis, Ion Exchange, evaporation and degassing for treatment. Treated liquid effluents are recycled as make-up demineralised water in the RI, or, in some cases, discharged to the environment.

10.12.16 Radioactive gaseous effluent is discharged to the environment via the RR SMR stack. The stack takes the combined filtered discharges from the controlled area extracts and discharges the gaseous effluent at an appropriate height to achieve the required dispersion that meets BAT.

10.12.17 The peak annual dose to a member of the public is calculated to be 12.3 μSv at the site fence.

Accident Conditions

10.12.18 Many regulatory requirements and plant features are aimed at providing protection of the public against radiation releases from accidents. The results of the radiological consequences in the event of DBAs are around 0.01 mSv, which demonstrates that the RR SMR has large margin below the BSL.

10.12.19 RR SMR accident scenarios consider core melt with successful in-vessel retention and containment isolation. The offsite effective dose for these scenarios is within project targets, and sufficiently low that the requirement for and geographic extent of offsite countermeasures (such as evacuation) are expected to be reduced for the RR SMR relative to other PWRs. The only offsite protective action considered in these analyses are legally mandated food bans which would also apply in accident scenarios for existing justified practices.

10.13 Security Considerations

10.13.1 The security performance of the RR SMR will be assessed, initially, as part of the GDA process. There are no unique factors that affect the ability of the RR SMR to deliver high levels of security compared to other nuclear power plant. For the UK, conceptual security arrangements will be assessed during the GDA process. Site specific security measures will be developed by the utility in a site security plan based on the conceptual security arrangements which will be assessed during the nuclear site licensing process.

10.13.2 Furthermore, the RR SMR will be able to resist the deliberate impact of a large aircraft such that the integrity of the reactor building is maintained and the fuel in the Reactor Core and SFP is cooled and protected from severe damage.

10.13.3 The RR SMR, similar to existing PWRs, will meet safeguards verification requirements and represents no unique technology challenges with safeguards provisions on PWRs well established in Europe and elsewhere in the world.

10.14 Licensing Status

UK GDA Process

10.14.1 The EA, ONR and NRW need to make sure that any new nuclear power station built in the UK meets the required high standards for:

- Safety;
- Security;
- Safeguards;
- Environmental protection; and
- Waste management.

10.14.2 The GDA, allows the regulators to assess the generic design of new nuclear power stations to assess if there are any obvious barriers to their deployment in the UK. Successful completion of a GDA in the UK does not necessarily mean that construction of a nuclear reactor can start. Further permits and permissions are required. For GDA, Rolls-Royce SMR Limited is known as the RP, the organisation submitting its generic reactor design for GDA.

10.14.3 The objective for GDA is to provide confidence that the proposed design is capable of being constructed, operated and decommissioned in Great Britain in accordance with the standards of safety, security, waste management, safeguards and environment protection required.

10.14.4 The GDA process has 3 steps:

Step 1: Initiation;
Step 2: Fundamental assessment; and
Step 3: Detailed assessment.

10.14.5 Rolls-Royce SMR Limited entered Step 1 of the GDA Process on 1 April 2022. Step 1 is the project initiation stage of the design assessment process and will involve discussions to ensure a full understanding of the requirements and processes that will be applied, readiness of the RP to begin Step 2 and a review of the RP's security and Quality Assurance arrangements. The completion of Step 1 of the GDA is the most significant milestone so far in securing consent for the RR SMR to be deployed in the UK.

10.14.6 Step 2 is the first substantive technical assessment step. It focuses on the Safety. Environmental, Security and Safeguards fundamentals of the design. It includes assessing the methodologies, approaches, codes, standards and philosophies the RP is using to substantiate their environment case.

10.14.7 Rolls-Royce SMR Limited entered Step 2 of the GDA assessment process in April 2023 and expects to seamlessly continue to Step 3 in July 2024.

10.14.8 Other pre-licensing activities are also under way with the IAEA undertaking a Technical Safety Review, mapping the RR SMR design against international safety standards. The UK GDA process is also being observed by various overseas regulators ahead of possible deployment in a wide range of countries.

10.15 Operation and Maintenance

10.15.1 The RR SMR has gone through a series of evolutionary changes and has achieved significant technological evolution from the current generation of PWRs. The major key features of RR SMR evolutionary design which have contributed to the improvement and facilitation of operation and maintenance tasks are the following:

- Improved safety and reliability;
- A simpler and more robust design; and
- Advanced design and construction technologies.

10.16 A Summary of the Major Contributions to Operation and Maintenance

10.16.1 An example of simplification within the RR SMR is the Boron Free primary circuit chemistry.

10.16.2 Unlike other designs, no concentration of soluble boron is maintained in the primary coolant for duty reactivity control. Duty reactivity control is provided through movement of Control Rods and use of the negative moderator temperature coefficient inherent to PWRs. Long term shutdown is also achieved through the insertion of the Control Rods. No addition of soluble boron is required to maintain a suitable subcritical margin at any temperature or level of burnup.

10.16.3 The absence of soluble boron means the Reactor System is not subject to boron dilution accidents and can also respond faster to power reduction transients. There is no requirement for the primary coolant to change temperature to control reactivity at nominal power which increases plant thermal efficiency and thus, maximises the plant power output for a given core loading. This benefits the operator by providing ultimately higher thermal output from a given plant footprint. Boron free chemistry can greatly increase effluent recycling possibilities and supports the minimisation of liquid discharges in normal operation and reduces the requirement for evaporators to process liquid waste (which minimises waste).

10.16.4 The absence of soluble boron also ensures the reactor operates with a strong negative reactivity coefficient, meaning that as the temperature of the primary circuit rises the efficacy of the moderator reduces and reduces the reactivity of the core. The benefit of this approach is that is ensures a degree of inherent core stability such that perturbations in output are self-correcting, which enhances safety.

10.16.5 One of Rolls-Royce SMR Limited's Build Certainty principles is *"minimise variation across all areas."* An approach of 'do once and use many times' is being used on the RR SMR to meet this principle, which is the standardisation philosophy. The aim is to reduce costs by reducing part numbers whilst increasing part volumes, increase repeatability of component installation and maintenance, reduce the number of different installation and maintenance procedures, and increase part compatibility and interoperability.

10.16.6 A key feature of the RR SMR is 'economies of volume'. Large nuclear power plants are built in smaller quantities than the fleet approach anticipated for RR SMRs. This approach aims to achieve 'economies of scale', where learning from constructing units, standard design, and commoditisation of component parts can be leveraged to produce a low Levelised Cost of Electricity. Whereas a key feature of the RR SMR is the aim to achieve 'economies of volume', which relates to the standardisation approach being taken.

10.16.7 The 'economies of scale' is achieved by minimising the number of unique parts across the plant and maximising number of Commercial Off-The-Shelf components. This is of particular importance in the nuclear industry where nuclear classified components require significant quality assurance procedures and documentation, thus reducing the number of component types reduces the quality assurance procedures needing to be performed. This will reduce the cost of the RR SMR.

10.16.8 An example in which Rolls-Royce SMR Limited is applying standardisation is incorporating a modular solution to the civil structures constructed on-site. The Civil Kit of Parts ("CKoP") are modular components that offer a standardised structural system to be used to build a variety of structures across the plant. This enables a standardised build schedule for structures using the same or similar group of CKoP elements, increasing the construction efficiency, and reducing the build time, whilst simultaneously reducing construction risk. It also simplifies the maintenance of the plants' civil structures as the number of maintenance procedures is reduced, compared to a conventional build, saving both time and cost.

10.16.9 Rolls-Royce SMR Limited continues to build its CKoP catalogue, developing novel techniques to solve challenges typically seen in large construction projects. An example of this is the Aseismic Bearing Pedestals. These are used to support the Reactor Core, which removes the need to design site specific seismic isolation. Only adjustments to the Basemat are needed to meet site specific conditions.

10.17 Spent Fuel and Radioactive Waste Management

Overview

10.17.1 The RR SMR has been developed to significantly reduce waste generation by adopting improved technologies and efficient operation. All system designs are requirements led and consider ALARP and BAT as key design objectives. The radioactive waste treatment systems have been developed to reduce the radioactive material discharge to the environment.

10.17.2 An example of the improvements regarding the discharges of radioactive material to the environment is the use of backwashable filters, instead of cartridge filters, to filter particulates from the reactor coolant system. Backwashable filters offer the elimination of filter changing, which removes a large solid Intermediate Level Waste ("ILW") stream, removes the need for a filter change machine and removes the need to isolate the coolant system. This simplification reduces operating costs and waste for the power plant.

10.17.3 Backwashable filters can be regenerated remotely, meaning that no direct operator interaction is required and therefore reduces operator dose in comparison to the cartridge filter option. A back-washable filter does not require opening reactor coolant pressure boundary and thus simplifies operations for the operator.

10.17.4 The radwaste treatment systems comprise the Liquid Waste Treatment System ("LWTS"), Gaseous Waste Treatment System and Solid Waste Treatment System.

10.17.5 The predicted annual radionuclide discharge data, for liquid and gaseous discharges is presented in Chapter 7.

Liquid Waste Treatment System

10.17.6 The substitution of the standard PWR chemistry (boron and lithium hydroxide based) with a potassium hydroxide-based (soluble boron-free) chemistry will result in significant reduction in the inventory of tritium in the primary coolant, as neutron activation of dissolved boron and lithium in primary coolant accounts for the bulk (>90 %) of tritium produced in PWRs under normal operating conditions. The level of boron in primary coolant is a key driver for the bleeding and discharge of aqueous radioactive effluent; the elimination of soluble boron will therefore eliminate the need to bleed primary coolant, potentially resulting in zero-discharge of liquid radioactive effluent.

10.17.7 As such, the RR SMR eliminates the need for routine discharge of aqueous effluent to the environment under normal operating conditions—although very small amounts of liquid may require discharge for water balance, tritium management (if required to meet derived air concentration limits for refuelling options) or following an anticipated operational occurrence. Effluent to be discharged will be collected at the Liquid Monitoring and Discharge System, where it would be monitored and sampled for confirmatory analysis to check that the water meets relevant quality criteria and regulatory limits; any effluent that doesn't meet these criteria is returned to the LWTS for further treatment. Effluent that meets the discharge criteria will be released to the environment through a single discharge line fitted with further flow monitoring and sampling equipment.

10.17.8 The quantities and volumes of aqueous and gaseous radioactive effluent discharged from the RR SMR to the environment (per unit MW generated) are therefore expected to be comparable to or less than discharges from existing PWRs, under both normal operations and accident conditions.

Gaseous Waste Treatment System

10.17.9 The RR SMR abates the discharge of volatile fission products to the environment. The gaseous waste treatment system comprises a hydrogen/oxygen re-combiner to prevent the formation of explosive atmospheres, and absorber delay beds to permit activity (noble gases and iodine) to decay, as well as HEPA filters to remove and capture particulate radionuclides prior to discharge to the environment through a gaseous emission stack.

10.17.10 The RR SMR uses a nitrogen cover gas system to treat systems that handle reactor coolant, primary circuit effluent or make-up water. Key sources for these gases are the vacuum degasser within the processing and treatment system for liquid radioactive effluent, and the reactor coolant drains tank. Hydrogen and volatile fission products are purged from the system and collected as gaseous effluent which is further cooled to separate tritiated liquid effluent and entrained particulates. This nitrogen cover gas is mostly recycled within a semi-closed loop whilst excess gas is directed to activated charcoal delay beds where fission products undergo hold-up and decay prior to discharge to the environment. As a result, only small quantities of noble gases are expected to be released during normal operations and the radioactivity of the discharge gaseous effluent is reduced to appropriate levels.

10.17.11 The primary effluent storage tanks are the largest volume of gas and an increase in primary liquid effluent letdown will require some gaseous effluent volume to be discharged through the delay beds. Degassing operations for these storage tanks are also expected to generate significant quantities of hydrogen and fission product effluent.

10.17.12 The nuclear HVAC system maintains ambient atmospheric conditions and removes air contaminated with radioactivity from the atmospheres of controlled areas and auxiliary areas of the RICA. Extracted air, contaminated by effluent leakages and neutron activation within these areas, is treated by the HEPA filters and discharged to the environment.

10.17.13 The Condenser Air Removal System also strips non-condensable gases from effluent which is then discharged to the environment.

10.17.14 Through a combination of the systems and measures identified, the remaining gaseous discharges represent the BAT for the gaseous waste stream.

Solid Waste Treatment System.

10.17.15 The Solid Waste Treatment System is designed to control, collect, handle, process, package, and temporarily store wet and dry solid radioactive waste prior to shipment. This waste is generated as a result of normal operation and anticipated operational occurrences. These wastes are categorised as wet solid wastes (such as spent ion exchange resin beads and filter backwash arising from the operation of the LWTS etc.) or dry solid wastes (such as HEPA filters, protective clothing, tissue paper etc.).

10.17.16 Both Low Level Waste and ILW are processed by the Solid Waste Treatment System.

10.17.17 Disposability Assessments are being undertaken by NWS for RR SMR radioactive wastes during the GDA process. The results are expected to be available to inform the Secretary of State's consideration of this application. Initial assessments show that RR SMR wastes can be accommodated within the UK's future Geological Disposal Facility.

Spent Fuel Management

10.17.18 The anticipated load of the reactor through life will include 1,696-1,876 Fuel Assemblies (42-47 assemblies per cycle), all of which will be transported from the site before final decommissioning. Following an initial cooling period in the SFP, the spent fuel assemblies will be packaged into steel canisters within transfer casks for transfer to the Spent Fuel Store and then moved into concrete over-packs until sufficiently cooled for disposal to the Geological Disposal Facility.

10.17.19 The on-site SFP has the capacity to store fuel for at least 10 years before it is loaded and transferred to the Dry Spent Fuel Store for the remainder of the RR SMR's 60-year operational life.

10.18 Construction

10.18.1 Rolls Royce SMR Limited will utilise the breadth of the UK supply chain, which is able to contribute in excess of 80 % of each RR SMR by value—focusing on standardised, commercially available and off-the-shelf components. Rolls-Royce SMR Limited will move away from the high cost and high-risk complex construction programme principles into predictable factory-built commodities. Approximately 90 % of manufacturing and assembly activities are carried out in factory conditions, helping to maintain an extremely high-quality product and reduce onsite disruption.

10.18.2 Rolls-Royce SMR Ltd is looking to significantly reduce the use of radiography required during fabrication and construction by utilising alternative methods. Additionally, the fabrication of modules within a factory environment and construction in a Site Factory should ensure any radiography that is required can be carried out in significantly more controlled (and shielded) environments, reducing the radiation dose to construction workers.

Site as a Factory

10.18.3 Rolls-Royce SMR Limited is adopting a 'Site as a Factory' approach to onsite construction and assembly to achieve build certainty. This innovative approach assumes modularisation has been maximised to minimise on site complexity, reducing on-site activities to largely placement, jointing and final commissioning.

10.18.4 The Site Factory provides an environmental shelter to the RR SMR assembly area, providing a significant change in the construction methodology from traditional nuclear construction. Enabling installation of mechanical, electrical, C&I, and process equipment in a controlled environment for up to 24 hours a day, 365 days a year.

10.19 Decommissioning

10.19.1 New nuclear power stations must be considered to facilitate future decommissioning in a safe and environmentally acceptable way at the early stage. This includes design principles and fulfilment of IAEA requirements related to decommissioning. The incorporation of decommissioning considerations into the RR SMR has been applied by lessons learnt from decommissioning work all over the world. Design for Decommissioning has been included in the RR SMR from its concept this ensures that radioactive wastes and exposures of radiation to workers from decommissioning activities will as a minimum be as in line with the best performing PWRs and in all cases ALARP.

10.19.2 Due to RR SMR being an evolving design, it is too early to provide the volume and nature of waste streams which are expected to arise from decommissioning. The waste streams will be broadly similar to previous decommissioned nuclear power stations. However, given the advancement of decommissioning strategies, policies and techniques Rolls-Royce SMR Limited will work to improve the disposal procedures. For example, aiming to segregate the concrete bioshield depending on the level of activation.

10.19.3 An important distinction between RR SMR and existing PWRs which will be consequential for decommissioning is the modular approach to design and construction which is central to the RR SMR concept. The structure of the RR SMR will extensively comprise of steel framed modules, which contrasts with existing large PWRs which largely comprise of concrete cells. Therefore, the decommissioning of the RR SMR is expected to produce a greater ratio of steel to concrete relative to larger nuclear power plants. It is anticipated that this steel will be able to be recycled post decommissioning.

The modular concept is advantageous for decommissioning. Disassembly of modular clusters may broadly be the reverse of assembly. The relative structural independence of each primary structure means that their removal (in reverse order) would not significantly compromise the remaining modular structure (cluster).

Integral handling and transportation features could be used for their removal from the plant. Primary structures would inherently act as vehicles for the removal of Mechanical, Electrical and Plumbing plant to where the equipment could be safely decommissioned. It is considered that the frame itself would pose no exceptional issues for decontamination and recycling.

10.20 Other Environmental and Health Effects

10.20.1 The non-radiological environmental and health impacts associated with the operation of the RR SMR are described as follows.

Cooling Water Systems

10.20.2 During operation, the cooling water abstraction requirements (assuming sea water indirect cooling) will be around 1.3 m^3s^{-1}. A detailed site-specific assessment will be required to assess the effects of abstraction and the thermal discharges and demonstrate that the impact on the local marine environment has been minimized.

Chemicals

10.20.3 The chemicals used in RR SMR will be similar to those in all other PWR nuclear power plants. Major chemicals will include the following:

- Corrosion inhibitors – bespoke polymer blend;
- Biocides – e.g. Sodium Hypochlorite;
- Anti-scalants – bespoke polymer blend;
- Hydrazine;
- Ammonia; and
- Technical Gases e.g. Hydrogen.

10.20.4 Based on the low quantities used, the impact from discharges to air or to water should be very low.

10.20.5 During the design process, an assessment of the quantities and form of these chemicals is being undertaken to assess whether a RR SMR site is likely to fall under the Control of Major Accident Hazard (“COMAH”) Regulations 2015. Based on current information the RR SMR is unlikely to be an upper tier COMAH establishment.

10.20.6 The chemical supply system architecture will be progressed from 2024 onwards and a greater understanding of chemical usage and storage quantities, and types will be developed as this design progresses.

Conventional Waste

10.20.7 The conventional waste generated by the RR SMR is expected to be broadly similar in nature to that from any other nuclear power plant. The exact amount of conventional waste produced, will depend on the exact methods of operation of the RR SMR and also the practices of the operator, but is expected to be less in absolute terms compared to GW sites.

10.20.8 The waste hierarchy will be followed to ensure that waste generation is minimised and waste streams are appropriately controlled and segregated as is the practice at any large industrial facility in the UK.

Noise

10.20.9 The major sources of continuous noise from the RR SMR plant are the following:

- Stand-by diesel generators (when operating);
- Transformers, turbine generator units; and
- Large motor-driven pumps (circulating water, feedwater, etc).

10.20.10 For RR SMR these will be operated in accordance with the conditions and limitations specified in the Environmental Permit.

Air Quality

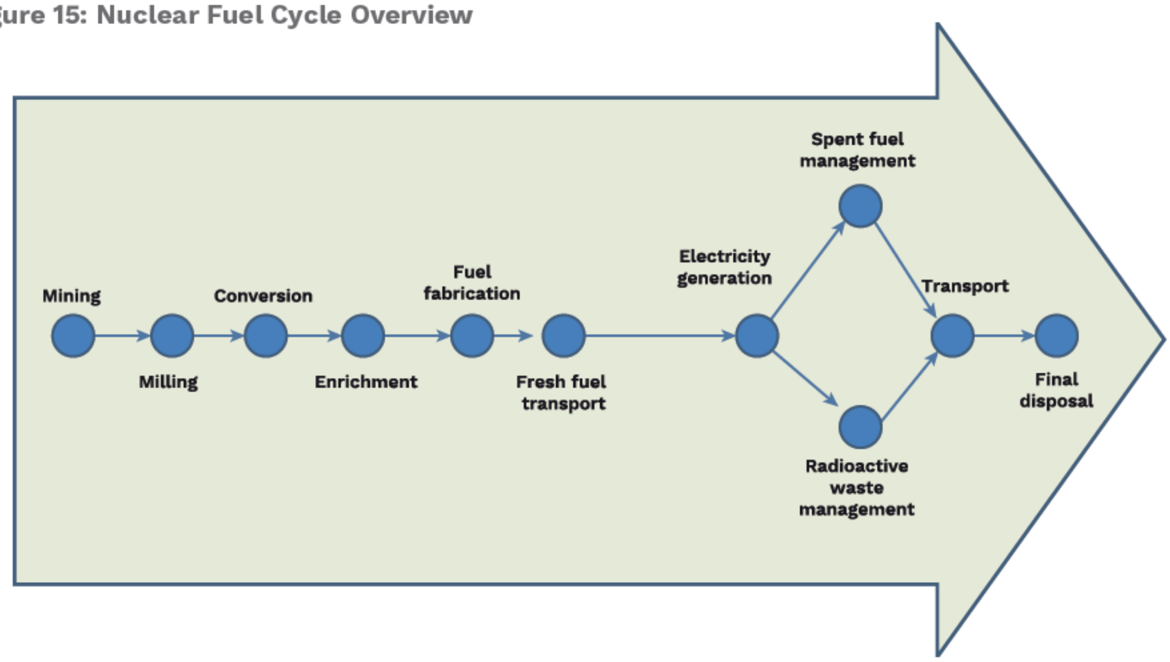
10.20.11 The stand-by diesel generators would be used for only a few hours per year for periodic tests or if the grid connection is lost. The emissions from the stand-by diesel generators are small and would be operated in accordance with the conditions and limitations specified in the Environmental Permit.

11: ANNEX 2 - NUCLEAR FUEL CYCLE

11.1 Introduction

11.1.1 The nuclear fuel cycle is the progression of nuclear fuel through a series of differing stages. The front end consists of the steps to manufacture the fuel and its use in electricity generation. The back end consists of those steps to safely manage and then dispose of spent nuclear fuel. Figure 15 is a schematic of an open fuel cycle as fuel is disposed of after use.

Figure 15: Nuclear Fuel Cycle Overview



11.2 Uranium Mining and Milling

11.2.1 Uranium is abundant in the earth's crust and estimated reserves are in excess of 8,000,000 tonnes **[122]**. The largest producers of uranium are Australia, Cananda and Kazakhstan. Other uranium producing countries include Russia, Namibia, and Niger. Uranium is recovered either by mining hard rock or by in situ leaching, in which either a strong acid or a strong alkaline solution is used to dissolve the uranium and bring it to the surface.

11.2.2 Milling of mined ore extracts the uranium to produce a uranium oxide concentrate that is shipped from the mill. This concentrate is referred to as "yellowcake". The remainder of the ore becomes tailings, which are contained and treated in engineered facilities near the mine (often in a mined-out pit). Leaching does not involve the generation of tailings.

11.2.3 There are no uranium mines in the UK, and thus no mining or milling activities in the UK.

11.3 Conversion, Enrichment and Fuel Fabrication

11.3.1 Natural uranium is predominantly a mixture of two radioactive isotopes (atomic forms) of uranium (U235 and U238). U235 makes up on average just 0.7% of natural uranium and is the uranium isotope used for fission by slow moving ("thermal") neutrons. Inside a nuclear reactor the nuclei of U235 split (fission) and, in the process, release energy.

11.3.2 The solid uranium oxide (U_3O_8) from the mine is purified and converted into gaseous form as uranium hexafluoride (UF_6) for the enrichment process. Enrichment increases the fraction of the U235 isotope through the use of diffusion or centrifuge technology. Both methods use the physical properties of molecules, specifically the 1% mass difference between U235 and U238, to separate the isotopes.

11.3.3 The enriched UF_6 is subsequently converted to uranium dioxide (UO_2) powder (which has a very high melting point), and these are pressed into ceramic pellets. These are then loaded into hollow metal tubes to form fuel rods. Clusters of these rods held in a regular geometry by grids form fuel assemblies (or elements) for use in the core of the nuclear reactor. The fabricated fuel is robust; the fuel pellets have a high melting point and are chemically stable and are themselves enclosed in gas tight metal tubes which are resistant to chemical corrosion.

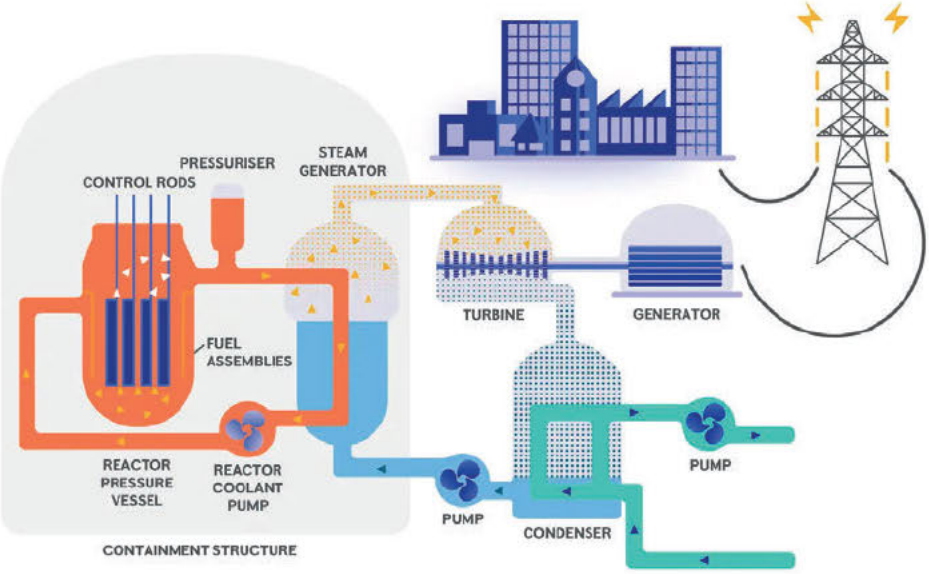
11.3.4 The RR SMR technology, in common with most reactor designs for electricity generation, utilises nuclear fuel of low enrichment, i.e. the proportion of U235 has generally been increased to around 5% or less. It is physically impossible for uranium at this level of enrichment to sustain a nuclear chain reaction without the presence of a moderator (a material like water or graphite that slows down neutrons). It is also impossible for a nuclear explosion to be achieved with material at this low level of enrichment.

11.3.5 Enrichment and fuel manufacture for the new technology could be sourced from either overseas or from the UK.

11.4 Electricity Generation

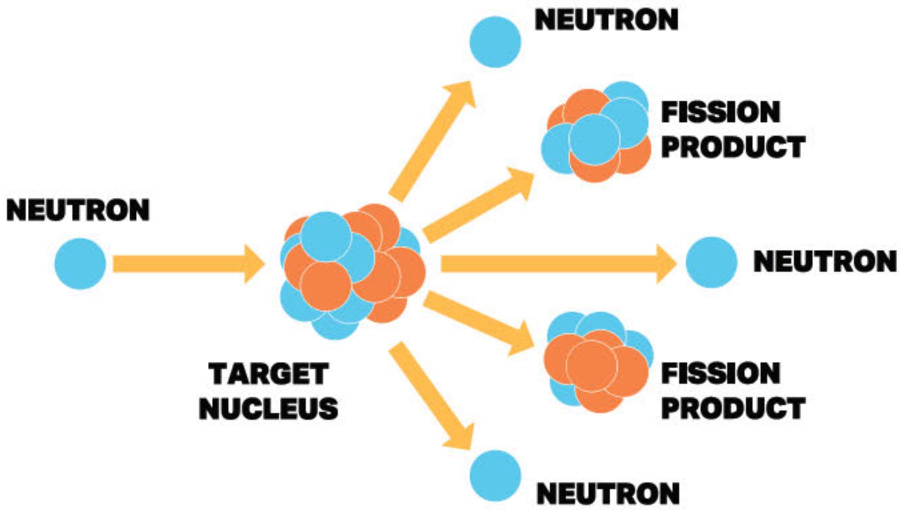
11.4.1 Nuclear reactors produce electricity by heating water to make steam. This steam is then used to drive turbines that generate electricity as shown below in Figure 16 (note: this depicts a generic PWR design. Specific information about the RR SMR design can be found in Annex 1). In this respect nuclear reactors are similar to other thermal power stations, where the heat is provided by burning coal or gas.

Figure 16: Generic Pressurised Water Reactor



11.4.2 The U235 atomic nuclei within the fuel rods in the reactor vessel release energy by splitting (fission). This is illustrated in Figure 17. Each fission event releases neutrons that can then cause other uranium atoms to undergo fission resulting in a chain reaction. A moderator is used to slow down the neutrons to help achieve this process, while control rods absorb excess neutrons to ensure the chain reaction continues at a controlled rate.

Figure 17: Schematic of the Fission Process



11.4.3 The main source of additional radioactivity generated as a result of this process are the fission products—the fragments remaining after the U235 nucleus has split. These fission products remain trapped inside the fuel pellets' ceramic structure and within the fuel's metal cladding.

11.4.4 Further information specific to the RR SMR is provided in Annex 1.

11.5 Spent Fuel Management

11.5.1 A nuclear fuel assembly can produce a very large amount of energy before it needs to be replaced. Typically, assemblies remain inside the reactor for 3-4 years. Light water reactors are shut down for refuelling—typically refuelling is at 1-2 year intervals when a quarter to a third of the fuel inside the reactor is replaced with fresh fuel.

11.5.2 When removed from a reactor, a fuel assembly emits both radiation and heat, principally from the fission products inside each fuel rod. Spent fuel is unloaded into an engineered storage "pond" (which looks like a very deep swimming pool) adjacent to the reactor where its radiation and heat level gradually decreases. The water in these ponds provides both radiation shielding and absorbs the heat. Spent fuel may be held in such ponds for periods from several months to many years.

11.5.3 Beyond the storage period in the ponds there are two main options available to the plant owner. The first is transfer of fuel to an engineered wet or dry storage awaiting a final repository for disposal. With this option, fuel could be stored on site throughout the life of the station. The second option is transfer to a GDF, which the Government has made clear that a process is well underway to identify a suitable site in which to develop a GDF that has suitable geology and the support of a local community **[123]**.

11.6 Radioactive Waste Management

11.6.1 Nuclear power stations generate radioactive waste in solid, liquid and gaseous forms. The vast majority of radioactivity generated remains confined within the fuel and is safely stored and managed as described above. Liquid and gaseous wastes are filtered and treated, and only very small quantities are permitted to be discharged into the environment in accordance with the Environmental Permitting (England and Wales) Regulations 2016 (as amended) **[124]**. These regulations require permits to cover all disposals including any discharges of radioactivity into the environment. Key features within these permits are limits on quantities of radioactivity (with separate limits for various types) which may be discharged and a requirement to use BAT to limit the amounts of radioactivity released into the environment. The treatment of liquid and gaseous wastes means that most of the radioactivity is captured and contained on solid media (for example in filters, resins etc.). Solid LLW from power stations is packaged and disposed of in the national Low-Level Waste Repository in Cumbria. Solid ILW generated during reactor operations is packaged and will be stored on a nuclear licensed site until final disposal in the GDF can be made.

11.7 Decommissioning

11.7.1 Decommissioning is the final stage in the life cycle of any power plant, prior to returning the site back to a "green field" or "brown field" condition for re-use. The key stages in the decommissioning process are set out in Annex 3.

11.7.2 To date about 100 commercial reactors and over 250 research reactors have been retired from operation and some of these have been fully decommissioned and dismantled **[125]**. Progress is being made in decommissioning commercial UK reactors under the aegis of the NDA, noting these are very different reactors to those elsewhere in the world. Further information on world-wide experience in decommissioning is included in Annex 3.

11.8 Transport

11.8.1 The operation of nuclear power stations requires the transport of radioactive materials to and from the site. Radioactive materials transport linked to RR SMR power station(s) would comprise:

- The transport of new fuel assemblies to the station;
- The transport of spent fuel from the station; and
- The transport of radioactive waste materials—either during normal operation or as part of the station's decommissioning.

11.8.2 These movements may take place by sea, road or rail. All three types of transport would be subject to UK regulations, which are framed so as to ensure that any possible additional radiological health detriment resulting from transport is extremely low. Radioactive material containers for highly radioactive material (e.g. spent nuclear fuel) are of high integrity to provide a very high level of protection for the public and workers from their radioactive contents. The containers are designed to withstand severe impacts without releasing their contents: this is demonstrated through a series of stringent tests as set out in IAEA regulations **[126]** which apply to the RR SMR.

11.8.3 Transport of radioactive materials is a well-established practice: about twenty million packages, of all sizes containing radioactive materials are routinely transported worldwide annually on public roads, railways and ships. Only around 5% of these movements are related to the nuclear power industry. Since 1971 there have been over 25,000 shipments of used fuel over more than 19 million kilometres. In summary, the industry has over 50 years of experience of nuclear transport with no transport accidents that have resulted in the release of radiation.

11.9 Low Level Waste Disposal

11.9.1 The UK has a low-level radioactive waste disposal facility located close to the West Cumbrian coastline in the North-West of England near Drigg. Established in 1959, the site has safely disposed of LLW for over 65 years. LLW is placed in engineered containers and is grouted prior to disposal in engineered concrete vaults or trenches.

11.9.2 It is envisaged that LLW arising from RR SMR operations will be transported to this low-level repository for final disposal. VLLW will be disposed of through conventional waste disposal streams in accordance with current government policy.

11.10 Intermediate and Spent Fuel Disposal

11.10.1 ILW and spent fuel from RR SMRs will be remain in interim storage on site until the UK GDF is available.

11.10.2 The NDA has responsibility for implementing geological disposal of higher activity radioactive waste. They are carrying out preparatory work to plan for geological disposal pending identification of a site under the Government’s Implementing Geological Disposal process.

11.10.3 More information on waste management and disposal can be found in Chapter 6.

12: ANNEX 3 - WASTE DISPOSAL AND DECOMMISSIONING

12.1 Introduction

12.1.1 At the end of the life of any power plant, it is necessary to decommission and demolish the facility so that the site can be made available for other uses. For nuclear power plants, the term decommissioning includes all clean-up of radioactivity and progressive dismantling of the plant. In 2023 the IAEA reported that, throughout the world, over 200 nuclear power plants had been permanently shut down. Of these, 21 have been fully dismantled. Approximately 50 are in the process of being dismantled with the other reactors being kept in a safe enclosure mode.

12.1.2 This Annex provides further background information relevant to Chapter 6 on:

- Worldwide approaches to disposal of radioactive waste;
- The different phases that comprise the decommissioning of a nuclear power station; and
- Worldwide experience of carrying out decommissioning.

12.2 Worldwide Experience on Radioactive Waste Disposal

12.2.1 Geological disposal at a depth of some hundreds of metres in a carefully engineered repository was first formally advanced as an appropriate, safe solution to radioactive management over sixty years ago, in the United States **[127]**.

12.2.2 The international situation is highly transparent. For example, the IAEA Joint Convention on Safety of Spent Fuel Management and the Safety of Radioactive Waste Management **[128]** obliges all signatory states (which include the UK) to submit regular, detailed overviews of their national waste management programmes.

12.2.3 Almost half of the 423 nuclear power reactors the world relies on today are expected to enter the decommissioning process by 2050 **[129]**.

12.3 Worldwide Approaches to Disposal of Intermediate-Level Waste

12.3.1 In a number of countries near surface disposal facilities for short-lived wastes have been developed at depths in excess of 80-100 m. For example, underground repositories for LLW and short-lived ILW have been operational in Finland for many years. Both the Olkiluoto and Loviisa nuclear power stations have on-site LLW and short-lived ILW repositories where conditioned wastes are disposed of in reinforced concrete silos approximately 70-100 metres underground. The final repository for short lived radioactive waste at Forsmark in Sweden uses a concrete silo constructed in a granite vault about 60 m below the surface. The same repository utilises large rock vaults (160 m long and 10-16 m high) for lower activity wastes and has been operating since 1988.

12.3.2 The long timescales over which some ILW and HLW—including Spent Fuel (when considered a waste)—remains radioactive has led to universal acceptance of the concept of deep geological disposal. Many other long-term waste management options have been investigated, but deep disposal in a mined repository is now the preferred option in most countries. The Waste Isolation Pilot Plant deep geological waste repository is in operation in the US for the disposal of transuranic waste—long-lived ILW from military sources, contaminated with plutonium.

12.3.3 All countries with repository plans for disposing of HLW or Spent Fuel also have plans for geological disposal of long-lived ILW (for example, arising from reactor decommissioning) and sometimes for all of their ILW. In some concepts (e.g. Switzerland) this would require a small extension to a Spent Fuel/HLW repository in the form of one or more caverns for the ILW packages. In other countries, a separate repository is planned (e.g. Sweden) and in Japan a low-level radioactive waste disposal centre at the Japan Nuclear Fuel Ltd. site at Rokkasho-Mura has been in operation since 1992.

12.4 Worldwide Approaches to Disposal of HLW and Spent Fuel

12.4.1 To date there has been no practical need for final HLW repositories as Spent Fuel may either by reprocessed or disposed of directly. Either way, there is a strong technical incentive to delay final disposal of HLW for about 40-50 years after removal, at which point the heat and radioactivity will have reduced by over 99%. Interim storage of Spent Fuel is mostly in ponds associated with individual reactors, or in a common pool at multi-reactor sites, or occasionally at a central site. At present there is about 263,000 tonnes of Spent Fuel in storage worldwide. Over two-thirds of this is in storage ponds, with an increasing proportion in dry storage **[4]**.

12.4.2 Progress on providing deep geological repositories for HLW and/or Spent Fuel is most advanced in Finland (where disposal operations are expected to commence in 2024) and Sweden.

12.4.3 Sweden is planning to encapsulate all of its spent fuel in copper canisters which will then be deposited in bedrock, (embedded in clay), and at a depth of 500 m. Fabrication techniques for the canisters have been tested at the Canister Laboratory in Oskarshamn and an application was submitted in November 2006 to build the disposal facility. Site investigations for the repository were begun at two sites—Oskarshamn and Forsmark in 2002, with the aim of selecting the most suitable site. In 2009 Forsmark was chosen by the Swedish Nuclear Fuel and Waste Management Company as the repository site and in 2011 a licence application for the repository was submitted to the Swedish Government and the Environmental Court, outline approval was granted in 2022. The next step in the licensing process is for the Land and Environment Court to establish conditions for the facilities. The Swedish Radiation Safety Authority will also decide on permit conditions under the Nuclear Activities Act. Only when all licences are in place can construction start, after which time, it will take about 10 years to build the Spent Fuel repository.

12.4.4 In Finland, detailed site characterisation was undertaken at four sites in the period 1993-2000 and in 1999 an application was made to Finish Government to proceed with the repository project and an underground rock characterisation facility called ONKALO at Olkiluoto. Parliament ratified the Government decision in May 2001 (by 159 votes to 3). Construction of the rock characterisation facility, which will eventually become an integral part of the repository, began in 2004 and the inclined tunnel stands at 4,987 m long and extends to a depth of 455 m. A construction application for a GDF for Spent Nuclear Fuel was submitted to the Finish Government in December 2012 with disposal operations planned to commence in 2024.

12.4.5 In France a siting process to determine a suitable location for a GDF was launched in 1992 with a National Call for volunteering. In 1998 an Underground Research Laboratory in the Meuse/ Haute-Marne region of France was licensed. A series of legally mandated public debates were initiated in May 2013 which will be followed by the final selection of sites for surface and underground installations. A decision on licencing the GDF has not yet been made (2024).

12.5 The Stages of Decommissioning

12.5.1 The decommissioning process can be broken down into the following stages:

- Defuelling;
- Post-Operations Clean Out;
- Dismantling;
- Site clearance; and
- De-licensing.

Defuelling

12.5.2 Defuelling of the reactor(s) would be the first step of decommissioning and would take place as early as possible once the reactor had been shut down for the last time. This activity accounts for the removal of 99.9% of the radioactive materials from within the reactor. Fuel is extracted from the reactor in the same manner, and using the same equipment, as routine refuelling operations during the electricity generation phase. The fuel from the reactor would initially be stored in the fuel ponds for a period of 6-10 years, before it was moved to a “stand-alone” interim storage facility which could be on the power station site but may be elsewhere. Interim storage would last until transport to a final GDF. Arrangements for storage of the lifetime arisings of fuel from the station will have been developed as part of planning for the operational life of the station (see section on spent fuel management in Chapter 6).

12.5.3 Completion of defuelling would allow those plant and systems previously required for the safe handling of the fuel to be decommissioned and the rate of progress of the station decommissioning can then be independent of the disposal timetable for the spent fuel itself.

12.5.4 The long-term care and maintenance and ultimate decommissioning of any on-site interim storage facilities would be incorporated into the station’s decommissioning strategy.

Post-Operations Clean Out

12.5.5 Once the reactor has ceased operating, post-operations clean out can begin. This phase is run as far as possible concurrently with defuelling, although clean out of some areas would need to wait until the Spent Fuel ponds are empty.

12.5.6 During this phase the plant is decontaminated. The term decontamination covers the broad range of activities intended to remove or reduce the radioactive contamination in or on materials, structures and equipment at a power station. Decontamination will be carried out on various internal and external surfaces of components and systems, building surfaces and the tools used during operations and decommissioning. The process of decontamination associated with decommissioning can be conducted before, during or after dismantling.

12.5.7 Decontamination helps to reduce the radiation doses to workers during decommissioning (see Chapter 5 for more details on dose during decommissioning). It also minimises the volume of radioactive waste by cleaning materials with only surface contamination, so allowing materials to be re-used or recycled.

12.5.8 A number of decontamination techniques such as chemical washing, shot blasting (with different types of media), high pressure water, surface scabbling and peelable coatings have been developed and are currently in use during decommissioning, both in the UK and internationally.

Dismantling

12.5.9 Dismantling involves cutting up large components into smaller pieces that are then removed. There are many available dismantling techniques such as diamond wire sawing, shearing, manual disassembly, thermal cutting and high-pressure abrasive cutting applicable to reactor decommissioning that have been used internationally and in the UK.

Site Clearance

12.5.10 During this stage the final buildings and materials are removed from the site for reuse, recycling or disposal. The interim storage facilities for ILW and spent fuel would also be removed at this stage if a final disposal facility was operating and all these materials had been removed and transported off-site. If a disposal facility were not available, they would remain on the site in interim surface storage facilities.

12.5.11 Once this work has been completed, a survey of the power station site would be performed to demonstrate that the residual activity levels on the land are at or below the levels stated in the decommissioning plan and at or below the levels the regulator requires for the land to be released for re-use or for another pre-defined purpose.

De-licensing

12.5.12 The final stage is when the operator of the site makes an application to the regulator for the site to be de-licensed. This is the process where there has been demonstrated to be no further need for regulatory control and the land can be released to be reused for other purposes.

12.6 Worldwide Experience in Decommissioning

United Kingdom

12.6.1 The Nuclear Decommissioning Authority is a Government-funded body responsible for safely and securely decommissioning the UK’s former nuclear sites and overcoming the challenges of managing and disposing of nuclear waste. With a workforce of 17,000 across 17 sites.

12.6.2 All ten Magnox power stations in the UK are currently at various stages of decommissioning. All sites will be decommissioned in accordance with the “Care and Maintenance” (“C&M”) strategy which comprises four main steps:

1. Defuelling.
2. Prepare the site for Care and Maintenance by:
   - Removing all conventional ancillary plant, equipment and buildings; and
   - Rendering the site passively safe for the medium to long term with minimal need for human intervention.

3. Care and Maintenance phase:
   - Maintain the bulk reactor structure (the reactor "Safestore") for a period of decades to allow radioactivity to decay; and
   - Transfer ILW to the GDF.
4. Final site clearance:
   - Dismantle and remove the reactor Safestore and the ILW store; and
   - Clear the site and release it for re-use.

12.6.3 The UK Magnox stations have had all of their fuel removed and preparations are now underway to place them into Care and Maintenance. In a first for the UK nuclear industry, the ONR granted permission for the Bradwell site in Essex to enter 'care and maintenance', meaning that the site has been put in a safe and secure state until final clearance in around 60 years. Trawsfynydd is also undertaking accelerated decommissioning with a view to moving into the C&M phase within the next few years, some 10 years earlier than originally planned. All the remaining stations, including Wylfa, are expected to enter C&M before 2030.

12.6.4 The following paragraphs provide some additional details of progress on power reactor decommissioning in the UK.

12.6.5 Berkeley nuclear power station closed in 1989, and defueling of the site was completed ahead of target in June 1992 with around 85,000 fuel elements discharged from the reactors. This was followed by the removal of asbestos insulation at the plant and its subsequent clean-up and dismantling. The decommissioning included the removal of reactor cooling circuit gas ducts and boilers, the complete dismantling and decontamination of the fuel handling equipment and cooling ponds, and the deplanting and demolition of the turbine hall, cooling water plant and ancillary buildings. It was possible for substantial quantities of plant, equipment and materials to be re-used or recycled. Contaminated plant was decontaminated where possible to minimise the quantities of radioactive waste resulting from decommissioning. The height of the reactor buildings was reduced and they were enveloped in a robust cladding to prepare the reactors for their extended period of "Safestore". In May 2023, work began to demolish four 'blower house' superstructures that surround Berkeley site's two reactor buildings. Once responsible for circulating gas through the reactors to transfer heat into 310 tonne boilers, creating steam to turn the turbines, the buildings will be emptied of the residual LLW, undergo a full asbestos clean and be demolished. One of the largest decommissioning projects seen at the site for several years, the project, originally planned for the 2070's, has been brought forward by five decades and will take eight years to complete.

12.6.6 The Windscale Advanced Gas Cooled Reactor ("WAGR") operated from 1962-1981 was the prototype for the seven commercial scale Advanced Gas-cooled Reactor stations now operated by Électricité de France ("EDF") Energy. The decommissioning of WAGR was initially undertaken as a demonstration exercise and substantial progress has been displayed. Fuel removal was completed in 1983, with the fuel handling equipment, heat exchangers, reactor top biological shield and pressure vessel head all removed by 1995. In the period to 2006, the reactor core and remainder of the reactor vessel were also removed. Decommissioning is expected to be complete in 2120.

12.6.7 The low power research reactor GLEEP at Harwell is an example in the UK where, following over 40 years of operation, decommissioning has progressed to the stage where the entire reactor has been removed and the land made available for economic regeneration.

United States

12.6.8 There is a range of experience available from the US. Ten plants classified as "power reactors" have either had their licenses terminated completely by the Nuclear Regulatory Commission ("NRC"), the US nuclear safety regulator, as a result of completed decommissioning or retain a licence only for the purpose of fuel storage in an Independent Spent Fuel Storage Installation ("ISFSI"). An additional 23 plants are recorded by NRC (September 2023) as currently undergoing decommissioning. These include the San Onofre Unit 1 plant which is substantially decommissioned but had the removed reactor vessel in storage on the site. Humboldt Bay 3 and Zion 1 & 2 are recorded as having a decommissioning ("DECON") status indicating that active decommissioning is in progress. Two plants, San Onofre Units 2 and 3 shut down in January 2012 with defueling completed in August 2020. The licensee projects that all decommissioning activities will be completed by 2051, approximately two years after the anticipated removal of the last spent fuel from the site.

12.6.9 At multi-unit nuclear power stations, the approach has generally been to place the first closed unit into storage until the others end their operating lives, so that all can be decommissioned in sequence. This optimises the use of staff and the specialised equipment required for cutting and remote operations and achieves cost benefits. Thus, after 14 years of comprehensive clean-up activities, including the removal of fuel, debris, and water from the 1979 accident, the Three Mile Island Unit 2 was placed in Post-Defuelling Monitored Storage (Safestore) until the operating licence of Unit 1 expired in 2014. Fuel was removed from Unit 1 in 2016 and placed in dry storage in an ISFSI. Unit 1 is now in Safestore ahead of decommissioning and Unit 2 is undergoing decommissioning which is expected to be complete in 2052. Similarly, Indian Point Unit 1 was shut down in 1974 and subsequently defueled. It was placed in Safestore condition awaiting closure of Units 2 and 3, which ceased operations in April 2020 and April 2021. Work is currently being undertaken to prepare all 3 units for decommissioning.

12.6.10 An example of a US DECON project is the 60 MWe PWR at Shippingport, Pennsylvania that operated commercially from 1957 to 1982. It was used to demonstrate the safe and cost-effective dismantling of a nuclear power plant and the potential for early release of the site. Defuelling was completed in two years, and five years later the site was released for use without any restrictions. Because of its modest size, the pressure vessel could be removed and disposed of intact. This has also been the approach of a number of subsequent larger US projects.

12.6.11 Immediate DECON was also the option chosen for the facility at Fort St Vrain, Colorado, a 330 MWe high-temperature, gas-cooled reactor which closed in 1989. This took place on a fixed-price contract for US$ 195 million (hence costing less than 1 cent/kWh despite only a 16-year operating life) and the project proceeded on schedule to clear the site and relinquish its licence early in 1997—the first large US power reactor to achieve this.

12.6.12 For Trojan (1,180 MWe, PWR) in Oregon the dismantling was undertaken by the utility itself. The plant closed in 1993, steam generators were removed, transported and disposed of at the Hanford Site in Washington State in 1995, and the reactor vessel was removed and transported to Hanford in 1999. Except for the used fuel storage area, the site was released for unrestricted use in 2005.

12.6.13 Another US DECON project was carried out at Maine Yankee, an 860 MWe PWR plant that closed down in 1996 after 24 years of operation. The containment structure was finally demolished in 2004 and, except for 5 hectares of land used for the dry storage of spent fuel, the site was released for unrestricted public use in 2005 on schedule and within budget.

Spain

12.6.14 Spain's Vandellos-1, a 480 MWe gas-graphite reactor, was closed down in 1990 after 18 years of operation, due to a turbine fire that made the plant uneconomic to repair. In 2003, Empresa Nacional de Residuos Radiactivos, S.A. ("ENRESA"), the state decommissioning and waste management organisation, concluded phase 2 of the reactor decommissioning and dismantling project, which allows much of the site to be released. After 30 years in Safestore, when activity levels will have diminished by 95%, the remainder of the plant will be removed. The cost of the 63-month project was €93 million.

12.6.15 Jose Cabrera power station is a 160 MWe PWR which operated from 1968 until 2006. In 2010 after defueling and Post Operational Clean Out, the site license was transferred to ENRESA. Decommissioning is proceeding with the reactor internals removed, the turbine hall deplanted and converted to a waste processing facility, and other components and structures removed. Decommissioning is in the final phase of site restoration. Total cost of dismantling is expected to be €135 million (in 2003 money values) plus €35 million for spent fuel management and an undisclosed sum for waste disposal.

12.6.16 Santa Maria de Garona, a 446 MWe boiling water reactor unit, was permanently shut down in 2017. The site licence was transferred to ENRESA in 2023 and the first stage (of two stages) of the dismantling project commenced, this initial phase is expected to take 3 years and activities include the removal of spent fuel to interim onsite storage and the dismantling of the turbine building. A second phase, for which ENRESA will need separate authorisation, will involve the dismantling of the reactor and other buildings. This phase will run from 2026-2033 and will culminate with the environmental restoration of the site, in Burgos, northern Spain. The total decommissioning programme, that will last for 10 years, is expected to cost an estimated €475 m ($528 m).

Japan

12.6.17 Japan's Tokai-1 reactor, a UK Magnox design, is being decommissioned after 32 years of service, ending in 1998. After 10 years storage, in Phase 2 (to 2011) the steam generators and turbines were removed, and in Phase 3 (to 2018) the reactor is being dismantled, the buildings demolished and the site left ready for re-use. The total cost will be JPY 93 billion (USD 1.04 billion)—$35 billion for dismantling and $58 billion for waste treatment.

12.6.18 Following the 2011 Great East Japan Earthquake 21 nuclear reactors have entered the decommissioning process:

Fukushima Daiichi Nuclear Power Station

12.6.19 Tokyo Electric Power Company Holdings ("TEPCO") oversees the decommissioning of the four damaged Fukushima Daiichi reactors. The project consists of treating radioactive water, removing nuclear fuel debris, and spent nuclear fuels, managing radiological waste, and ultimately demolishing the facilities. Removing fuels and fuel debris in Units 1, 2, and 3 is still an uncharted area for the domestic and international nuclear communities. To reduce the risk of any accident, preparations for this most challenging part of the project are under way. The aim is to conduct the inner investigation of the Unit 2 reactor, begin the trial retrieval while removing obstacles within the pressure container vessel, and gradually enlarge the scale of the retrieval. The International Research Institute for Nuclear Decommissioning, GOJ, and Mitsubishi Heavy Industries ("MHI") jointly developed the robotic arms specifically for these efforts. In this ongoing 40-year project, to date, U.S. firms have contributed products and technologies critical to water treatment efforts and have offered U.S. waste management methodologies.

Non-Accident Commercial Reactors

12.6.20 As of August 2023, fourteen non-accident shutdown reactors are being decommissioned at an average estimated cost of $500–$700 million each. Generally, domestic reactor vendors Toshiba, MHI, and Hitachi, as well as major engineering firms or general contractors, serve as the prime contractors to licensees. However, U.S. firms gained foothold by partnering with Japanese firms and participating in bigger decommissioning projects in western Japan using PWRs.

Germany

12.6.21 At present, 28 German nuclear power plants (power and prototype reactors) are in the process of being decommissioned and three power plants have been dismantled completely. Germany chose immediate dismantling over safe enclosure for the closed Greifswald nuclear power station in the former East Germany, where five reactors had been operating.

12.6.22 Similarly, the site of the 100 MWe Niederaichbach nuclear power plant in Bavaria was declared fit for unrestricted agricultural use in mid-1995. Following removal of all nuclear systems, the radiation shield, and some activated materials, the remainder of the plant was below accepted limits for radioactivity and the state government approved final demolition and clearance of the site.

12.6.23 The 250 MWe Gundremmingen-A unit was Germany's first commercial nuclear reactor, operating from 1966-77. Decommissioning work started in 1983, and moved to the more contaminated parts in 1990, using underwater cutting techniques. This project demonstrated that decommissioning could be undertaken safely and economically without long delays, and with most of the metal being recycled.

12.6.24 Stade was a 662 MWe PWR that operated from 1972 until 2003. Decommissioning is in progress with the steam generators, reactor internals and reactor vessel removed by specialist contractors selected for each task. The conventional demolition of individual buildings on the power plant site began in 2023.

12.6.25 Würgassen was a 640 MWe Boiling Water Reactor ("BWR") plant which operated from 1975 until 1994. Decommissioning has been in progress since 1997, mainly carried out by the site workforce and is now substantially complete. The reactor internals and vessel were segmented and packaged by a specialist contractor. Two interim storage facilities for low and intermediate-level radioactive waste remain at the site, although the interim storage facility located in the power plant building is currently being cleared. In contrast to the interim storage facilities at other nuclear power plant sites, no spent fuel assemblies are stored in Würgassen.

France

12.6.26 To decommission its retired gas-cooled reactors at the Chinon, Bugey, and St Laurent nuclear power stations, Électricité de France chose partial dismantling and postponed final dismantling and demolition for 50 years. As other reactors will continue to operate at those sites, monitoring and surveillance do not add to the cost.

12.6.27 Currently nine reactors have been shut down and are being decommissioned: Brennilis, Bugey Unit 1, Chinon units A1, A2 and A3, Chooz A, Creys-Malville and Saint-Laurent units A1 and A2.

12.6.28 The PWR at Chooz A is a 310 MWe PWR which operated from 1967 to 1991. It is an unusual design in that the reactor and its auxiliary systems were built into two rock caverns rather than being housed in a conventional containment building and annexes. Dismantling of all plant and systems outside the caverns began in 1999 and was completed in 2004. Since 2010, work has been carried out on removal of the systems within the cavern. Removal of the steam generators is complete and primary circuit removal is progressing. Decommissioning of the reactor pressure vessel began in 2016, the main operation in progress is the dismantling of the vessel's internal equipment, which is carried out under water. The licensee is required to monitor the water in the cave until an effluent concentration of tritium is compatible with the cessation of treatment and discharge. The last stage of the process will include the complete dismantling of the residual equipment of the caves and the effluent treatment station, the demolition of the buildings and the redevelopment of the site.

12.6.29 At Marcoule, a recycling plant is being built for steel from dismantled nuclear facilities. This metal will contain some activation products, but it can be recycled for other nuclear plants.

12.7 Summary

12.7.1 International experience has demonstrated that, where appropriate waste disposal routes exist, nuclear facilities have been successfully and completely decommissioned. Modern reactor designs are more straightforward to decommission than older designs, using for example improved materials which are less susceptible to activation and employing routine decontamination during operations. In particular, the activated primary circuits are smaller and more straightforward to dismantle.

13: ANNEX 4 - SUPPLEMENTARY NOTES ON RADIATION

13.1 How good is our understanding of the health risks from radiation exposure?

13.1.1 Radioactive materials and nuclear reactors are among sources of what is termed ionising radiation. Other sources include X-ray generators and cosmic rays that strike the Earth from outer space. Its effects on human health have been studied throughout the twentieth century and into the twenty-first century and over this time scientific understanding has advanced enormously, especially over the last 70 years. The health effects of exposure to ionising radiation are better understood than are the effects of chemical and biological exposures resulting from the use of many common everyday materials—with the possible exception of tobacco smoke, ionising radiation has been the most extensively studied of all environmental exposures.

13.1.2 This understanding is based on scientific research. Among the most important is the epidemiological study of people who have been exposed to this type of radiation, drawing on data gathered over many years. This includes studies of those who have been exposed through their jobs (such as hospital radiographers or nuclear industry workers) or through such major events as the atomic weapons explosions at Hiroshima and Nagasaki in Japan. International groups of scientists collaborate on this work and several bodies have developed a worldwide reputation as authoritative sources of advice. These include the International Commission on Radiological Protection ("ICRP"), the United Nations Scientific Committee on the Effects of Atomic Radiation ("UNSCEAR"), the Committee on the Biological Effects of Ionizing Radiations ("BEIR") of the US National Research Council and, in the UK the UK Health Security Agency ("UKHSA") formerly, Public Health England ("PHE", previously the Health Protection Agency incorporating what was formerly the National Radiological Protection Board).

13.1.3 In its most recently published 2007 Recommendations the ICRP saw no reason to change its existing advice on radiation dose limits **[130]**—dose limits that have now been in place for over 30 years. This is evidence of a stable position.

13.1.4 Despite this stability, based on a high level of consensus and a mature scientific understanding, there remain areas of debate, continuing research and residual uncertainty. This is part of normal scientific progress as areas of uncertainty are addressed and reduced. However, it is important to recognise that the scale of this remaining uncertainty is too small to cast any significant doubt over the conclusions on radiological health detriment presented in this Application. More detail on this is provided within this Annex.

13.1.5 Exposure to ionising radiation gives rise to two types of health effects: deterministic effects (now also known as tissue reactions) and stochastic effects. Deterministic effects occur only above certain threshold doses while stochastic effects are thought to be effects for which there is no dose threshold and for which the likelihood of occurrence is related to the level of exposure to radiation **[131]**.

13.1.6 The approach to radiological protection is designed to eliminate all deterministic effects and to reduce the probability of stochastic effects to a level that is acceptable to exposed individuals and society. What level is acceptable is derived from comparisons with the range of voluntary and involuntary risks that people accept in everyday life, including the risk posed by essentially unavoidable exposure to natural background radiation (see Box 5 in Chapter 5 of this application).

13.1.7 The relationship between the probability of the occurrence of a stochastic health effect (the response) and the level of exposure to radiation (the dose) at the low levels of radiation exposure routinely experienced at work or in the environment is assumed, for the purposes of radiological protection, to be linear no-threshold ("LNT") **[130]**—put simply, the response is assumed to be directly proportional to the dose with no threshold dose below which the effect does not occur. This approach is taken because it is believed to be prudent and so is likely to err in the direction of caution, with the ICRP stating it is the *"best practical approach to managing risk."* It is also an approach that has the considerable merit of practicality for those managing radiation protection. The commonly used shorthand statement *"There is no such thing as a safe dose of radiation"* derives from this assumption of no threshold dose for stochastic effects, but is a distortion of the LNT approach because it equates "safe" with *"no effect at all, no matter how small"*, which is not correct—it is the level of risk upon which a judgement is made as to whether or not an exposure is safe.

13.1.8 Two types of stochastic health effect are of concern to radiological protection: cancer in the exposed individual and hereditary disease in the individual's descendants. Studies have steadily shown that, of these two, the evidence for genetic effects is extremely weak but there is clear evidence of increased cancer risks for exposures of over 50 mSv.

13.1.9 The ICRP has assessed the nominal risk coefficients **[130]** (the average additional risk, weighted by the health detriment of the effect, per unit radiation dose received) following low dose and/or low dose-rate exposure is shown in Table 20.

Table 20: ICRP nominal risk coefficients

Exposed Population*	Cancer (Sv-1)	Heritable Effects (Sv 1)	Total Detriment (Sv-1)**
All Ages	5.5%	0.2%	5.7%
Adult	4.1%	0.1%	4.2%

* The differences between the risk factors for the whole population and those for the adult population alone are due to the higher sensitivity of children to radiation-induced cancer and the longer length of time over which the risk is expressed, and the fact that younger people have a greater potential period for reproduction and passing on heritable effects.

**The somatic health effects are weighted to take account of the severity of the effect (e.g. lethality, years of life lost).

13.1.10 These factors are based on an average of sex, age and population and are not meant to be exact. They are nominal risk coefficients derived for the purposes of making decisions on radiological protection not for predicting precise numbers of health effects in a specific population. Significant effort has been expended in recent years to quantify the uncertainty associated with these risk estimates.[152] These uncertainty analyses take account of a range of possible contributions including, for example, variations to the assumption of the LNT relationship at low doses/dose-rates (see above). Overall, these indicate that the uncertainty in the coefficients tabulated is unlikely to be more than a factor of two in either direction (i.e. the "true" risk coefficients are likely to lie within a range from half to twice the risk coefficients adopted by the ICRP).

13.1.11 This does not mean to say that the uncertainty cannot be smaller or larger for a particular set of exposure circumstances but that the overall risk coefficients upon which the framework of radiological protection is based will be accurate within a factor of around two.

13.1.12 There are other issues under discussion within the scientific community that could, to varying degrees, affect radiation risk coefficients and radiological protection. Probably the most important of these is whether exposure to low levels of radiation can increase the risk of diseases other than cancer in the exposed individual, in particular, cardiovascular disease. *"There is increasing evidence of cardiovascular and cerebrovascular effects from radiation exposure. The subcommittee established by COMARE is reviewing evidence of the potential health impacts that may be caused by low doses of radiation. A draft report completed during 2023 has been reviewed by external experts."* [153]

13.1.13 However, the ICRP has judged that the present scientific evidence is not persuasive that low dose/dose-rate exposure does increase the risk of non-cancer diseases in the exposed individual and has concluded that these diseases should not be included in the risk estimates that underly the Commission's Recommendations for radiological protection. Nonetheless, ICRP is monitoring the evidence for radiation-induced non-cancer diseases to ascertain whether there is a need to include these diseases into the scheme of radiological protection. In particular, it will be important to properly account for the influence of major risk factors such as smoking and obesity before any effect of low-level radiation exposure can be fully assessed. This is illustrated by a study of the workforce of British Nuclear Fuels plc ("BNFL") **[132]**, which found that no firm conclusions could be drawn with regards to the rate of non-cancer mortality in relation to low-level radiation exposure. An association with circulatory disease mortality was found, but with multiple uncontrolled factors, including the impact of shift work, limiting any results. The study was also limited by lack of internal dose exposure data, and an observed inhomogeneous dose-response. The authors concluded that further work was required to examine the possible influence upon the association of major risk factors in circulatory diseases (smoking, diet, etc.) before the finding could be properly understood.

152] The ICRP, as part of the continuing process of the creation and promulgation of its recommendations, researches the wide array of subjects that make up the study of radiation exposure and risk. The 2021 publication of "Keeping the ICRP recommendations fit for purpose" (C Clement et al 2021 J. Radiol. Prot., Vol. 41 1390) marked the start of the collation of research for the next set of recommendations. As part of this process, ICRP task groups are formed to further the understanding of various areas of radiological protection. At the time of the publication of this application, there are 30 Active, Work-In-Progress task groups, studying a wide range of subjects, which can be further explored at https://www.icrp.org/page.asp?id=404.

153] COMARE_Annual_Report_2023_-_final.pdf (publishing.service.gov.uk)

13.2 What is the evidence of health effects around United Kingdom nuclear sites?

13.2.1 Despite the United Kingdom nuclear power industry's excellent safety record, there have been concerns raised over suggestions that there may be heightened levels of certain cancers in areas close to some nuclear sites. These concerns have been the subject of extensive independent research over a period of 40 years.

13.2.2 In the UK, the Committee on Medical Aspects of Radiation in the Environment ("COMARE") is the independent expert body that has overseen this subject since its establishment in 1985 **[133]**. Its Tenth report was published in 2005 **[134]**. So far as nuclear power station sites are concerned, the conclusion of this report was unambiguous stating:

"We can, therefore, say quite categorically that there is no evidence from this very large study that living within 25 km of a nuclear generating site within Britain is associated with an increased risk of childhood cancer."

13.2.3 In 2011, COMARE published its Fourteenth Report **[135]**, considering further the incidence of childhood leukaemia around nuclear power stations in Great Britain. The report concluded:

"Based on the evidence presented in this review, COMARE sees no reason to change its previous advice to Government (as given in our tenth report – COMARE, 2005) that there is no evidence to support the view that there is an increased risk of childhood leukaemia and other cancers in the vicinity of NPPS [nuclear power plants] in Great Britain."

13.2.4 The Tenth COMARE report recommended that despite the lack of evidence of any link between proximity to nuclear power stations and childhood cancers (most prominently non-Hodgkins lymphoma ("NHL") and leukaemia), the incidences of such cancers should be kept under surveillance and periodic review. It was as part of this review regimen that the Seventeenth COMARE report was published in 2016 **[136]**, to ensure analysis was kept up to date. The report concluded that:

"The absence of correlation between the incidence rates of leukaemia and NHL predicted on the basis of assessed radiation doses and the observed incidence rates at three different nuclear sites further supports the conclusion that radiation cannot be a major causal factor in these areas."

13.2.5 The report also noted that there is no evidence that proximity to Sellafield or Dounreay increase the risk of leukaemia or NHL amongst children or young adults—in fact there has been only a single case of leukaemia, and none of NHL in these areas between 1991 and up to the publication of the COMARE report in 2016.

13.2.6 The study of these issues is complex, and a summary of the history is provided within this Annex.

13.2.7 In November 1983, the broadcast of the documentary "Windscale – the Nuclear Laundry" led to understandable concern; the programme makers pointed to a notable excess in cases of childhood leukaemia that had occurred in the West Cumbrian coastal village of Seascale, adjacent to the Sellafield nuclear complex (previously known as "Windscale and Calder Works"). The implication was clear: radioactive discharges from Sellafield had been responsible.

13.2.8 The Government immediately established an independent expert inquiry, chaired by Sir Douglas Black, to examine the claim, and the report of the inquiry was published in July 1984. In essence, that report confirmed that a notable "cluster" of childhood leukaemia had occurred in Seascale, but that the amounts of radioactive material discharged from Sellafield were more than one hundred times too small to be responsible.

13.2.9 Reports of further "clusters" of childhood leukaemia near certain nuclear installations followed, in particular an excess of cases near the Dounreay establishment in Caithness, northern Scotland (once home to the only large-scale fuel reprocessing plant in Britain other than at Sellafield). These reports, together with revisions that had to be made to the Sellafield discharge record, led to further concern, with suggestions that radiation exposures had been much greater than previously assessed and/or that the risk of childhood leukaemia from radiation had been seriously underestimated.

13.2.10 Substantial research followed during the 1980s, overseen by the independent expert COMARE that had been set up on the recommendation of Sir Douglas Black's group. By 1990, an effective scientific consensus had been reached that direct exposure to radioactive material discharged from nuclear installations could not be responsible for the reported "clusters" **[137]**. For example, it was shown that if risk estimates for childhood leukaemia had been severely underestimated, then a pronounced excess of cases of childhood leukaemia should have occurred in Great Britain as a result of the fallout from atmospheric nuclear weapons testing during the late-1950s and early-1960s whereas no such marked increase had been observed. The study of the influence of fallout from nuclear weapons test explosions, which led to the intake of radioactive materials similar to those released from nuclear power stations, has continued, and although the global presence of these radionuclides is readily detectable and in quantities generally much greater than that from the discharges of nuclear installations, the absence of any discernible resulting increase in the incidence of childhood leukaemia weighs heavily against the intake of these radionuclides causing these "clusters".

13.2.11 Research into these "clusters" nevertheless continued, and in 1990 Professor Martin Gardner and his colleagues appeared to have found a possible explanation for the Seascale "cluster" from an epidemiological study they had conducted in West Cumbria. Among many potential factors they had studied, radiation exposure of fathers working at Sellafield before the conception of their children seemed to be capable of accounting statistically for the Seascale cluster. The statistical association they found appeared significant, although a causal explanation was at odds with other scientific evidence relating to childhood leukaemia. A cause-and-effect interpretation of Gardner's statistical association became more unlikely when the same finding was not confirmed by other similar studies using independent data—for example, an excess of childhood leukaemia was not observed in the offspring of survivors of the atomic bombings of Hiroshima and Nagasaki, and it was found not to account for the excess of cases near Dounreay. Moreover, no increased rate of childhood leukaemia was found among children of the much greater number of Sellafield fathers who lived outside the village of Seascale. By the end of the 1990s the idea that childhood leukaemia "clusters" might be the result of radiation exposure of fathers was effectively abandoned.

13.2.12 In 2008, the findings of a study (the "KiKK Study") **[138]** of cancer in young children less than 5 years of age living in the vicinity of nuclear power stations in Germany were published. It was reported that, at the time of diagnosis, young children affected by cancer tended to live closer to the stations than young children free of cancer—a result that was essentially due to leukaemia among young children resident within 5 km of a nuclear power plant. These findings prompted the German Commission on Radiological Protection (("SSK"), broadly equivalent to COMARE) to examine whether radiation exposure due to the operation of German nuclear power stations could be responsible. SSK concluded that:

"The natural radiation exposure within the study area, and its fluctuations, are both greater, by several orders of magnitude, than the additional radiation exposure caused by the relevant nuclear power plants. If one assumes that the low radiation exposures caused by the nuclear power plants are responsible for the increased leukaemia risk for children, then, in light of current knowledge, one must calculate that leukaemias due to natural radiation exposure would be more common, by several orders of magnitude, than they are actually observed to be in Germany and elsewhere."

13.2.13 COMARE examined the KiKK Study as part of its Fourteenth Report **[135]**. The Committee pointed to a number of difficulties faced by those conducting the KiKK Study, such as problems in selecting representative control children with which children affected by cancer were compared, and in the interpretation of the results. For example, distance from a nuclear power station was in terms of residence at diagnosis only, and full residential histories were not obtained, nor was any attempt made to assess radiation doses by taking into account factors such as wind direction or source of foodstuffs. Further, the influence of a previously known "cluster" of childhood leukaemia cases near the Krümmel nuclear power station may not have been fully taken into account in interpreting the results of the KiKK Study **[139]**. The Krümmel cluster has been investigated intensively, but no evidence has been found to indicate that radioactive discharges could be involved.

13.2.14 Studies attempting to reproduce the KiKK Study have now been conducted in a number of countries, the largest of these being carried out in France and Great Britain. In France, an association between residential distance and leukaemia in young children was found, but when doses from atmospheric discharges were estimated on the basis of wind direction rather than distance alone, the association disappeared **[140] [141]**. In Great Britain, in a study designed to be as similar as possible to the KiKK Study with the data available, no association with distance of maternal residence at birth from a nuclear power station was found **[142]**. These two British and French studies do not support the notion of a material increase in the risk of leukaemia in young children living close to nuclear power stations and give further reason to reject an interpretation of the findings of the KiKK Study in terms of radiation exposure.

13.2.15 So, what is the explanation for the excesses of childhood leukaemia that have been found near certain nuclear installations? It should be appreciated that "clusters" of childhood leukaemia have been reported over many years (including reports from before the era of nuclear power), and that they are by no means associated only with nuclear installations. A striking example, and the most extreme cluster that has been reported, is from the town of Fallon in rural Nevada, which is not close to a nuclear facility.

13.2.16 An idea that has been discussed for many years, but which has been developed significantly since the late-1980s, is that infections play a major role in the development of childhood leukaemia. In the unusual conditions where previously isolated, largely rural, communities (such as West Cumbria or Caithness) undergo substantial population mixing (as occurred, for example, when large nuclear facilities were constructed in the 1950s and subsequently underwent major expansion), unusual infective processes may have resulted in raised risks and the observed "clusters".

13.2.17 For example, Professor Leo Kinlen has suggested that childhood leukaemia is a rare response to a common (but as yet unidentified) infection, and that unusual patterns of urban-rural population mixing lead to "mini-epidemics" of the relevant infection (that are often sub-clinical) and an enhancement of the rare response, childhood leukaemia. Professor Mel Greaves has suggested that it is the delayed exposure of the immune system of a young child to a broad range of infective agents that increases the risk of childhood leukaemia, and that circumstances encouraging the prevention of exposure to infections in the early years of life (such as the social isolation of the community and/or the child) increase the risk of the disease. Many studies have now pointed to the importance of infective patterns in determining the risk of childhood leukaemia, in many different circumstances, indicating that infection is indeed a major factor in the risk of childhood leukaemia **[143]**. The village of Seascale and the area around Dounreay have undoubtedly been exceptionally unusual communities over many years—a high socio-economic class, mobile population within a geographically isolated area—conditions that will have been inevitably conducive to those infective patterns that are now believed to increase the risk of childhood leukaemia.

13.2.18 More recent studies such as that covered by the COMARE Eleventh Report, 2006 **[144]**, have demonstrated that the background risk of childhood leukaemia throughout Great Britain is far from uniform, and that "clusters" are a natural result of this geographically variable risk. What seems to have happened in the 1980s is that "clusters" near some nuclear installations were preferentially identified because of media and scientific interest in the phenomenon, and because social conditions around certain nuclear sites led to these areas being particularly prone to a raised risk of childhood leukaemia. However, with the broader perspective that is now available, it would appear that only a small fraction of the total pieces in the whole jigsaw were being examined—now that a greater proportion of the puzzle can be observed, the "clusters" near nuclear installations can be seen to fit into the general background pattern.

13.2.19 Taking the evidence as a whole, it is most unlikely that those "clusters" that have been found near some nuclear facilities are indicative of a serious underestimation of the risk of exposure to radiation. Three decades of intensive research into whether the risk of childhood leukaemia has been seriously underestimated have not revealed any major shortcomings in the risk assessments that demonstrate that radiation doses received from radioactive discharges are far too small to cause the observed excesses of cases. For example, radionuclides released during the period of intense atmospheric nuclear weapons testing did not produce a discernible increase in childhood leukaemia incidence, which they should have done if risk estimates had been wildly wrong. In contrast, a better understanding of the pattern of childhood leukaemia incidence away from nuclear installations has indicated that "clustering" may well be a natural result of the way in which the major causes of childhood leukaemia behave. Infective processes appear to be related to the risk of childhood leukaemia, and unusual patterns of infection lead to unusual patterns of childhood leukaemia. The atypical population mixing experienced around large industrial installations (such as nuclear power stations) in predominantly rural areas, and the patterns of infections that they induce, could well be behind the excesses of cases of childhood leukaemia reported from areas around certain nuclear facilities, as well as areas away from such facilities.

13.3 Conclusions

13.3.1 To summarise, a low dose of radiation is one of many factors that can lead to an increased risk of cancer, but there are other possible factors, for example exposure to particular chemicals or infections. Based on the large body of evidence that has been collected over the last 70 years, including detailed, regular and recent reviews of biological and epidemiological date, the UK Health Protection Agency (now UKHSA) **[145]** has confidence that the radiation risk factors used by ICRP provide a sound basis for a radiological protection system.

14: ANNEX 5 - CONSIDERATION OF SEVERE ACCIDENTS AND EXTREME EVENTS

14.1 Introduction

14.1.1 This Annex provides detailed information underlying our conclusion in this Application that the risk of significant detriment from extreme events and severe accidents is low.

14.2 Overview

14.2.1 This Annex has two parts:

14.2.2 Part 1 provides a review of the safety provisions in place to protect against accidents, including those caused by extreme events. These measures include regulatory, cultural, and engineered safeguards. As a result of these provisions the risk of detriment resulting from extreme events causing widespread station impacts, such as sustained loss of cooling or electrical power supplies, is considered to be low.

14.2.3 Part 2 provides a review of severe reactor accidents at, or above, Level 5 on the International Atomic Energy Agency's ("IAEA") International Nuclear Event Scale ("INES"). This concludes that the measures described elsewhere in this Application ensure that the risk of a similar severe accident involving the Proposed Practice and the resulting detriments are very low.

14.3 Part 1 – Safety Provisions

14.3.1 In the almost 70 years since the first commercial-scale nuclear reactor opened at Calder Hall in Cumbria, there have been over 18,500 cumulative reactor years of safe operation in 36 countries around the world **[146]**. Since the Chernobyl accident in 1986, there have been 14,000 years of cumulative reactor running time. The only major nuclear incident in this time occurred in March 2011, at the Fukushima Daiichi site in Japan. Following the most powerful earthquake in recorded Japanese history, a 10m tsunami hit the east coast, overtopped the sea wall at the plant, and disabled the backup diesel generators and electronics, leading to a loss of ultimate heat sink. The accident highlighted the possibility for multi-unit power stations to be affected by severe natural disasters, and for such an accident to adversely impact the ability to maintain cooling and backup electrical power.

14.3.2 While the United Kingdom has a far lower risk of earthquakes and tsunamis than Japan, the UK nuclear industry took the opportunity following this severe accident to self-reflect and ensure the existing safety and regulatory culture was effective. Dr Mike Weightman, then the head of the ONR, was asked to produce a report on the implications of the Fukushima accident for the UK.

14.3.3 In his final report (the "Weightman Report") **[147]**, Dr Weightman provided a series of conclusions on the UK nuclear and regulatory regime. Some of the conclusions relevant to the Proposed Practice are summarised below:

- The UK approach to identifying the design basis for nuclear facilities is sound for initiating events such as those at Fukushima.
- Periodic Safety Reviews provide a robust means of ensuring that operational facilities are adequately improved in line with advances in technology and industry standards.
- Consideration of the Fukushima accident has not revealed any gaps in scope or depth of the Safety Assessment Principles for nuclear facilities in the UK.
- Considerations of the events in Japan, and the possible lessons for the UK, has not revealed any significant weaknesses in the UK nuclear licensing regime.

14.3.4 The following subsections provide an overview of the factors that together provide a high level of assurance that the risks from extreme events and severe accidents are effectively managed to be very low. These provisions remain subject to continuous improvement and development in the light of experience and lessons learnt and will continue to evolve. These factors broadly encompass:

- The capability and resilience of UK plants that is being further enhanced in the light of lessons from Fukushima.
- The commitment of UK operators to nuclear safety.
- Stress tests conducted on European Union nuclear installations in response to Fukushima to ensure that any further improvements to the resilience of plants were identified for implementation.

- The robustness of the regulatory regime and the independence and effectiveness of the UK nuclear regulator in promoting and overseeing high levels of governance in the nuclear industry.

14.3.5 Further information on the Fukushima accident is provided in Part 2 below.

Capability of UK Nuclear Power Plants

14.3.6 With regards to the existing safety standpoint at UK plants, the Weightman Report **[147]** stated:

"I remain confident that our UK nuclear facilities have no fundamental safety weaknesses. The Office for Nuclear Regulation already requires protection of nuclear sites against the worst-case scenarios that are predictable for the UK."

14.3.7 Nevertheless, the Weightman Report identified a number of areas where further improvements could and should be made to further enhance the resilience of the UK nuclear power sector. In particular, the report identified actions that new nuclear plants should take to explicitly ensure weaknesses that were present in the Fukushima plant are not present in UK plants.

14.3.8 The UK Government accepted the Weightman Report and affirmed its commitment to implementing its recommendations. **[148]**

14.3.9 Annex 1 shows that the RR SMR addresses the learnings of Fukushima highlighted in the Weightman report. While some recommendations are general, for example further flooding studies during potential site selection, there are some directly related design features to highlight.

14.3.10 As part of the modular construction of RR SMR, the initial groundworks are carried out in a site-dependent manner to allow for the efficient installation of the reactor and turbine in a standardised layout. These groundworks will include an aseismic bearing isolating the concrete foundations from the reactor, ensuring mitigation of seismic impact on the turbine and reactor. In addition, the RR SMR design uses a Passive Decay Heat Removal system ("PDHR") to prevent a build-up of decay heat in the event of station blackout, preventing loss of ultimate heatsink.

14.3.11 The control room of the RR SMR is equipped with emergency habitability systems to ensure operators can continue to monitor and remediate any issues in the event of a hazard, while a supplementary control room provides a local backup of this safety functionality and ensures separation and segregation. In the event of a hazard requiring a managed response, such as fire or radiation release, the Emergency Response Centre will co-ordinate these activities. A backup Emergency Response Cedntre, based in a permanent off-site location, ensures that these activities can continue if the accident has progressed to the point of requiring this capability.

Commitment of UK Nuclear Operators to Nuclear Safety

14.3.12 Prime responsibility for the safety of a nuclear power plant rests with the operator of the plant. This is in accordance with IAEA Fundamental Safety Principles. Each nuclear site licensee is therefore responsible for the safety of its nuclear plant and also for the health and safety of workers and members of the public who might be affected by the plant's operations.

14.3.13 Under the terms of the nuclear site licence, operators are required to make suitable arrangements to assure nuclear safety. A core requirement that permeates all the operator's activities and is a duty that is set out in the Health and Safety at Work Act 1974, is the obligation to ensure that the risk of harm is kept as low as reasonably practicable ("ALARP"). The ALARP principle requires operators to demonstrate they have done everything practicable to reduce risks. This covers not only physical plant provisions and management control measures, but also extends to broader organisational considerations. Operators are required to demonstrate their organisational capability and provision of adequate human and financial resources to ensure the safe operation of the plant at all times. This means that the licensee will have the knowledge and resources to ensure that they maintain effective control of operations that take place at the licensed sites for which the licensee is responsible. The Ionising Radiation Regulations 2017 further protect nuclear workers and the public by requiring doses are kept ALARP, and no greater than defined dose limits.

14.3.14 The UK's ninth national report on compliance with the IAEA Convention on Nuclear Safety obligations (published in 2022) highlights the high priority given to safety by UK nuclear utilities, including their involvement in internal, independent and international peer review and assessment.

14.3.15 The ONR also highlighted the UK nuclear industry's strong commitment to nuclear safety in the aftermath of the Fukushima accident. One conclusion of the Weightman Report was that:

"The Industry and others have responded constructively and responsibly to the recommendations made in our interim report and instigated, where necessary, significant programmes of work.

This shows an on-going commitment to the principle of continuous improvement and the maintenance of a strong safety culture."

14.3.16 It is therefore concluded that UK nuclear operators have a strong commitment to nuclear safety, and the capability to maintain such safety. Any operator deploying the Proposed Practice will need to demonstrate such commitment to nuclear safety and organisational capability before ONR would grant a nuclear site licence.

European Stress Tests

14.3.17 International oversight is an additional component of the already robust UK regulatory regime to ensure that severe accident risks are effectively managed to be very low.

14.3.18 Following the Fukushima accident, every nuclear power generating country in Europe agreed to carry out safety 'stress tests' to reassess relevant safety margins. The tests were completed by licensed operators, and their respective national regulators compiled reports.

14.3.19 Seventeen such national reports were submitted for peer review by the European Nuclear Safety Regulators Group ("ENSREG") **[149]** and the European Commission in December 2011.

14.3.20 ENSREG is an independent, authoritative expert body created in 2007 by the European Commission *"to help to establish the conditions for continuous improvement and to reach a common understanding in the areas of nuclear safety and radioactive waste management."* Although the UK has left the EU, it continues to participate as an observer and maintains an interest in ENSREG activities.

14.3.21 The stress test reports emphasised the importance of continuous review and improvement in safety across European nuclear power plants, which is also a key feature of the UK regulatory regime. The European Commission **[150]** concluded that:

"Based on the stress tests, national regulators concluded that there are no technical reasons requiring the shutdown of any NPP in Europe and identified a series of good practices."

14.3.22 The ONR, as of 2017, was satisfied that UK nuclear operators had implemented the majority of identified improvements from the ENSREG scheme as well as internal analysis of the Fukushima accident, and that remaining recommendations would be applied as a matter of course in continuing operation **[151] [152]**.

Robustness of Regulatory Regime

14.3.23 Within the UK, the ONR is the independent nuclear regulator for safety, security and safeguards. It is responsible for regulating and monitoring the safety of nuclear workers and the general public from conventional and nuclear hazards; the physical and cyber security of nuclear sites; and the safeguarding of nuclear materials to ensure the UK meets its international obligations after the withdrawal of the UK from the European Atomic Energy Community ("Euratom") after leaving the EU.

14.3.24 The existence of an effective regulatory regime which governs the UK nuclear industry to secure high levels of plant safety and operator competence provides important assurances that the risk of potential detriments arising from accidents will be low. The commitment of operators to nuclear safety, described above, is enabled in part by an effective and experienced regulator, able to identify and highlight areas where safety can be further improved. Finally, the presence of the ONR, as an independent and powerful regulator, provides statutory oversight and enforcement in the event that safety standards are not met.

Adequacy of Safety Standards

14.3.25 The safety levels demanded by the UK regulatory regime meet international requirements that arise through treaty and other legal obligations, as well as defined benchmarks.

14.3.26 The UK is a signatory to the International Convention on Nuclear Safety **[153]** which entered into force on 24 October 1996. This Convention legally commits participating states to maintain a high level of safety for nuclear power plants by setting international benchmarks which states subscribe to. Under the terms of the Convention, the UK regularly submits reports **[154]** for peer review that describe how the UK satisfies its obligations under the Convention.

14.3.27 The IAEA has developed a system of fundamental safety principles, standards and guides **[155]** for ensuring nuclear safety. The IAEA safety standards have a status derived from the IAEA's Statute, which authorizes the IAEA: *"To establish or adopt, in consultation and, where appropriate, in* *collaboration with the competent organs of the United Nations and with the specialised agencies concerned, standards of safety for protection of health and minimisation of danger to life and property … and to provide for the application of these standards".*

14.3.28 The UK is also part of the Western European Nuclear Regulators' Association ("WENRA"). A key objective of WENRA is to develop a common approach to nuclear safety, and part of this objective is to establish a forum for the sharing of experience and discussion of significant safety issues. WENRA has developed common reference safety levels for reactor safety, decommissioning safety, radioactive waste and spent fuel management to act as a benchmark for the various national practices **[156]**. Furthermore, WENRA has established safety objectives for new nuclear power plants **[157]** that set out a common position to promote enhanced safety as compared to existing plant, especially through design improvements.

14.3.29 In the UK, ONR has established a set of SAPs **[158]** to guide its regulatory decision making as to whether site licensees have met their legal obligations to reduce risks so far as is reasonably practicable. ONR regularly reviews the SAPs to ensure consistency with IAEA safety standards and WENRA reference levels. An analogous set of principles, SyAPs **[159]**, are used to provide a framework for the ONR to make consistent regulatory judgements on the adequacy of security arrangements. Underpinning these principles are Technical Assessment Guides ("TAGs") which provide further clarity to licence holders on the expectations of the regulator. ONR also bases its decision making on the adequacy of the management arrangements developed by operators to comply with the conditions attached to each nuclear site licence **[160]**.

Effectiveness of the Regulator

14.3.30 The ONR is an independent statutory corporation created by the Energy Act 2013 and funded via a levy on nuclear operators. It is responsible for the monitoring of existing sites, the licensing of new sites, and the assessment of new designs via the GDA process.

14.3.31 After the accident in Fukushima, in the interim report prepared by ONR, the regulator highlighted their philosophy of continuous improvement as follows:

"no matter how high the standards of nuclear design and subsequent operation are, the quest for improvement should never stop. Seeking to learn from events, new knowledge and experience, both nationally and internationally, must be a fundamental feature of the safety culture of the UK nuclear industry".

14.3.32 The effectiveness of the UK nuclear regulator has been independently assessed by the IAEA. The UK government, in keeping with international good practice, invites IAEA Integrated Regulatory Review Service missions to the UK to review the readiness and practices of the ONR. The most recent of these missions was in 2019 with a follow up mission in 2024 **[161]**.

14.3.33 The 2013 mission was itself a follow up on the 2009 and 2006 missions, which concluded that the UK has a mature and transparent regulatory system with highly trained, expert and experienced nuclear inspectors. In 2009, it was found that the ONR, (then the HSE's Nuclear Safety Directorate) was making good progress on the implementation of the 2006 suggestions, while providing further recommendations on the transition to becoming the ONR. The 2013 mission provided further vindication of the progress of the ONR, along with further suggestions with respect to the newly independent body and the learning from the Fukushima accident. The 2014 mission successfully closed 21 of 26 outstanding findings from the previous missions.

14.3.34 During the 2019 mission, the review team found that the UK is committed to strengthening its regulatory framework for nuclear radiation, radioactive waste and transport safety. They identified strengths in the UK's regulatory authorities, including the competence of staff and the extensive regulatory guidance that has been developed for those legally responsible for nuclear and radiation safety. The team leader for the 2019 mission, Ramzi Jammal, stated that **[162]**:

"The ONR has a mature regulatory framework that could be emulated by other countries' regulatory authorities to improve their understanding and implementation of IAEA safety standards in the oversight of nuclear and radiation safety."

14.3.35 While the IAEA's Greg Rzentkowski, Director, Division of Nuclear Installation Safety, stated:

"The mission clearly demonstrates the UK's commitment to implement IAEA safety standards and to provide for the effective coordination of all regulatory functions."

14.3.36 Further, the UKs environmental regulators are each independent statutory bodies held to account by Government (the UK Parliament in the case of the Environment Agency; the Welsh Government in the case of Natural Resources Wales; and the Scottish Ministers in relation to Scottish Environmental Protection Agency), each of which was also found to be effective in the full-scope Integrated Regulatory Review Service mission of 2019.

Conclusion

14.3.37 The UK has an effective and independent regulator in place with the capability and resources to ensure that high levels of nuclear safety are maintained by operators of new nuclear power plants where the Proposed Practice is deployed.

14.4 Part 2 - Overview of severe accidents

IAEA International nuclear event scale

14.4.1 The International Nuclear and Radiological Event Scale ("INES") **[163]** is a worldwide tool for communicating to the public the safety significance of nuclear and radiological events. Events are classified by the following scale: levels 1–3 are called "incidents" and levels 4–7 "accidents".

14.4.2 This Annex provides an overview of commercial reactor accidents rated 5 and above on INES, and also considers the 1957 Windscale accident which occurred in the UK.

Table 21: International Nuclear Event Scale

Description	Level	Example
Major Accident	Level 7	Fukushima, Japan (2011) (Significant release of radioactivity, roughly 10% of that during Chernobyl). Chernobyl, former Soviet Union (1986) (Widespread health and environmental effects. External release of a significant fraction of reactor core inventory).
Serious Accident	Level 6	Kyshtym, former Soviet Union (1957) A failed cooling system at a military nuclear waste reprocessing facility caused an explosion with a force equivalent to 70–100 tons of TNT. About 70 to 80 metric tons of highly radioactive material were carried into the surrounding environment. At least 22 villages were evacuated.
Accident with Wider Consequences	Level 5	Three Mile Island, United States (1979) (Severe damage to the reactor core). Windscale, United Kingdom (1957) (Release of radioactive material to the environment following a fire in a reactor core).
Accident with Local Consequences	Level 4	SL1 Experimental Power Station, United States (1961). The reactor reached prompt criticality, killing three operators.
Serious Incident	Level 3	Davis-Besse Nuclear Power Station, United States (2002) negligent inspections resulted in corrosion through 150 mm of the carbon steel reactor head leaving only 9.5 mm of stainless steel cladding holding back the high-pressure reactor coolant.
Incident	Level 2	Hunterston B Nuclear Power Station, Scotland (1998) Emergency diesel generators for reactor cooling pumps, failed to start after multiple grid failures during the Boxing Day Storm of 1998.
Anomaly	Level 1	Gravelines, France (2009) During the annual fuel bundle exchange in reactor 1, a fuel bundle snagged on to the internal structure. Operations were stopped, the reactor building was evacuated and isolated in accordance with operating procedures.
No Safety Significance (Below Scale)	Level 0	Eurajoki, Finland (2020) Reactor shutdown due to dissolved filter substances in reactor water.

Windscale, UK, 1957

Overview of the Accident

14.4.3 The Windscale fire of 10 October 1957 is the only nuclear event in the UK's history that has been rated as an "accident" according to INES: it was retrospectively ranked at level 5 in severity on the 7-point scale.

14.4.4 The accident occurred when the core of the Unit 1 nuclear reactor at Windscale caught fire and burned for 3 days, releasing radioactive contamination into the surrounding area. Of particular concern at the time was the radioactive isotope iodine-131.

Radiological Consequences and Other Impacts

14.4.5 Iodine-131 was quickly identified as the major radiological hazard arising from the accident, which may lead to cancer of the thyroid. No one was evacuated from the surrounding area, but there was concern that milk might be dangerously contaminated. Milk from about 500 km² of nearby countryside was diluted and destroyed for about a month. A 2010 study of workers directly involved in the clean-up found no significant long-term health effects from their involvement.

Applicability to the Proposed Practice

14.4.6 The Windscale accident demonstrated the importance of regulation of the nuclear industry and understanding the science of radiological protection. A committee chaired by Sir Alexander Fleck investigated the wider implications of the accident, which led to, among other things:

- The establishment of the National Radiological Protection Board ("NRPB") in 1971 (since 2004, subsumed within the Health Protection Agency as the Radiation Protection Division) and now UKHSA; and
- The creation of the Nuclear Installations Inspectorate (now part of ONR) to provide independent regulation of the civil nuclear power programme.

Three Mile Island (TMI-2), USA, 1979

Overview of the Accident

14.4.7 TMI-2 was a 900 MWe pressurised water reactor located near Harrisburg, Pennsylvania, in the United States of America. The accident, which occurred on 28 March 1979, was caused by a cooling malfunction resulting in part of the core melting. The accident at TMI-2 was caused by a combination of equipment failure and the inability of plant operators to understand the reactor's condition because of poor training, and confusing control, indication and alarm systems.

14.4.8 The accident was rated 5 on INES as it caused severe damage to the reactor core and the release of radioactivity inside the installation was high. There was, however, no significant release of radiation outside of the containment.

14.4.9 Today, the TMI-2 reactor is permanently shut down and all its fuel has been removed. The reactor coolant system is fully drained and the radioactive water has been decontaminated and evaporated.

Radiological Consequences and Other Impacts

14.4.10 The partial meltdown resulted in the release of a small quantity of radioactive gas, however this was not enough to cause any significant dose to local residents. The average radiation dose to people living within 10 miles of the plant has been estimated to be 0.08 mSv, with no more than 1 mSv to any single individual. In response, and to allay any fears that these exposures might result in any radiation-induced health effects, principally cancer, the Pennsylvania Department of Health set up a registry of more than 30,000 people who lived within five miles of Three Mile Island at the time of the accident. The registry was discontinued in 1997 without any evidence of unusual health trends in the area **[164]**.

14.4.11 Confused communications between government agencies and misunderstandings about the seriousness of the accident led to a debate about whether to evacuate or not. As a result of media reporting of the accident, many members of the public in the locality decided not to await official advice and left the area, effectively evacuating themselves. The manner in which these events unfolded over the first two days of the accident caused considerable fear and stress among some members of the public. These were the main consequences of the accident in terms of public health.

14.4.12 The TMI-2 accident caused no injuries. Experts concluded that the amount of radioactive material released into the atmosphere was too small to result in discernible direct health effects to the population in the vicinity of the plant. This has been confirmed by a number of comprehensive studies by US Government departments, agencies and independent groups.

Applicability to the Proposed Practice

14.4.13 The TMI-2 accident showed that design and operational measures to assure the adequacy and availability of safety systems are essential and that the phenomena associated with severe accidents were mostly unknown at the time. Consequently, reactor designs were improved to enhance the reliability of safety systems and take into account the possibility of severe accidents. The importance of human factors (including man-machine interface) became clear and improved training of operators also resulted. Emergency response planning also further developed in the light of TMI-2. The accident also demonstrated the value of conservative design provisions in nuclear power plants, such as the effective containment structure that limited the radiological releases to very low levels.

Chernobyl, former Soviet Union, 1986

Overview of the Accident

14.4.14 The Chernobyl nuclear power plant is located in Ukraine, which in 1986 was part of the Soviet Union. It consisted of four RBMK reactors, a Soviet designed reactor that was not built outside of the Soviet Union, which had inherent power instabilities and other serious design flaws. During an experiment on reactor Unit 4 on 26 April 1986, a sudden power surge caused a steam explosion that ruptured the reactor vessel. The experiment had been carried out by operators in violation of safety regulations and with important safety systems switched off. Further violent fuel-steam interactions destroyed the reactor core and severely damaged the reactor building. The large graphite moderator in Unit 4 burned for a further 10 days and large releases of radioactivity occurred. The accident was a result of a combination of several factors including design flaws in the reactor and important safety systems being over-ridden by the operators, which allowed the reactor to reach an unstable condition.

14.4.15 The reactor unit is now enclosed by a large concrete sarcophagus to stop the release of radioactivity into the atmosphere.

Radiological Consequences and Other Impacts

14.4.16 In 2006 the Chernobyl Forum (an initiative of the IAEA, in co-operation with the World Health Organisation, United Nations Scientific Committee on the Effects of Atomic Radiation (“UNSCEAR”), the World Bank, the Governments of Belarus, the Russian Federation and Ukraine, and various other international bodies) produced a report assessing the health, environmental, and socio-economic impacts **[165]**. Their findings and those of UNSCEAR **[166]** are summarised below.

14.4.17 The highest radiation doses were received by emergency workers and on-site personnel during the first days of the accident; 134 of these workers received radiation doses that were sufficiently high to produce acute radiation sickness (“ARS”) from which 28 workers died. The local Soviet authorities delayed evacuation of communities near Chernobyl for about 36 hours and did not immediately impose food restrictions. This led to tens of thousands of children receiving high doses (>1 Sv) to the thyroid gland of radioactive iodine (which concentrates in the thyroid), mainly through drinking heavily contaminated milk. As a consequence, excess cases of thyroid cancer started to appear in 1989-1990 among those exposed as children (whose thyroids are especially sensitive to radiation-induced cancer). To date, several thousand thyroid cancers in the heavily contaminated areas of the former Soviet Union can be attributed to exposure to radioactive iodine from the accident, which aligns with predictions from standard radiation risk models for thyroid cancer. Thyroid cancer is usually treatable, so in the great majority of these cancers did not prove fatal.

14.4.18 Apart from this increase in thyroid cancer incidence among those exposed at a young age, there has been no clearly demonstrated increase in the incidence of other solid cancers or leukaemia due to radiation in the most affected populations. This is because the doses received by other tissues were much less than the thyroid doses received from the intake of radioactive iodine. Even a large study of childhood leukaemia in the heavily contaminated areas could not unambiguously find an increase in risk associated with exposure.

14.4.19 The study of the health effects of Chernobyl is very difficult in light of the dissolution of the Soviet Union in the early-1990s, due to the impact on record keeping, and more importantly, due to the difficulties in distinguishing these specific effects from the general health effects of the associated socio-economic turmoil. For example, whilst mortality rates in western Europe have steadily decreased since the 1990s, mortality rates across Russia markedly increased, including in the far east which was hardly affected by Chernobyl contamination. Nonetheless, studies continue to investigate whether health effects may be discerned.

14.4.20 The cloud of radioactive material from Chernobyl affected much of Europe outside the Soviet Union, although to a much lesser extent than the heavily contaminated areas of present-day Ukraine, Belarus and the Russian Federation. Consequently, and unsurprisingly given the low doses involved, no unequivocal health effects in populations resident outside the former Soviet Union that may be attributable to Chernobyl contamination have been found, even for thyroid cancer and childhood leukaemia.

14.4.21 One group of people where health effects may be detected is the recovery workers, who worked in difficult conditions, especially in the early years after the accident. Over half a million workers have been involved in recovery operations, including nearly a quarter of a million during 1986-1987 when exposure would have been highest. There are indications of an excess risk of leukaemia in these recovery workers, which is not unexpected, although these studies are not easy to conduct.

14.4.22 There were other impacts, however, which include: the evacuation of about 115,000 people from the areas surrounding the reactor and the relocation of about 220,000 people from Belarus, Russia and Ukraine; and an increase in psychological problems among the affected population, compounded by the economic depression that followed the break-up of the Soviet Union.

14.4.23 An overview of the economic consequences, particularly for Belarus and Ukraine, is provided in the 2003-2005 report of the Chernobyl Forum **[26]**. The report advises that the resulting costs of the Chernobyl accident continue to have a significant economic effect on the budgets of these countries. A variety of government estimates put the cost of the accident over decades at hundreds of billions of dollars comprising: the direct costs of the accident; indirect costs from the loss of use of agricultural land and the closure of industrial facilities; and opportunity costs including the additional energy costs resulting from the loss of power from the Chernobyl plant.

Applicability to the Proposed Practice

14.4.24 In conclusion, the Chernobyl accident in 1986 was the most severe nuclear accident in the history of the global nuclear industry. It occurred in a reactor design limited to countries within the former Soviet Union, that was not licensable in Western Europe and occurred as a result of the actions of the operators that were in direct contravention of the operational procedures for the reactor design.

However, Chernobyl clearly illustrated the trans-boundary impacts of a nuclear accident and so following the tragic accident at the Chernobyl nuclear generating station, nuclear operators worldwide were determined to work together to ensure such an accident could never happen again. From this, the World Association of Nuclear Operators (“WANO”) was formally created on 15 May 1989 with the objective of maximising the safety and reliability of nuclear power plants worldwide. WANO is being renewed after the Fukushima accident in 2011 to further increase the standard of nuclear safety across the world **[27]**.

Fukushima

Overview of the accident

14.4.25 On 11 March 2011, Japan suffered a magnitude 9 earthquake and major tsunami. The three operating reactors at the Fukushima Daiichi nuclear power site shut down safely after the earthquake as intended, however a tsunami (estimated to be over 14 metres high) later inundated the site. The earthquake resulted in loss of power supplies to the site, so the site was electrically isolated, but the diesel generators started up to provide emergency power. However, the diesel generators were inundated by the tsunami and failed; the tsunami also caused damage to the emergency heat exchangers. Without power, the reactors could not be adequately cooled, the reactors overheated, the fuel was severely damaged, and over the next few days hydrogen explosions occurred and radioactive material was released into the environment.

14.4.26 As a precaution, tens of thousands of people were quickly evacuated from the area of up to 20 km from the site. A major release of radioactive material on 15—16 March to the northwest of the site badly contaminated an area extending some 40 km from Fukushima Daiichi, so that other communities had to be evacuated, and while blanket evacuation orders on the communities to the northwest of the site were lifted in 2022, approximately 40,000 people remain evacuated. All the other reactors in Japan that were operating at the time—some closer to the epicentre than Fukushima—shut down safely without any release of radioactive material or serious damage.

Radiological Consequences and Other Impacts

14.4.27 In the years following Fukushima, UNSCEAR has released studies summarising the information that has become available as time has passed after the incident. The most recent of these was released in 2021, and summarized all available new information, measurements and results since the 2013 report.

14.4.28 Conclusions in the report with regards to the exposed population of Japan are as follows:

- No adverse health effects among Fukushima residents have been documented that could be directly attributed to radiation exposure.
- Estimates of dose are such that future radiation-associated health effects (including cancer) are unlikely to be detectable.
- No credible evidence of excess birth defects, stillbirths, premature births or low birthweights related to radiation exposure has been found.
- There is unlikely to be excesses of radiation-sensitive cancer because of the generally low levels of radiation exposure in the Fukushima Prefecture population.
- 10 years on, the levels of radiation exposure for the accident, in all but the most highly contaminated areas, have reduced to levels that are below the radiation exposure from natural background.
- On the balance of available evidence, there has not been an increase in thyroid cancer as a result of radiation exposure.

14.4.29 Meanwhile, the average effective dose to the more than 20,000 emergency workers involved in mitigation and other activities at the Fukushima Daiichi Nuclear Power Station site from March 2011 to the end of March 2012 was about 13 mSv. About 36% received an effective dose more than 10 mSv, while 0.8% (174 workers) were assessed to have received more than 100 mSv in this period.

14.4.30 No worker has received an annual effective dose of more than 50 mSv since April 2013, at which point average annual effective doses had dropped to 2.5 mSv.

14.4.31 The UNSCEAR 2020/2021 Report **[167]** determined that an increase in the incidence of cancers is unlikely to be discernible amongst workers for leukaemia, total solid cancers, or thyroid cancer.

14.4.32 Although the accident was rated as 'major' on the INES (along with Chernobyl) the magnitude of the radioactive release that resulted was much lower (by a factor of about six). The UK, in common with many other countries, studied the events surrounding the incident in order learn lessons that could be used to further increase the resilience of its operating reactors, even though these are not subject to external events of such severity (e.g. tsunami).

Investigation Of the Event

14.4.33 Although the sequence of events that resulted in the Fukushima accident was initiated by a powerful earthquake and tsunami, a number of post-accident studies have concluded that the release of radioactive material that resulted from multiple steam explosions at several of the reactors can be attributed directly to a combination of factors that were specific to this location and situation, and a failure of the operators to fully implement the lessons learnt from TMI-2 and Chernobyl.

14.4.34 Principally, inadequate provisions were in place to protect the coastal facility from a foreseeable severe tidal event in what is a seismically active location. There had been a reassessment carried in 2002 that showed the original seawall design may have been below the required hight, and some compensatory measures were taken, but these were proven to be insufficient during the accident. It should also be noted that the seawall at the Onagawa Nuclear Power Plant was adequately sized and robust enough to prevent serious damage to the power plant.

14.4.35 Further, a combination of organisational deficiencies and poor communication between the operator, the regulator and the Government hindered the timely and adequate response to the crisis. The report produced by the Fukushima Nuclear Accident Independent Investigation Commission of the National Diet of Japan in 2012 concluded that:

"Although triggered by these cataclysmic events, the subsequent accident at the Fukushima Daiichi Nuclear Power Plant cannot be regarded as a natural disaster. It was a profoundly manmade disaster—that could and should have been foreseen and prevented. And its effects could have been mitigated by a more effective human response."

14.4.36 Similarly, the Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company in their July 2012 **[168]** final report commented extensively on major problems after the accident.

14.4.37 Dr Weightman, the HM Chief Inspector of Nuclear Installations, led a thorough analysis of the Fukushima event and its implications for the UK. In this, he drew on national and international expert opinion, and led a fact-finding mission to Japan in June 2011—including a visit to the Fukushima Daiichi plant. His findings were published in September 2011 in a final report **[147]**. Commenting on this report, Dr Weightman said:

"I remain confident that our UK nuclear facilities have no fundamental safety weaknesses. The Office for Nuclear Regulation already requires protection of nuclear sites against the worst-case scenarios that are predictable for the UK. But we are not complacent. Our philosophy is one of continuous improvement. No matter how high our standards, the quest for improvement must never stop. We will ensure lessons are learned from Fukushima. Action has already been taken in many cases, with work under way to further enhance safety at UK sites."

Applicability to the Proposed Practice

14.4.38 The Fukushima accident highlighted the potential for multi-unit nuclear power stations to be affected by severe natural disasters, and also for a severe accident to adversely impact the ability to maintain cooling and long-term electrical power supplies.

14.4.39 An operator of the Proposed Practice will be supported by a series of highly robust design features that are described in more detail in Annex 1. These give a great deal of confidence that the essential safety functions of long-term cooling and containment can be maintained even following a postulated extreme event or other accident. Taking into account the robust regulatory regime and the safety culture that will be expected of the operator, the risk of significant detriment from deployment of the Proposed Practice is low.

14.5 Overall Conclusion

14.5.1 There are substantial provisions that ensure a high level of nuclear safety is maintained by the nuclear operators of a nuclear power plant such as the Proposed Practice. As a result of these extensive and highly regulated provisions the risk of detriment resulting from extreme events causing widespread station impacts such as sustained loss of cooling or electrical power supplies is considered to be low. These provisions continue to evolve and are subject to on-going review and improvements.

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16: ANNEX 6 - GLOSSARY

Term	Definition
2008 Application	The NIA application submitted to the Justifying Authority in 2008 seeking Justification of new nuclear power stations in the UK.
2010 Justification Decisions	The reasons for the Secretary of State's Decision as Justifying Authority on the 2008 Application—for the EPR™ and AP1000®—October 2010.
2013 Application	The NIA application Radiological Justification Application for UK ABWR Nuclear Reactor.
2015 Justification Decision	UK Government, "The Justification Decision (Generation of Electricity by the UK ABWR Nuclear Reactor) Regulations 2015 SI No. 209" 12 February 2015
Appropriate Assessment	A competent authority must make an appropriate assessment of the likely significant effects on the protected European sites (SACs and SPAs) in view of the site's conservation objectives, before deciding whether to authorise a particular development.
Activation	This term refers to the process of creating a radioisotope. This is achieved when a stable element is bombarded with either neutrons or protons.
Activity content	Attribute of an amount of a radionuclide. Describes the rate at which transformations occur in it. Unit Becquerel, symbol Bq. 1 Bq = 1 transformation per second.
ALARA	As low as reasonably achievable. It is a key part of the general duties of the Health and Safety at Work etc. Act 1974. This involves weighing a risk against the trouble, time and money needed to control it.
ALARP	As low as reasonably practicable. It is a key part of the general duties of the Health and Safety at Work etc. Act 1974. This involves weighing a risk against the trouble, time and money needed to control it.
Baseload plant	Power station that provides a continuous, steady electricity supply and does not greatly vary its output over a 24-hour period.
Basic Safety Level (BSL)	Basic Safety Level (BSL) BSLs and BSOs (see below) are used by UK nuclear inspectors to translate the TOR (Tolerability of Risk) framework into targets. ONR's policy is that the BSLs indicate dose limits, dose levels, or risk levels which a new facility or activity should at least meet.
Basic Safety Objectives (BSO)	BSLs and BSOs (Basic Safety Objectives) are used by UK nuclear inspectors to translate the TOR (Tolerability of Risk) framework into targets. The BSO dose/risk levels have been set at a level where ONR considers it not to be a good use of its resources or taxpayers' money, nor consistent with a proportionate regulatory approach, to pursue further improvements in safety. In contrast, licensees have an overriding duty to consider whether they have reduced risks to as low as reasonably practicable (ALARP) on a case by case basis irrespective of whether the BSOs are met. As such it will in general be inappropriate for licensees to use the BSOs as design targets, or as surrogates to denote when ALARP levels of dose or risk have been achieved. The ONR SAPs explain further that the BSOs form benchmarks that reflect modern nuclear safety standards and expectations.
Basic Safety Standards Directive	The Basic Safety Standards Directive" is Council Directive 2013/59/Euratom laying down basic safety standards for the protection against the dangers arising from exposure to ionising radiation, keeping the UK in line with international best practice.
Becquerel	The international (SI) unit used to measure quantities of radioactivity. The unit is extremely small, 1 Becquerel (Bq) is 1 disintegration per second. An average adult body contains around 7 thousand Becquerels (7KBq) of radioactive material.
Best Available Techniques (BAT)	Best Available Techniques. The available techniques which are the best for preventing or minimising emissions and impacts on the environment.
Biocide	A chemical agent that is capable of destroying living organisms.

Chain reaction	A reaction that stimulates its own repetition, in particular here the neutrons originating from nuclear fission cause an on-going series of fission reactions.
Chlorination	To disinfect (water) by addition of chlorine.
Collective dose	The total radiation dose incurred by a population. This is the sum of all of the individual doses to members of a particular group of people. The unit of collective dose is man-sievert – see chapter 5 for more information.
Collective effective dose	The total effective dose incurred by a population. This is the sum of all of the individual effective doses to members of a particular group of people. The unit of collective effective dose is man-sievert.
Condenser	Any device for reducing gases or vapours to liquid or solid form. A condenser is used to convert the exhaust steam from a steam turbine back to water.
Connection and Use of System Code (CUSC)	The Connection and Use of System Code is the contractual framework for connecting to and using the National Electricity Transmission System (NETS).
Control rod	A rod, plate, or tube containing a neutron absorbing material such as boron used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fissions.
Conversion	Chemical process turning Uranium Oxide U_3O_8 into uranium hexafluoride UF_6 preparatory to enrichment.
Core	The central part of a nuclear reactor containing the fuel elements and any moderator.
Cosmic radiation	Ionising radiation that originates from outer space and the sun. It contributes about 13% of public radiation levels on Earth.
Critical	The condition within a nuclear reactor where an average of 1 neutron emitted by each nuclear fission goes on to induce a further nuclear fission. That is, a stable power condition where the rate of nuclear fission remains constant over time.
Decommissioning	The process of closing down a nuclear reactor, removing the spent fuel, dismantling some of the other components, and preparing them for disposal. The term is also applied to other nuclear facilities.
Defence in depth	The provision of a series of levels of defence aimed at preventing accidents and for dealing with the consequences of any accidents so as to minimise them. This entails a provision of multiple barriers against the release of Radioactive materials to the environment. Key aspects of the defence in depth approach are: • Prevention of abnormal operation and plant failures e.g. through high quality design and construction; • Provision of equipment and operating practices that prevent or control operational disturbances so as to avoid them becoming problems; • Provision of redundant and diverse systems to detect problems and place the plant into a safe state; • In the event of a severe accident, provision of design features and procedures to prevent or limit radioactive releases and for management of the damaged plant; and • Provision of emergency control and an on and off-site emergency response in the highly unlikely event of significant releases of radioactive substances
Detriment	The Basic Safety Standards Directive defines health detriment as an estimate of the risk of reduction in length and quality of life occurring in a population following exposure to ionising radiations. This includes loss arising from somatic effects, cancer and severe genetic disorder. This Application also describes other potential (non-radiological health) detriments.

Diffusion technology and centrifuge technology	There are two enrichment processes in large-scale commercial use, each of which uses uranium hexafluoride as feed: gaseous diffusion and gas centrifuge. Both use the physical properties of molecules, specifically the 1% mass difference, to separate the isotopes. The product of this stage of the nuclear fuel cycle is enriched uranium hexafluoride, which is reconverted to produce enriched uranium oxide.
Dirty bomb	A device designed to spread radioactive material by conventional explosives.
Dose	Quantity of energy imparted by ionising radiation to a unit mass of matter such as tissue.
Dose limit	The value of the effective dose or the equivalent dose to individuals from planned exposure situations that shall not be exceeded. [From ICRP 103]
Dose Constraint	A prospective and source-related restriction on the individual dose from a source, which provides a basic level of protection for the most highly exposed individuals from a source, and serves as an upper bound on the dose in optimisation of protection for that source. For occupational exposures, the dose constraint is a value of individual dose used to limit the range of options considered in the process of optimisation. For public exposure, the dose constraint is an upper bound on the annual doses that members of the public should receive from the planned operation of any controlled source. [From ICRP 103]
Effective dose	The weighted sum of doses to take into account the different radiation sensitivities of different tissues and organs. The unit of effective dose is Sievert (Sv).
Emission	The action of discharging something, especially heat, light, gas or radiation.
EN-1	The Overarching National Policy Statement for Energy.
EN-6	The National Policy Statement for Nuclear Power Generation.
EN-7	The National Policy Statement for new nuclear power generation: new approach to siting beyond 2025.
Energy White Paper	The energy white paper sets out the UK's plan to transform its energy system and reach net zero emissions by 2050.
Enrichment	The physical process of increasing the proportion of U235 to U238. Natural uranium is 99.3% U238 with U235 only constituting about 0.7%.
European Utility Requirements (EUR)	The European Utility Requirements (EUR) document develops requirements addressed to the LWR plant designers and vendors.
Existing Practices	Justified by virtue of being a class or type of practice existing in the UK prior to 6 February 2018. Under paragraph 5 of the Justification Regulations, a practice is justified if a practice in that class or type of practice was carried out in the United Kingdom before 6 February 2018. These practices are listed in Annex 3 of DEFRA guidance. The Justification of Practices Involving Ionising Radiation (Amended) Regulations 2018; Guidance on their application and administration, Version May 2023.
Fissile material	Material which can undergo nuclear fission following the absorption of a neutron, e.g. ^{235}U, ^{233}U, ^{239}Pu.
Fission	A process in which a nucleus splits into two or more nuclides and energy is released. Frequently refers to the splitting of a nucleus of 235U into two approximately equal parts by a thermal neutron also resulting in the emission of other neutrons.
Fission fragments	The nuclides formed by the fission of heavy elements, plus any nuclides formed by subsequent radioactive decay of fission fragments.
Fossil fired plant	Coal, gas and oil-fired electricity generating power plants.
Fuel flasks (cask)	A heavily shielded container used to store and/or ship radioactive materials. Lead and steel are common materials used in the manufacture of flasks.
Fuel rods	A long, slender tube that holds the fuel pellets; fuel rods are assembled into bundles called fuel elements or fuel assemblies that are loaded individually into the reactor core.

Gamma radiation	Gamma radiation is one of the three types of naturally occurring ionising radiation. Gamma rays are electromagnetic radiation, like X-rays. They are the most energetic form of electromagnetic radiation, with a very short wavelength of less than one-tenth of a nanometre.
Generic Design Assessment	The process being used in the UK by the nuclear regulators (ONR and EA) to generically assess new nuclear power station designs. The regulators make rigorous and structured examination of the generic safety, security and environmental aspects of new reactor designs. Site specific applications to build the designs still need to be made. See http://www.hse.gov.uk/newreactors/ for further information.
Geological Disposal Facility (GDF) or Geological repository	A purpose built facility for deep burial of higher activity radioactive wastes with no intention of later retrieval.
Greenhouse gas emissions	Radiative gases in the Earth's atmosphere which absorb long-wave heat radiation from the earth's surface and re-radiate it, thereby warming the Earth. Carbon dioxide and water vapour are examples.
Grid Code (GC)	The Grid Code details the technical requirements for connecting to and using the National Electricity Transmission System (NETS).
Heat exchangers	Any device that transfers heat from one fluid (liquid or gas) to another fluid or to the environment.
Health Detriment	Health detriment is the reduction in length and quality of life occurring in a population following exposure, including those arising from tissue reactions, cancer and severe genetic disorder
Higher activity waste	Refers to high level waste, spent fuel, intermediate level waste and low level waste unsuitable for prompt disposal at a low level waste repository.
In situ leaching	The recovery of minerals from the ground by dissolving them and pumping the resultant solution to the surface where the minerals can be recovered. There is no physical excavation or waste rock generated. Also known as solution mining.
Ionising radiation	Radiation that contains enough energy to remove tightly bound electrons from the orbit of an atom causing the atom to become charged or ionised. Examples are alpha particles, gamma rays, x-rays and fast neutrons.
Ionising Radiations Regulations 2017	These regulations set out the legal framework for the protection of people and the environment from the risks of ionising radiation in the UK.
Irradiated	Exposed to radiation or reactor fuel and components that have been subject to neutron irradiation and hence become radioactive themselves.
Isotope	Nuclides with the same number of protons but different numbers of neutrons. Not a synonym for nuclide.
Justification	High level assessment pursuant to the Justification of Practices Involving Ionising Radiation Regulations 2004 (SI 2004 No 1769) to demonstrate the economic, social or other benefits resulting from a new class or type of practice involving the use of ionising radiation outweigh the radiological health detriments. In this Application, potential (non-radiological health) detriments are also discussed.
Justification Regulations	The Justification of Practices Involving Ionising Radiation Regulations 2004.
Light water reactor	A reactor that uses natural water as a moderator and coolant, and low-enriched uranium as fuel. The most common type of nuclear power reactor currently in use around the world.
Load factor	The ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full capacity over that time period.
Milling	Process by which minerals are extracted from ore, usually at the mine site.
Moderator	A material used in nuclear reactors to reduce the energy and speed of the neutrons produced as a result of fission.
Net benefit	Advantageous result that does more good than harm.

Optimisation	The process of determining what level of protection and safety makes exposures and the possibility and magnitude of potential exposures, 'as low as reasonably achievable, economic and social factors being taken into account', (ALARA)
Outage	A period of interruption of a reactor's operation to enable scheduled maintenance and refuelling to be performed.
Pellets	The uranium fuel for nuclear reactors in the form of ceramic uranium oxide cylinders. These "pellets" are stacked in long tubes to form fuel rods.
Periodic safety review	A comprehensive assessment against modern standards of the state of a facility to determine whether it is adequately safe and can continue to be adequately safe to the next periodic safety review. It is ONR policy that site licensees conduct a periodic safety review once every 10 years.
Plutonium	A heavy, radioactive, metallic element with atomic number 94. It exists in only trace amounts in nature.
Practice	The Basic Safety Standards Directive defines a "practice" as "a human activity that can increase the exposure of individuals to radiation from an artificial source or from natural radiation sources where use is being made of its radioactive, fissile or fertile properties ...". The latest ICRP Recommendations and the proposed recast of the BSS distinguish between existing, planned and emergency exposure situations.
Proposed Practice	The generation of power from nuclear energy using oxide fuel of low enrichment in fissile content in a light water cooled, light water moderated thermal reactor currently known as the RR SMR designed by Rolls-Royce SMR Limited.
Radiation	The emission and propagation of energy by means of electromagnetic waves or particles.
Radioactivity	The spontaneous decay of an unstable atomic nucleus, giving rise to the emission of radiation.
Radon	A heavy radioactive gas given off by rocks containing radium (or thorium). Rn222 is the most common isotope.
Reactor	A piece of equipment designed to contain materials undergoing a reaction.
Red Book	Uranium Resources, Production and Demand, also familiarly known as the "Red Book", is a biennial publication produced jointly by the NEA and the IAEA under the auspices of the joint NEA/IAEA Uranium Group.
Representative person	Those individuals in the population of interest who receive, or are expected to receive, the highest doses. This term is the equivalent of, and replaces "average member of the critical group".
Reprocessing	Chemical treatment of spent reactor fuel to separate uranium and plutonium from the small quantity of fission waste products and transuranic elements, leaving a much-reduced volume of high-level waste.
Risk factors	The probability of cancer and leukaemia or hereditary damage per unit equivalent dose. Usually refers to fatal malignant diseases and serious hereditary damage. The unit of measurement is Sv-1.
Security & Quality of Supply Standard (SQSS)	The Security and Quality of Supply Standard set out the criteria and methodology for planning and operating the National Electricity Transmission System.
Shielding	Any material or obstruction that absorbs radiation and so can be used to reduce radiation levels to protect personnel or materials from the effects of ionising radiation.
Shutdown	Cessation of fission in a reactor (usually by the insertion of control rods into the core).
Spent fuel	Fuel assemblies removed from a reactor after use.
Tailings	Ground rock remaining after particular ore minerals (e.g. uranium oxides) are extracted.
The Guidance	The application and administration of The Justification of Practices Involving Ionising Radiations Regulations 2004 was issued in 2019 and revised in 2023.

Thermal neutron	Any free neutron (one that is not bound within an atomic nucleus) that has an average energy of motion (kinetic energy) corresponding to the average energy of the particles of the ambient materials. Relatively slow and of low energy, thermal neutrons exhibit properties that make them desirable in nuclear reactor chain-reactions.
Thermal plume	A thermal plume is a column of hotter fluid moving through another: for a power station this would be the discharged cooling water.
Uranium	A mildly radioactive element with two isotopes which are fissile (U235 and U233) and two which are fertile (U238 and U234). Uranium is the basic fuel of nuclear energy.
Waste management	The control of radioactive waste from creation to disposal.
White Paper	White papers are official proposals for future legislation by the UK government.
Yellowcake	A uranium oxide concentrate that is sometimes referred to as “yellowcake”. This is the form in which uranium is marketed and exported

17: ACRONYMS AND ABBREVIATIONS

Abbreviation	Meaning
1oo3	One out of Three
ABWR	Advanced Boiling Water Reactor
ABWR™	Advanced Boiling Water Reactor
ACMS	Auxiliary Cooling and Make-Up System
AGR	Advanced Gas cooled Reactor
ALARA	As Low as Reasonably Achievable
ALARP	As Low as Reasonably Practicable
AMR	Advanced Modular Reactor
AMS	Accident Management Systems
AP1000®	Advanced Passive 1000
ARS	Acute Radiation Sickness
ASC	Available Supply Capacity
ASD	Atmospheric Steam Dump
ASF	Alternative Shutdown Function
ASME	American Society of Mechanical Engineers
BAT	Best Available Techniques
BEIR	Biological Effects of Ionising Radiations
BEIS	Department for Business, Energy and Industrial Strategy
BNFL	British Nuclear Fuels plc
BoP	Balance of Plant
Bq	Becquerel
BSC	Brussels Supplementary Convention
BSL	Basic Safety Level
BSO	Basic Safety Objective
BSS	Basic Safety Standards
BSSD13	Basic Safety Standards Directive 2013
BWR	Boiling Water Reactor
C&I	Control and Instrumentation
C&M	Care and Maintenance
CCC	Committee on Climate Change
CCAF	Climate Change Adjustment Factor
CCF	Common Cause Failure
CCGT	Combined Cycle Gas Turbines
CCS	Component Cooling System

CCS	Carbon Captur and Storage
CDHR	Condenser Decay Heat Removal
CFD	Contracts for Difference
CH	Closure Head
CHP	Combined Heat and Power
CKoP	Civil Kit of Parts
CM	Capacity Market
CNSS	Civil Nuclear Security and Safeguards
CO_2	Carbon Dioxide
CoFT	Control of Fuel Temperature
COMAH	Control of Major Accident Hazard
COMARE	Committee on Medical Aspects of Radiation in the Environment
CoR	Control of Reactivity
CoRM	Confinement of Radioactive Material
CoSHH	Control of Substances Hazardous to Health
CRDM	Control Rod Drive Mechanisms
CSS	Component Support Structure
CT	Computed Tomography
CV	Containment Vessel
DBA	Design Basis Accident
DBC	Design Basis Condition
DEC	Design Extension Condition
DECC	Department of Energy and Climate Change
DECON	Decommissioning
DEFRA	Department of the Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
DHR	Decay Heat Removal
DiD	Defence in Depth
DPS	Diverse Protection System
DVI	Direct Vessel Injection
DWMP	Decommissioning and Waste Management Plan
E3S	Environment, Safety, Security and Safeguards
EA	Environment Agency
EA(S)R	Environmental Authorisations (Scotland) Regulations 2018
ECC	Emergency Core Cooling
ECCS	Emergency Core Cooling System

EDF	Électricité de France
EIA	Environmental Impact Assessment
EIADR	Environmental Impact Assessment for Decommissioning Regulations 1999
EIDAR	Environmental Impact Assessment of Decommissioning Regulations
ENRESA	Empresa Nacional de Residuos Radiactivos, S.A.
ENRMF	East Northants Resource Management Facility
ENSREG	European Nuclear Safety Regulators Group
EPR16	Environmental Permitting Regulations 2016
ERC	Emergency Response Centre
ESWS	Essential Service Water System
EU	European Union
EUR	European Utility Requirements
Euratom	European Atomic Energy Community
FAP	Funding Arrangements Plan
FDP	Funded Decommissioning Programme
FHM	Fuel Handling Machine
FID	Final Investment Decision
FOAF	First of a Fleet
FOAK	First of a Kind
FPCS	Fuel Pool Cooling System
FPPS	Fuel Pool Purification System
FPSS	Fuel Pool Supply System
FTC	Fuel Transfer Channel
FSA	Food Standards Agency
FSF	Fundamental Safety Principle
GB	Great Britain
GCGT	Combined Cycle Gas Turbines
GCR	Gas Cooled Reactor
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
GSE	Generic Site Envelope
GHG	Greenhouse Gases
GWP	Global Warming Potential
HAZOP	Hazard and Operability
HLW	High-Level Waste
HPR	High Pressure Reactor

HPR1000	Hualong Pressurised Water Reactor
HRH	Hot Reheat
HTHR	High-Temperature Heat Removal
HVAC	Heating, Ventilation and Air Conditioning
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEA	International Energy Agency
IEF	Initiating Event Frequency
IHP	Integrated Head Package
ILW	Intermediate-Level Waste
INES	International Nuclear Event Scale
IPCC	Intergovernmental Panel on Climate Change
IRR17	Ionising Radiations Regulations 2017
ISFSI	Independent Spent Fuel Storage Installation
IWS	Integrated Waste Strategy
JNFL	Japan Nuclear Fuel Ltd
KOH	Potassium Hydroxide
LCA	Life Cycle Assessment
LCI	lifecycle inventory
LCOE	Levelised Cost of Electricity
LiOH	Lithium Hydroxide
LLW	Low-Level Waste
LLWR	Low-Level Waste Repository
LNT	linear no-threshold
LOCA	Loss of Coolant Accident
LP	Low Pressure
LPIS	Low-Pressure Injection System
LTDHR	Low Temperature Decay Heat Removal
LWR	Light Water Reactor
LWTS	Liquid Waste Treatment System
MCWS	Main Circulating Water System
MCR	Main Control Room
MDCT	Mechanical Draft Cooling Tower
MFB	Mobile Fired Boilers
MHI	Mitsubishi Heavy Industries
MSR	Moisture Separator Reheater

MSS	Main Steam System
mSv/yr	Millisieverts/Year
NDA	Nuclear Decommissioning Authority
NDCT	Natural Draft Cooling Towers
NEA	Nuclear Energy Agency
NHL	non-Hodgkins lymphoma
NIA	Nuclear Industry Association
NIEA	Northern Ireland Environment Agency
NLFAB	Nuclear Liabilities Financing Assurance Board
NOAK	Next of a Kind
NPP	Nuclear Power Plant
NPS	National Policy Statement
NPT	Non-Proliferation Treaty
NRC	Nuclear Regulatory Commission
NRPB	National Radiological Protection Board
NRW	Natural Resources Wales
NSAN	National Skills Academy Nuclear
NWS	Nuclear Waste Services Limited
OCGT	Open-Cycle Gas Turbine
OECD	Organisation for Economic Co-operation and Development
OLC	Operating Limits and Condition
ONR	Office for Nuclear Regulation
OPEX	Operating Experience
PAMS	Post Accident Management System
PDHR	Passive Decay Heat Removal
PHE	Public Health England
PIE	Postulated Initiating Events
PPE	Personal Protective Equipment
PSA	Probabilistic Safety Analysis
PV	Photovoltaic
PWR	Pressurised Water Reactor
QIA	Qatar Investment Authority
R3	Round 3
RAB	Regulated Asset Base
RAMTED	Radioactive Materials Transport Event Database
RCP	Reactor Coolant Pump

RCPs	Representative Concentration Pathways
RCS	Reactor Coolant System
RGP	Relevant Good Practice
RI	Reactor Island
RIFE	Radioactivity in Food and the Environment
RPDP	Radiological Protection Developed Principles
RPS	Reactor Protection System
RPV	Reactor Pressure Vessel
RR	Rolls-Royce
RR SMR	Rolls-Royce Small Modular Reactor
RSA	Radioactive Substances Act 1990
RSR	Radioactive Substance Regulation
RWM	Radioactive Waste Management Limited (now NWS)
RWS	Radioactive Waste Strategy
SA	Severe Accident
SAA	Severe Accident Analysis
SAMS	Severe Accident Management System
SAP	Safety Assessment Principle
SAFESTOR	Post-Defuelling Monitored Storage
SCR	Secondary Control Room
SEPA	Scottish Environment Protection Agency
SFAIR	So Far As Is Reasonably Practicable
SFP	Spent Fuel Pool
SFR	Final Repository for Short Lived Radioactive Waste
SG	Steam Generator
SIS	Seismic Isolation System
SKB	Swedish Nuclear Fuel and Waste Management Company
SMR	Small Modular Reactor
SSC	Structures, Systems and Components
SSK	German Commission on Radiological Protection
Sv	Sievert
Sv/yr	Sieverts/Year
SyAPs	Security Assessment Principles
TAG	Technical Assistance Guide
TEPCO	Tokyo Electric Power Company
TMI-2	Three Mile Island (Unit 2)

TRO	Total Residual Oxidant
TSC	Technical Support Centre
U235	Uranium 235
U238	Uranium 238
UF_6	Uranium Hexafluoride
UHS	Ultimate Heat Sink
UK	United Kingdom
UKCP18	UK Climate Projections 2018
UKHSA	United Kingdom Health Security Agency
UKIB	United Kingdom Investment Bank
UKTAG	UK Technical Advisory Group
UNECE	United Nations Economic Commission for Europe
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UO_2	Uranium Dioxide
URL	Underground Research Laboratory
US	United States
VHR	Very High Reliability
VLLW	Very Low-Level Waste
WAGR	Windscale Advanced Gas Cooled Reactor
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators’ Association
WNTI	World Nuclear Transport Institute

The NIA is the trade association for the civil nuclear industry in the UK. The NIA represents more than 300 companies across the supply chain. The diversity of NIA membership enables effective and constructive industry-wide interaction.

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Charlie Powell
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19 November 2024

Tom Greatrex
Nuclear Industry Association
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WC2B 6UJ

Dear Mr Greatrex

Rolls-Royce SMR Regulatory Justification Application: Notice requiring additional information

Further to our letter of 6 August 2024 acknowledging submission of the NIA's application for regulatory justification for the Rolls-Royce (RR) SMR, we are writing as the Justifying Authority to give notice that we require additional information to support our assessment. This notice is given under Regulation 16(1) of the Justification of Practices Involving Ionising Radiation Regulations 2004 (as amended). As per Regulation 16(5), please let us know within 14 days if you consider there are grounds for this notice to be varied or withdrawn.

We understand that some of the information we require would be subject to change following work on optimisation of techniques, for example to minimise wastes, discharges and radiological impacts. Nonetheless, we consider this additional information would assist us in considering your application.

Please submit the additional information detailed below by 17 January 2025. If your response is likely to be after this date, then please let us know your anticipated timeline. Please note that a prolonged delay in your response is likely to increase the overall time for our determination of your application.

The additional information you provide will be subject to public consultation. Please consider the best way to provide the additional information, including how to take account of any corrections required.

In addition to the main body of this letter, please also note the requests contained within Annex A and B.

Additional information required

1. **CTP Definition**

   Please provide a definition of 'power' as used within the class or type of practice definition put forward within the application. Please clarify the definition in regard to the generation of electricity, heat, or energy for any other uses.

2. **GHG Lifecycle Assessments**

   Please provide a commentary on the suitability of GHG Lifecycle Assessments for gigawatt (GW) scale Pressurised Water Reactors (PWRs) as a representative benchmark comparator for the RR SMR. Within this, please outline any expected differences relating to each stage of the plant lifecycle, including the impact of plant generation capacity, reactor size, and a modular build approach on GHG emissions arising from construction and decommissioning of an RR SMR.

3. **Radiological detriment to health**

   Please provide a RR SMR design- or type-specific health and radiological detriment assessment. Information provided should include high-level estimates of:

   i. collective and maximum individual occupational exposures for normal operations and accident scenarios,

   ii. representative person public radiation exposures for accident scenarios, and

   iii. radiological risks to the most exposed members of the public for accident scenarios

   associated with totality of the life cycle, including construction, operation, waste disposal and decommissioning.

   Please provide clarifications for the following apparent inaccuracies identified within the application, including:

   i. The discrepancy between the 0.02 μSv/y for the RR SMR found in Table 9 (p.47) of the application and the equivalent figure given as part of the GDA process in Table 30.3-7 of Issue 2 of Chapter 30: Prospective Radiological Assessment which claims an annual dose of 12.3 μSv/y.

   ii. Reference 49 shows that the doses included in Table 9 for the RR SMR are only direct external doses from the facility ('direct shine') and therefore do not include any dose estimates for discharges of radioactive material to the atmosphere or aquatic environments which would form part of normal operations for such a facility. This is in contrast to the annual doses presented, for example, for the EPR design of 25.8 μSv which include gaseous and aqueous discharges (GDA UK EPR nuclear power plant radiological impact assessment report). The table does not therefore compare like for like in terms of the dose estimates. The same information is also presented in the final sentence of paragraph 5.9.11 and 10.12.16 as the 'peak annual dose to a member of the public', which also does not account for gaseous or aqueous discharges which make up the majority of the dose to members of the public for PWRs such as Sizewell B.

iii. Paragraph 5.8.26 refers to the dose rate for an average citizen being nearly a million times smaller than the dose rate from naturally occurring sources of radiation. As there is no reference given here, it is presumed that this follows on from the values presented in the preceding paragraph of 28 man-Sieverts for the reactors in Europe compared to the background contribution of 2.4 million man-Sieverts. This is around 100,000 times smaller rather than a million times smaller as presented.

iv. Figure 5 refers to 1 mSv annual dose as the ‘annual dose constraint’. It should be referred to as the ‘annual dose limit’. The ‘annual dose constraint’ is 0.3 mSv.

v. In the workers section of Table 12 (p.59), the value of 20 mSv per year is referred to as a ‘dose constraint’. This is incorrect as the value is a dose limit.

Please provide commentary on the relevance and validity for the RR SMR design of any general / comparator dose values used within the application including the extent to which the representative person annual dose presented for the RR SMR is a fair like for like comparison with the values given for the other reactors.

Please also detail whether the RR SMR has particular design/layout/features (including the implications of a highly compact design, of a boron free design and the use of potassium hydroxide in the primary circuit) that may give rise to greater occupational and/or public exposures in comparison to the other existing reactor technologies referred to in the application e.g. shine paths and radionuclide fingerprint/dominant exposure pathways.

The level of detail should be proportionate to the level required for justification, noting that these aspects would be subject to further assessment and scrutiny by nuclear regulators as the proposed practice continues to progress through GDA and subsequent licensing and permitting.

4. Waste Management and decommissioning

Please provide a commentary on the relationship between PWR reactor size and fuel throughput and scale of waste produced on a per unit of energy basis. Please outline any implications this may have for the suitability of GW scale PWRs used as benchmarks for the RR SMR and any implications for the balance of benefits and detriments. Please cover all waste types with a commentary on both scale of waste and characteristics, including liquid and gaseous discharges where relevant.

Please provide commentary to address the fact that when values within Table 13 and 14 (p.63) are normalised, some discharges per unit of energy are higher for the RR SMR than GW-scale benchmarks used.

Please provide an assessment of any matters arising that may impact on the benefits and detriments as set out in the application following the publication in May 2024 of the government’s updated policy on radioactive waste management (UK policy framework for managing radioactive substances and nuclear decommissioning).

5. **Other benefits and detriments**

Please provide a commentary on the validity of comparisons made in the application to GW scale nuclear plants in relation to environmental impacts including but not limited to diesel backup generator consumption and attributes related to direct and indirect cooling. Please consider the validity of comparisons to GW scale nuclear on an energy output basis as well as a per unit basis.

At 7.2.21 in relation to the impact of cooling towers, the application states “these effects will be discussed further in this Chapter, along with the separate impacts the use of direct cooling would have”. However, in paragraphs 7.2.38-40 related to noise impacts, and in several other areas of the chapter, the impact of cooling towers is not considered. Please provide additional commentary on the benefits and detriments related to potential forms of cooling used by the proposed practice.

Please let us know if you have any questions or require clarification. We look forward to receiving your response.

Yours sincerely

Charlie Powell
Team Leader, Nuclear Justification
Environmental Quality Directorate
[redacted]

Annex A - Information accuracy and consistency

The following were noted as potential inaccuracies or information inconsistencies:

Section 2.8 proposes a capacity factor of 80%+ based on international averages, but the Annex states a RR SMR-specific capacity factor of >92%. Please provide a commentary that reconciles these figures.

Section 2.7.2 proposes that 4.3 tonnes of 'natural uranium' – which is interpreted to mean unenriched uranium – will be required per year for a single unit of the proposed practice. Separately, RR SMR-specific values are provided in the annex at Table 17 (p.101), suggesting 1976 fuel assemblies discharged over 60 years with ~350 kg 'heavy metal' per assembly, resulting in approximately 11.5 te/y enriched fuel, which (neglecting the contribution from enrichment and fabrication) appears to be an order of magnitude different to the mass claimed in the body of the application itself. Please provide a commentary on how these figures are arrived at.

In Table 2 (p.10), the final line reads 'final disposal of RR SMR ILW and SF' implying there is no high level waste (HLW), yet there is reference to HLW arising at paragraph 9.1.15. Please provide clarity on the level of HLW arising.

The CTP definition provided refers to 'oxide fuel of low enrichment', which is taken to mean solely 'uranium dioxide fuel'. Please confirm this interpretation is correct.

Paragraph 1.2.6 refers to 'uranium oxide fuel', whilst acronyms and abbreviations at page 165 suggest that 'uranium oxide' is U_3O_8. Please provide a commentary to explain the apparent difference.

Please clarify the text at 3.6.9, which says, "The review concluded that the median LCA after harmonisation was 12 gCO_2e/kWh for both LWRs and PWRs". We understand this may be an error as PWRs are LWRs. Please clarify whether this should refer to Boiling Water Reactors (BWRs) and PWRs.

Paragraph 13.1.2 refers to Public Health England as an extant organisation, this should be updated to refer to the UK Health Security Agency instead.

Similarly, paragraph 13.3.1 refers to the UK Health Protection Agency in the present tense, so this should now refer to the UK Health Security Agency.

Paragraph 14.4.6 refers to 'now Public Health England' which should be corrected to UK Health Security Agency.

Paragraph 6.6.2 refers to RIFE reports as being 'annual reports for the UK Health Security Agency'. This is incorrect as the reports are produced by the UK environmental and food standards agencies. Although UKHSA is an interested party of the reports along with many others, they are not produced for UKHSA's purposes.

Annex B – Optional additions

The below are considered as updates that could be beneficial to the application.

The application could benefit from a commentary on the resilience of the RR SMR design to climate change over the expected lifecycle of the reactor.

Paragraph 21.5.1 of Chapter 21 of the published E3S Case on the RR SMR website, for Decommissioning and End of Life Aspects (Issue 1), states “the RR SMR design philosophy of modularisation provides significant opportunities for decommissioning”. The application could benefit from a commentary on these.

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17 January 2025

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Dear Mr Powell,

Rolls-Royce SMR Regulatory Justification Application: Notice requiring additional information

We write in response to your letter dated 18th November 2024; this letter, it's attachment and our updated application (which will be sent by 24th January as discussed via email with Toby on 15th January) contain the additional information requested. For clarity we have included text from our original application in blue, any text we are removing is highlighted and additional text to be included in our application is in red. A record of change is added to the application to catalogue all amendments.

Additional information required

1. CTP Definition

Please provide a definition of 'power' as used within the class or type of practice definition put forward within the application. Please clarify the definition in regard to the generation of electricity, heat, or energy for any other uses.

Response: RR SMR Limited recognise that the potential alternative uses of the heat and power, generated by the RR SMR, such as grid, synthetic fuels, hydrogen etc, remain unlimited and all these areas are possible future uses for the RR SMR.

A Footnote is added to the class or type of proposed practice in paragraph 1.2.1.

Original text:

1.2.1 This Application is made to support the construction, operation and, ultimately, the decommissioning of new nuclear power stations in the UK by reference to the Rolls-Royce SMR Limited technology. The class or type of proposed practice for which Justification is sought (the "Proposed Practice") can be summarised as:

"The generation of power from nuclear energy using oxide fuel of low enrichment in fissile content in a light water cooled, light water moderated thermal reactor currently known as the RR SMR designed by Rolls-Royce SMR Limited"

Change: red text added as footnote to *power* italic text:

Power, as measured in Mega Watts thermal (MW_{th}) which could be used for the provision of heat and/or the generation of electricity.

2. GHG Lifecycle Assessments

Please provide a commentary on the suitability of GHG Lifecycle Assessments for gigawatt (GW) scale Pressurised Water Reactors (PWRs) as a representative benchmark comparator for the RR SMR. Within this, please outline any expected differences relating to each stage of the plant lifecycle, including the impact of plant generation capacity, reactor size, and a modular build approach on GHG emissions arising from construction and decommissioning of an RR SMR.

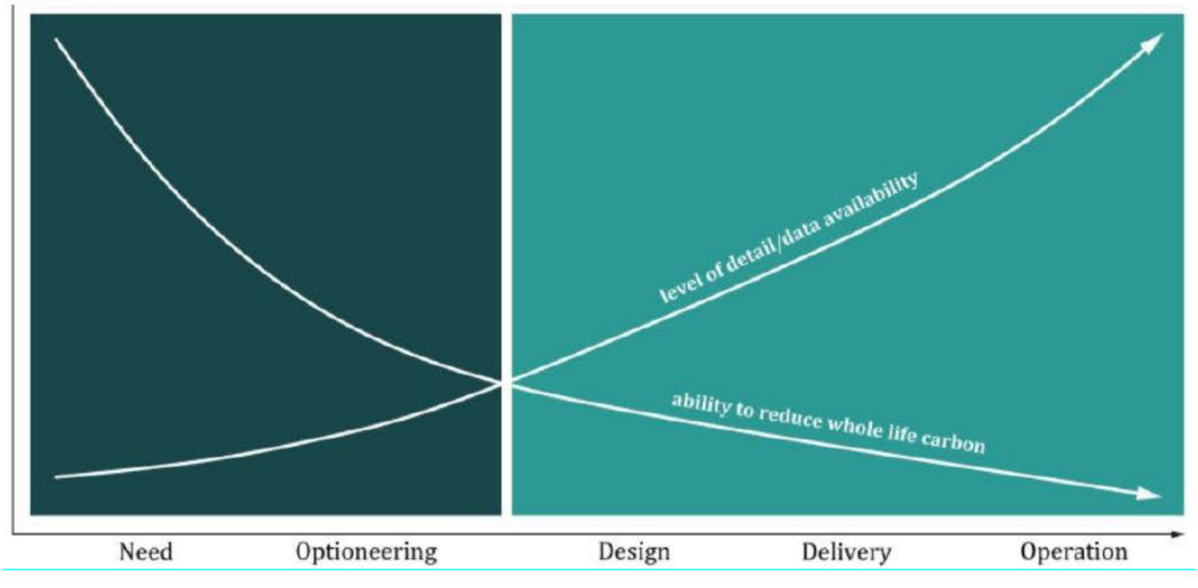
Response:

GHG Lifecycle Assessments (LCA) are commonly used as a method to assess the greenhouse gas emissions of any technology as well as nuclear technologies/ designs. There are several examples of LCAs available in the public domain, which utilise varying methods of assessment. The method of assessment has an impact on the accuracy and robustness of the findings. Best practice assessments are those that are carried out in line with ISO standards 14040[1] and 14044[2].

Carrying out an LCA for any technology or project allows for a calculation/ modelling (estimate) of the life cycle environmental impact (including greenhouse gas emissions and other indicators) of a technology or design. Any LCA carried out will be highly reliant on the quality of the data available which is often a consideration when determining when the LCA will be carried out within the project programme.

As explained in the PAS2080 guidance[3], whilst carrying out an LCA at an early stage during in the project lifecycle presents challenges in terms of data availability, it provides valuable opportunities to bring about continuous improvement as the design progresses. Carrying out an LCA at a later stage of the programme reduces the opportunities for positive interventions and design changes (refer to Figure 1).

Figure 1



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[1] International Organization for Standardization. (2006). ISO 14044:2006; Environmental management - Life cycle assessment - Requirements and guidelines. ISO.

[2] International Organization for Standardization. (2006). ISO 14040:2006 / AMD 1:2020; Environmental management - Life cycle assessment - Principles and framework. ISO.

[3] Graph extracted and adapted from PAS2080:2023 Carbon management in buildings and infrastructure. https://www.bsigroup.com/globalassets/localfiles/en-th/pas-2080/pas2080_final-th.pdf

We understand that each LCA is unique to the design it relates to, as well as the data quality and availability. It is also, as defined by the international standards referenced above, not necessarily appropriate to make direct comparisons between LCAs as approach, system boundaries, data and designs will differ, which ultimately will impact the overall findings. Benchmarking is possible as an indication of magnitude, but like-for-like comparison and comparative assertions are not appropriate.

As a means to assess, track and measure the environmental impact of the RR SMR technology and bring about continuous improvement and reduction in GHG emissions as part of our design process, Rolls-Royce SMR Limited has chosen to carry out a LCA of its SMR design. This work has been carried out by appointed external consultants Ricardo, who have undertaken a LCA of a RR SMR. The assessment was carried out against a specific reference design.

The main objectives of the LCA study were:

- To provide Rolls-Royce SMR Limited with robust, specific, evidence on the potential environmental impacts associated with the life cycle of its design;
- To identify significant contributions to the potential environmental impacts (known as "hotspots") associated with the generation and later distribution of electricity from the RR SMR; and
- To quantify the potential environmental impacts of the RR SMR design to focus on areas for lowering environmental impacts as design develops.

The expected differences (not quantified) between RR SMR technology and GW scale reactors and how these differences may impact on the GHG emissions arising from construction, operation and decommissioning are:

- In some cases, LCAs for nuclear power stations are carried out based on an existing and already operational design, therefore there is much greater data availability and smaller margins in any assumptions. It is anticipated that the carbon intensity of the RR SMR will reduce as efficiencies are found during the design process.
- GW reactor sites often with multiple reactor units will have a higher energy density than our generic site with a single reactor e.g. SZC has a single cooling water island serving twin reactors with a total power output of 3,200 MWe, whereas RR SMR has a cooling water island (albeit smaller than SZC) serving one reactor with a power output of 470 MWe. i.e. RR SMR requires similar systems (albeit smaller) but has a far smaller electrical output. Therefore, SZC is an energy dense site, which is likely to result in a lower carbon intensity.
- Steel is a significant material hotspot as per the results of the LCA- There is a significant quantity of steel used for the RR SMR module frames – this is effectively additional material that would not be required for "non-modular" power plants. This approach may increase greenhouse gas emissions and result in us having a higher carbon intensity, however it is envisaged that this would be recyclable, or the frames may be reused after decommissioning.

The RR SMR is seeking to minimise the use of concrete (per MW_e) compared to GW scale plants. Concrete usage is an area RR SMR continue to focus on as the design progresses and RR SMR seek opportunities to reduce its use and to use alternatives wherever possible where it does not impact on nuclear safety. RR SMR recognises that concrete is carbon intensive.

As the design progresses RR SMR will focus on hotspot areas for improvement for the subsequent iterations of the RR SMR LCA. At this stage of the areas of improvement that have been identified include but are not limited to:

- Water use during construction, operation and decommissioning.
- Pipework steel (as steel is a significant contributor to material related GHG emissions during construction).
- Electricity requirements during commissioning, operation and decommissioning.
- Operational radioactive waste production.
- Potential use of chemicals including corrosion inhibitors and chemicals used for cleaning for both during operation of the RR SMR and for decontamination within the Mechanical, Electrical and Piping factory.
- Potential use of “green” steel and/or concrete in certain applications that would not impact on nuclear safety.

3. Radiological detriment to health

Please provide a RR SMR design or type-specific health and radiological detriment assessment. Information provided should include high-level estimates of:

i. collective and maximum individual occupational exposures for normal operations and accident scenarios,
ii. representative person public radiation exposures for accident scenarios, and
iii. radiological risks to the most exposed members of the public for accident scenarios associated with totality of the life cycle, including construction, operation, waste disposal and decommissioning. Please provide clarifications for the following apparent inaccuracies identified within the application, including:

i. The discrepancy between the 0.02 μSv/y for the RR SMR found in Table 9 (p.47) of the application and the equivalent figure given as part of the GDA process in Table 30.3-7 of Issue 2 of Chapter 30: Prospective Radiological Assessment which claims an annual dose of 12.3 μSv/y.

ii. Reference 49 shows that the doses included in Table 9 for the RR SMR are only direct external doses from the facility (‘direct shine’) and therefore do not include any dose estimates for discharges of radioactive material to the atmosphere or aquatic environments which would form part of normal operations for such a facility. This is in contrast to the annual doses presented, for example, for the EPR design of 25.8 μSv which include gaseous and aqueous discharges (GDA UK EPR nuclear power plant radiological impact assessment report). The table does not therefore compare like for like in terms of the dose estimates. The same information is also presented in the final sentence of paragraph 5.9.11 and 10.12.16 as the ‘peak annual dose to a member of the public’, which also does not account for gaseous or aqueous discharges which make up the majority of the dose to members of the public for PWRs such as Sizewell B.

iii. Paragraph 5.8.26 refers to the dose rate for an average citizen being nearly a million times smaller than the dose rate from naturally occurring sources of radiation. As there is no reference given here, it is presumed that this follows on from the values presented in the preceding paragraph of 28 man-Sieverts for the reactors in Europe compared to the background contribution of 2.4 million manSieverts. This is around 100,000 times smaller rather than a million times smaller as presented.

iv. Figure 5 refers to 1 mSv annual dose as the 'annual dose constraint'. It should be referred to as the 'annual dose limit'. The 'annual dose constraint' is 0.3 mSv.

v. In the workers section of Table 12 (p.59), the value of 20 mSv per year is referred to as a 'dose constraint'. This is incorrect as the value is a dose limit. Please provide commentary on the relevance and validity for the RR SMR design of any general / comparator dose values used within the application including the extent to which the representative person annual dose presented for the RR SMR is a fair like for like comparison with the values given for the other reactors.

Please also detail whether the RR SMR has particular design/layout/features (including the implications of a highly compact design, of a boron free design and the use of potassium hydroxide in the primary circuit) that may give rise to greater occupational and/or public exposures in comparison to the other existing reactor technologies referred to in the application e.g. shine paths and radionuclide fingerprint/dominant exposure pathways. The level of detail should be proportionate to the level required for justification, noting that these aspects would be subject to further assessment and scrutiny by nuclear regulators as the proposed practice continues to progress through GDA and subsequent licensing and permitting.

Response:

i) High level estimates of occupational exposures during normal operations are presented in Table 9.

RR SMR Limited is carrying out Design Basis (DB) Radiological Consequences Analysis to provide confidence that there will be no significant radiological consequences to any person, either onsite or offsite, due to a mitigated design basis fault sequence. The applicable dose targets for a given DB fault are determined by the Initiating Event Frequency (IEF) and are based on the Basic Safety Level (BSL) and Basic Safety Objective (BSO) defined for Numerical Target 4 in the Office for Nuclear Regulation (ONR) Safety Assessment Principles (SAPs). Notwithstanding the BSL and BSO RR SMR will reduce exposures to ALARP. Severe Accident Analysis will commence in 2025 to confirm exposures in accident exposures are ALARP, and no greater than GW scale plants, and will be subject to regulatory assessment during GDA Step 3.

Radiological risks to the most exposed members of the public are discussed below.

ii) Reference 49 was written using early Radiation Protection analysis. Since its publication the RR SMR Source term has been updated and figures in Table 9 and sections 5.9.11 and 10.12.16 have been updated to current conservative values which include atmospheric and aquatic discharges. Work is still ongoing to further refine the source term and understand potential doses arising from waste stores constructed on the site. Once this work is complete it will be subject to assessment during GDA Step 3 and site-specific permitting.

Table 9 and paragraphs 5.9.11 and 10.12.16 have been updated to reflect currently available conservative values. Ref [49] Rolls Royce SMR Limited SMR0009159, "Dose to Other Workers and the Public from the Reactor Operation" December 2023 will be reissued March 2025, with revised figures.

Amendments made to Table 9, page 47 Existing text RR SMR [49] 0.02 μSv 0.00005 μSv/MW_e replaced with RR SMR [49] 12.3 μSv 0.026 μSv/MW_e.

Paragraphs 5.9.11 and 10.12.16 are amended with conservative estimates detailed below: removing highlighted text adding red text:

5.9.11 For the Proposed Practice we are seeking to justify, we believe it is sufficient to state that maximum doses to individual members of the public from the practice will always be less than 0.3 mSv/y, and those to workers will always be well within limits and, on average, less than 10 mSv/y. The peak annual dose to a member of the public is calculated to be 0.065 12.3 μSv, 100 m from the site boundary, or 0.026 μSv at the site fence.

10.12.16 The peak annual dose to a member of the public is calculated to be 0.065 12.3 μSv, 100 m from the site boundary, or 0.026 μSv at the site fence.

iii) Paragraph 5.8.26 is corrected: million is replaced by 100,000 and additional text in red added.

5.8.26 For perspective, the dose rate derived for an average citizen in the vicinity of a nuclear power plant in Europe (many of which were commissioned decades ago) is nearly a million times smaller than the dose rate received from other naturally occurring sources of radiation. While Permit applications for any nuclear power station(s) built as part of the Proposed Practice have not yet been made, it is clear that, even if the discharges significantly exceeded those referred to above, the potential health detriment would remain very small and immaterial in the context of the overwhelming benefits of the Proposed Practice.

iv and v) Table 5 is amended 'annual dose constraint' changed to 'annual dose limit'. Table 12 is amended 'dose constraint' changed to 'dose limit'

The "Representative Person" (RP) is the individual that is representative of the more highly exposed persons in a population group because of their circumstances or habits. The preferred approach to identifying the RP for a specific site involves habits surveys of local residents to identify those individuals most exposed (Candidates for the Representative Person, or CRP).

This approach is not possible for a generic site dose assessment and a proportionate approach has thus been adopted. Proposed exposure pathways were selected on the basis of the predicted discharges from the RR SMR to coastal and atmospheric environments, the RR SMR Generic Site Description and consideration of Relevant Good Practice (RGP) for choice of exposure pathways for coastal sites around the UK.

Potential CRP groups for the RR SMR are a 'fishing family' and 'local resident family', in alignment with the methodology in the Environment Agency's Initial Radiological Assessment Tool (IRAT). Radiological dose assessments were carried out for each CRP, including the major pathways of food ingestion, inhalation, external dose from the plume, deposited radioactive material and contaminated sediments, and direct radiation dose.

The parameters and assumptions applied in the assessment of radiological dose from discharge of radioactive effluent to the environment are based on realistic but conservative values for UK. A conservative value for direct radiation was adopted for direct radiation dose, based on previous GDA assessments. This approach should result in a proportionate assessment which can be reasonably compared with dose limits and constraints, and against site-specific assessments and measurements from existing nuclear power plant.

The RR SMR compact layout incorporates Operating Experience (OPEX) and RGP from existing PWRs and will reduce exposures to ALARP. The Boron free design significantly reduces volumes of Tritium in discharges reducing dose levels compared to other PWRs. The impact of using potassium hydroxide in the primary circuit is currently being evaluated and will be assessed during GDA Step 3, it is not envisaged to give rise to greater exposures.

4. Waste Management and decommissioning

Please provide a commentary on the relationship between PWR reactor size and fuel throughput and scale of waste produced on a per unit of energy basis. Please outline any implications this may have for the suitability of GW scale PWRs used as benchmarks for the RR SMR and any implications for the balance of benefits and detriments. Please cover all waste types with a commentary on both scale of waste and characteristics, including liquid and gaseous discharges where relevant. Please provide commentary to address the fact that when values within Table 13 and 14 (p.63) are normalised, some discharges per unit of energy are higher for the RR SMR than GW-scale benchmarks used. Please provide an assessment of any matters arising that may impact on the benefits and detriments as set out in the application following the publication in May 2024 of the government's updated policy on radioactive waste management (UK policy framework for managing radioactive substances and nuclear decommissioning).

Response:

Rolls-Royce SMR Limited has carried out a detailed waste comparison to other PWRs, drawing on considerable OPEX, this is presented in Rolls-Royce Small Modular Reactor – Disposability Case SMR0007665 and is being assessed by Nuclear Waste Services Limited and as part of the GDA process. This document is attached for information.

The RR SMR figures provided in Tables 13 and 14 were early estimates, these tables have been updated to current values. Noble gas discharges are of an order of magnitude higher than for other sites due to a very conservative assessment being used in determining the source term, this approach is being reviewed and refined to reflect more realistic conditions, details of revised values will be presented in Version 3 of the E3S Case for assessment during GDA Step 3.

There is currently no impact on benefits and detriments set out in the application following the publication in May 2024 of the government's updated policy on radioactive waste management (UK policy framework for managing radioactive substances and nuclear decommissioning). (RR SMR issued its Disposability Case after reviewing the draft updated policy).

Original tables 13 and 14 for information:

Table 13: Comparison of normalised annual gaseous radioactivity discharge

Reactor	Tritium (TBq/GWe)	Carbon-14 (GBq/GWe)	Iodine-131 (MBq/GWe)	Noble Gases (GBq/GWe)	Other (MBq/GWe)
RR SMR	0.0863	381	143	2.50	21.8
UK EPR	0.290	200	29.0	0.46	2.30
Sizewell B	0.521	250	24.0	2.59	4.84

Table 14: Comparison of normalised annual aqueous radioactivity discharge

Reactor	Tritium (TBq/GWe)	Carbon-14 (GBq/GWe)	Iodine-131 (MBq/GWe)	Noble Gases (GBq/GWe)	Other (MBq/GWe)
RR SMR	0.188	0.107	10.3	0.237	1.14
UK EPR	30.0	13.0	4.00	No Data	0.35
Sizewell B	21.7	No Data	No Data	0.405	5.09

Amendments made to Table 13:

Units in header Table 13: Noble Gases changed to (TBq/GWe)

RR SMR values replaced with:

Tritium	0.089 TBq/GWe
C-14	42.63GBq/GWe
I-131	40.71 MBq/GWe
Noble Gases	22.59 TBq/GWe

Other*	6.94 MBq/GWe

Amendments made to Table 14 RR SMR values replaced with:

Tritium	0.18 TBq/GWe
C-14	0.00002 GBq/GWe (1.71 kBq/Gwe)
I-131	0.0005 MBq/GWe (0.496 kBq/GWe)
Noble Gases	1.9 GBq/GWe
Other	1.01 MBq/GWe

5. Other benefits and detriments

Please provide a commentary on the validity of comparisons made in the application to GW scale nuclear plants in relation to environmental impacts including but not limited to diesel backup generator consumption and attributes related to direct and indirect cooling. Please consider the validity of comparisons to GW scale nuclear on an energy output basis as well as a per unit basis. At 7.2.21 in relation to the impact of cooling towers, the application states "these effects will be discussed further in this Chapter, along with the separate impacts the use of direct cooling would have". However, in paragraphs 7.2.38-40 related to noise impacts, and in several other areas of the chapter, the impact of cooling towers is not considered.

Please provide additional commentary on the benefits and detriments related to potential forms of cooling used by the proposed practice. Please let us know if you have any questions or require clarification. We look forward to receiving your response.

Response:

RR SMR's application provides a valid comparison to GW scale plants in relation to environmental impacts. At the current stage of the design most of the comparisons are based on scaled data from GW plants e.g. whilst the backup diesel generators on the RR SMR will run for a similar length of time as on a GW scale plant, their power output and subsequently fuel usage and associated combustion activities will be scaled accordingly. It is currently envisaged that RR SMR will have six diesel generators providing a power output of 22.8MW_{th} compared to 12 diesel generators providing a power output of 227 MW_{th} at Sizewell C. Backup diesel generators have been selected as the preferred option for safety critical equipment. However, this decision will be revisited during the lifecycle of the RR SMR and if a suitable new greener safety critical alternative becomes available, then a full BAT assessment could be carried out by the operator to see if it could be retrofitted.

The attributes relating to direct and indirect cooling are covered in Section 7, with additional information added under Noise and Vibration.

Mechanical Draft Cooling Towers are considerably smaller than conventional large scale concrete cooling towers commonly used at GW plants, the smaller visual footprint is also mitigated by the berm surrounding the RR SMR.

If direct cooling is the preferred option for a specific site less water will be extracted by RR SMR than GW scale plants, reducing the impact on marine environments. The RR SMR footprint could be could also be reduced by the removal of cooling towers which would simultaneously reduce the visual impact too. The benefits and detriments of the differences between indirect and direct cooling will be considered further on a site-specific basis.

Noise and Vibration

7.2.38 The design of the buildings and plant would ensure that the continuous operating noise from the Proposed Practice would be minimal and would represent only a small addition to the existing background level. The presence of the earth berm will also help to mitigate sound transmission from the plant.

New paragraphs are added after 7.2.38:

Best Available Techniques have been incorporated throughout the RR SMR design leading to the decision to use indirect cooling, via mechanical draft cooling towers, for the generic design.

The wet closed induced draught cooling towers are specified to have ultra-quiet blades engineered to minimise noise from airflow and an ultra-quiet double-flow stainless steel wet coil, which reduces the sound produced by water splashing or trickling, as well as the airflow turbulence that occurs during the heat transfer process. The cooling towers are specified to have excess capacity at design conditions that allows it to meet thermal performance requirements with lower airflow and reduced fan speed, decreasing the noise generated by air movement and fan operation.

7.2.39 Whilst some additional noise might result from the intermittent operation of ancillary equipment, such as auxiliary diesel generators, these systems would only be operated infrequently for intermittent testing or during abnormal conditions. Noise control during the operation of the power station would be subject to conditions and limitations specified within the Environmental Permit. Extra text is added: Acoustic enclosures could also be fitted around certain external plant if required to reduce noise.

7.2.40 As part of the development consent order process for any RR SMR build, a site-specific noise study would be carried out, and noise limits imposed on a site-by-site basis which the power plant would operate within.

The visual impacts of cooling towers are discussed in paras 7.2.45 and 7.2.46:

7.2.45 Two potential concerns around the use of cooling towers are their large physical size and highly visible plume. A visible plume is caused when warm, saturated (air that cannot be made any more humid) exhaust air exits the tower and is cooled on contact with colder air. This causes the water in the air to condense into visible droplets, which form the plume.

7.2.46 The large cooling towers usually associated with thermal generating stations are natural draft cooling towers (“NDCTs”). These use the rising hot air from the coolant to drive the airflow within the tower, requiring a large amount of space (around 100 m in diameter and more than 100 m high) resulting in saturated hot air exhausts that form a significant visible plume. These concerns have been mitigated through the RR SMR use of mechanical draft cooling towers (“MDCT”) which are much smaller than NDCTs at around 16 m wide and 10 m high, with tens of units being used instead of 2-10 large towers. The RR SMR MDCTs will be provided with plume abatement systems, which allow additional dry air to be drawn into the exhaust flow of the towers, cooling and drying the exhaust before it can create a visible plume.

Annex A - Information accuracy and consistency

The following were noted as potential inaccuracies or information inconsistencies: Section 2.8 proposes a capacity factor of 80%+ based on international averages, but the Annex states a RR SMR-specific capacity factor of >92%. Please provide a commentary that reconciles these figures.

Section 2.7.2 proposes that 4.3 tonnes of 'natural uranium' – which is interpreted to mean unenriched uranium – will be required per year for a single unit of the proposed practice. Separately, RR SMR-specific values are provided in the annex at Table 17 (p.101), suggesting 1976 fuel assemblies discharged over 60 years with ~350 kg 'heavy metal' per assembly, resulting in approximately 11.5 te/y enriched fuel, which (neglecting the contribution from enrichment and fabrication) appears to be an order of magnitude different to the mass claimed in the body of the application itself. Please provide a commentary on how these figures are arrived at. In Table 2 (p.10), the final line reads 'final disposal of RR SMR ILW and SF' implying there is no high level waste (HLW), yet there is reference to HLW arising at paragraph 9.1.15. Please provide clarity on the level of HLW arising.

The CTP definition provided refers to 'oxide fuel of low enrichment', which is taken to mean solely 'uranium dioxide fuel'. Please confirm this interpretation is correct. Paragraph 1.2.6 refers to 'uranium oxide fuel', whilst acronyms and abbreviations at page 165 suggest that 'uranium oxide' is U3O8. Please provide a commentary to explain the apparent difference.

Please clarify the text at 3.6.9, which says, "The review concluded that the median LCA after harmonisation was 12 gCO2e/kWh for both LWRs and PWRs". We understand this may be an error as PWRs are LWRs. Please clarify whether this should refer to Boiling Water Reactors (BWRs) and PWRs.

Paragraph 13.1.2 refers to Public Health England as an extant organisation, this should be updated to refer to the UK Health Security Agency instead. Similarly, paragraph 13.3.1 refers to the UK Health Protection Agency in the present tense, so this should now refer to the UK Health Security Agency.

Paragraph 14.4.6 refers to 'now Public Health England' which should be corrected to UK Health Security Agency.

Paragraph 6.6.2 refers to RIFE reports as being 'annual reports for the UK Health Security Agency'. This is incorrect as the reports are produced by the UK environmental and food standards agencies. Although UKHSA is an interested party of the reports along with many others, they are not produced for UKHSA's purposes.

Response: Section 2.8 is referring to worldwide capacity factor including ageing PWRs. RR SMR will be a modern efficient PWR targeting a capacity factor of >92%.

Paragraph 2.7.2 specifies total core load, of which a third is changed every 18 months. Hence a complete core is replaced every 4.5 years leading to the 11.5 te/y figure detailed in Table 17. HLW mentioned in paragraph 9.1.15 will be non-fuel core components of small volume and will be disposed of alongside spent fuel to a GDF.

Paragraph 2.7.2 is amended to:

Section 2.7.2 Furthermore, the physical quantity of fuel required is modest compared with that for fossil-fuelled plants. The Organisation for Economic Co-operation and Development ("OECD")'s Nuclear Energy Agency ("NEA") and the IAEA periodically review world uranium market fundamentals in their series of "Red Books". In the 2022 Red Book they calculated that the net generating capacity of 393 GWe of commercial reactors connected to electricity grids worldwide as of 1 January 2021 required a total of about 60,100 tonnes of natural uranium ("tU") annually.[38] The Rolls-Royce SMR in the Proposed Practice would require approximately 4.3 tonnes of natural uranium (enriched to no more than 5%), of which a third is replaced every 18 months, for a 470 MW plant.

Table 2 is amended adding red text: Final Disposal of RR SMR Intermediate-Level Waste (ILW), High-Level Waste (HLW) and spent fuel

Clarification in CTP definition add red text:

This Application is made to support the construction, operation and, ultimately, the decommissioning of new nuclear power stations in the UK by reference to the Rolls-Royce SMR Limited technology. The class or type of proposed practice for which Justification is sought (the "Proposed Practice") can be summarised as:

"The generation of power from nuclear energy using uranium dioxide fuel of low enrichment in fissile content in a light water cooled, light water moderated thermal reactor currently known as the RR SMR designed by Rolls-Royce SMR Limited."

Paragraph 1.2.6 is amended: uranium oxide to uranium dioxide

1.2.6 The RR SMR power station will have the capacity to successfully generate 470 MWe of low carbon energy, equivalent to more than 150 onshore11 wind turbines and enough to power a million homes for 60 years. RR SMR utilises fission by neutrons in the thermal spectrum and utilises industry standard low enriched uranium dioxide fuel. Light water is utilised in the design as both a moderator and a coolant.

U_3O_8 Uranium Oxide is removed from the acronym list.

Paragraph 3.6.9 is amended with clarification that it should read LWRs including PWRs

3.6.9 The review concluded that the median LCA after harmonisation was 12 gCO2e/kWh for both LWRs and including PWRs, and this was adopted in the IPCC report.

Paragraphs13.1.2 and 13.3.1 are amended with red text added:

13.1.2 This understanding is based on scientific research. Among the most important is the epidemiological study of people who have been exposed to this type of radiation, drawing on data gathered over many years. This includes studies of those who have been exposed through their jobs (such as hospital radiographers or nuclear industry workers) or through such major events as the atomic weapons explosions at Hiroshima and Nagasaki in Japan. International groups of scientists collaborate on this work and several bodies have developed a worldwide reputation as authoritative sources of advice. These include the International Commission on Radiological Protection ("ICRP"), the United Nations Scientific Committee on the Effects of Atomic Radiation ("UNSCEAR"), the Committee on the Biological Effects of Ionizing Radiations ("BEIR") of the US National Research Council and, in the UK the UK Health Security Agency ("UKHSA") formally Public Health England ("PHE"), previously the Health Protection Agency incorporating what was formerly the National Radiological Protection Board).

13.3.1 To summarise, a low dose of radiation is one of many factors that can lead to an increased risk of cancer, but there are other possible factors, for example exposure to particular chemicals or infections. Based on the large body of evidence that has been collected over the last 70 years, including detailed, regular and recent reviews of biological and epidemiological date, the UK Health Protection Agency (now UKHSA) [145] has confidence that the radiation risk factors used by ICRP provide a sound basis for a radiological protection system.

Paragraph 14.4.6 is amended with highlighted text removed and red text added:

14.4.6 The Windscale accident demonstrated the importance of regulation of the nuclear industry and understanding the science of radiological protection. A committee chaired by Sir Alexander Fleck investigated the wider implications of the accident, which led to, among other things:

- The establishment of the National Radiological Protection Board ("NRPB") in 1971 (since 2004, subsumed within the Health Protection Agency as the Radiation Protection Division) and now Public Health England UKHSA; and

- The creation of the Nuclear Installations Inspectorate (now part of ONR) to provide independent regulation of the civil nuclear power programme.

Paragraph 6.6.2 is amended with highlighted text removed and red text added:

6.6.2 The RIFE reports are annual reports for the UK Health Security Agency produced by the UK environmental and food standards agencies. They monitor all exposure pathways for the "representative person" and confirm they would receive an exposure below legal limits. The concept of the representative person is discussed in more depth in Chapter 5, however it simply represents the worst-case exposure for a member of the public. The most recent (2022) RIFE report found that the dose from any nuclear power plant in the UK was less than 2% of the required dose limits, taking into account all exposures from all factors, including radioactive discharge. This would represent an increase of no more than 0.5% from background exposures. It can therefore be concluded that radioactive discharge from nuclear power plants, including the proposed RR SMR, would pose no threat to the public.

Annex B – Optional additions

The below are considered as updates that could be beneficial to the application.

The application could benefit from a commentary on the resilience of the RR SMR design to climate change over the expected lifecycle of the reactor.

Paragraph 21.5.1 of Chapter 21 of the published E3S Case on the RR SMR website, for Decommissioning and End of Life Aspects (Issue 1), states "the RR SMR design philosophy of modularisation provides significant opportunities for decommissioning". The application could benefit from a commentary on these.

Response:

Paragraph 8.5.11 is removed and additional information is added:

Operators also commission site specific studies where further detail is required to ensure that plant provisions are adequately defined to cope with potential impacts.

Demonstrating that the design can withstand external hazards and adapt to potential climate change is a key focus of the RR SMR. For the generic design, a Generic Site Envelope ("GSE") has been produced, which identifies all hazards, including those judged to be impacted by climate change and provides Climate Change Adjustment Factor ("CCAF") for those hazards (where applicable and suitably conservative) based on the UK Climate Projections 2018 ("UKCP18"). Use of UKCP18 is conservative and selection of the Representative Concentration Pathways ("RCPs") and percentiles is endorsed by UK regulatory authorities, which state that the medium emissions scenario at the 84th percentile is adequately conservative for defining a design basis. We are following this guidance in selection of RCPs and percentiles. UKCP18 projections are aligned with the Intergovernmental Panel on Climate Change ("IPCC") but provide climate projections specific to the UK.

The Rolls-Royce SMR is designed to meet conservative external hazards requirements from the existing nuclear sites in Great Britain, more detailed hazard characterisation assessments accounting for climate change will be undertaken once a site is selected. RR SMR will develop a climate adaptation strategy for the site-specific plant to ensure the plant is resilient and the final site-specific design will allow the operator to develop and maintain climate change resilience through the lifetime of the power station. Having adaptation plans in place will ensure the plant can make any required changes in a timely manner. Re-characterisation of hazards incorporating a climate change allowance will be carried out periodically for the foreseeable lifetime of the plant based on the latest observations, RGP and most recent recommended projections, to determine whether the adaptation plans will be triggered.

Examples of hazards that are affected by climate change and the climate change values calculated using the UKCP18 RCPs to develop climate change projections are detailed in the GSE. The GSE presents the maximum and minimum dry bulb temperatures, (a CCAF has not been incorporated into the design for minimum dry bulb air temperature this would make the value higher and therefore less conservative). Additionally, heatwaves are discussed, and air temperature affected by climate change has been considered in the derivation of these values.

Table 1 is an extract from the GSE and shows examples of external hazards affected by climate change and the bounding values calculated. Not all the hazards in Table 1 are covered by UKCP18, and where this is the case the GSE has used other best available data. Flooding is not captured in the table as the values are site-specific.

Some simple examples of how the design is including climate change adaptations include sizing the Heating, Ventilation and Air Conditioning Systems ("HVAC"), which is generally sized to a relative humidity and wet bulb temperature. HVAC is being designed to accommodate the design basis value which includes a climate change adjustment factor. The Essential Services Water

System ("ESWS") and structures like surface water drains are being designed to accommodate for climate change, and structures like door thresholds are being raised.

External Hazard	Parameter	GSE Value	Commentary
Air temperature	Maximum dry bulb air temperature (hourly)	49.0 °C	Maximum air temp (not accounting for climate change) is 42 °C at Oldbury. A CCAF of +7 °C was determined from RCP 6.0 emissions scenario for a 90 % probability level to the year 2100
	Maximum wet bulb air temperature (hourly)	32.3 °C	Uses a relative humidity of 32 % and dry bulb temperature of 49.0 °C, with enthalpy of 111.4 $kJ.kg^{-1}$. Proposed value bounds previous GDA assessments and European Utility Requirements (EUR)
	Minimum dry bulb air temperature	-35.0 °C	Corroborates and is bounding of available data (consistent with UK EPR)
Rainfall	15-minute rainfall depth	203.1 mm	Present day value taken as the bounding 15-minute and 1-hour depth from the UK EOR GDA of 145.1 mm and 163.7 mm respectively. Incorporates a CCAF which corresponds to a 40 % enhancement from the present day
	1 hour rainfall depth	229.2 mm	
	24-hour rainfall depth	400 mm	Proposed value from EUR. Found to be bounding of the largest present-day value with addition of a CCAF
Cooling Water Temperature	Maximum Sea Water Temperature	32.3 °C	Present day value bounding of available data (consistent with UK HPR1000 GDA Submission and Sizewell B stress test at 28 °C)

Table 1: Example external hazards impacted by climate change and bounding values used to support design.

Additional text added to acronym list:

CCAF Climate Change Adjustment Factor

GSE Generic Site Envelope

RCPs Representative Concentration Pathways

UKCP18 UK Climate Projections 2018

Additional paragraphs added to in Annex 1 after paragraph 10.19.3.

The modular concept is advantageous for decommissioning. Disassembly of modular clusters may broadly be the reverse of assembly. The relative structural independence of each primary structure means that their removal (in reverse order) would not significantly compromise the remaining modular structure (cluster).

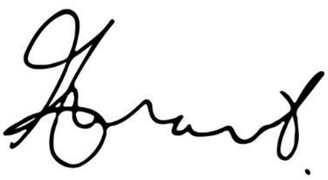
Integral handling and transportation features could be used for their removal from the plant. Primary structures would inherently act as vehicles for the removal of Mechanical, Electrical and Plumbing plant to where the equipment could be safely decommissioned. It is considered that the frame itself would pose no exceptional issues for decontamination and recycling.

Record of change added:

Date	Revision Number	Status	Reason for Change
July 2024	1	Issue	First issue of NIA Report Regulatory Justification Application Rolls-Royce SMR Limited.
January 2025	2	Issue	Second issue of NIA Report Regulatory Justification Application Rolls-Royce SMR Limited in response to request for additional information from the justifying authority. Changes have been made to the following paragraphs: 1.2.1 Footnote added to CTP definition. 2.7.2 additional clarification of core fuel load added. Numerical values in Paragraphs 5.9.11, 10.12.16 and Tables 9, 13 and 14 are amended as a result of a change made in reference data. Additional paragraphs added after 7.2.38 to provide additional information. Additional detail on climate change consideration is added in Chapter 8. Annex 1 contains additional commentary on how the modular concept is advantageous to decommissioning. Also minor template/editorial updates for overall consistency and accuracy.

We trust that this information provides adequate additional information and look forward to receiving further details of the applications' progress.

Yours sincerely



Tom Greatrex

Chief Executive

Department
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03 April 2025

Tom Greatrex
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Dear Mr Greatrex

RR SMR Regulatory Justification Application: additional information

We are writing in reply to your submission on 17 January 2025 of additional information relating to your application, in response to our letter dated 19 November 2024.

We consider that the proposed information is a helpful advance on information previously presented. However, when comparing our request with your proposal, there are some gaps (detailed in the Annex to this letter). Our meeting on 16 April provides an opportunity for further discussion.

Guidance on the level of information requested

Justification is a high-level assessment and does not require detailed technical data in relation to all potential detriments (albeit this information may be helpful where available). This is in contrast to the GDA. Where, for example, we have requested 'high-level estimates' within question 3. 'Radiological detriment to health', this does not require a quantitative figure for assessment, and we understand that this data may not be available at this stage of assessment.

Justification does require, at a minimum, a qualitative commentary on how the proposed practice design affects the expected exposures. This could include, for example, a qualitative description of the design differences between the RR SMR design and comparator PWRs for which there is existing data, with an explanation of the factors that would be expected to deliver a higher or lower radiological detriment. While such a comparison is not a requirement of justification, it may provide a useful point of reference for the analysis.

Yours sincerely

Charlie Powell
Team Leader, Nuclear Justification, Environmental Quality Directorate
[redacted]

Annex: Potential information gaps and clarifications requested against additional information provided by RR SMR on 17 January 2025

Information point requested (area of additional information request from 19 November shown in brackets)	Information Gap identified	Guidance on level of information required
1. Collective occupational exposures for normal operations (Section 3.i.)	No collective doses provided or described. The original application states that it does not attempt to quantify collective doses and this section remains unchanged.	A quantitative dose is not required. A qualitative description is required e.g. of the design characteristics and anticipated operational activities that would lead to a lower or higher expected exposure based on comparisons with existing PWRs. *
2. Maximum individual occupational exposures for normal operations (Section 3.i.)	Response states “High level estimates of occupational exposures during normal operations are presented in Table 9”. Table 9 contains estimated doses for “representative personal annual dose” which for RR SMR is updated to 12.3 μSv.	A quantitative dose is not required. A qualitative description is required e.g. of the design characteristics and anticipated operational activities that would lead to a lower or higher expected exposure based on comparisons with existing PWRs. *

Information point requested (area of additional information request from 19 November shown in brackets)	Information Gap identified	Guidance on level of information required
3. Collective occupational exposures for accident scenarios. (Section 3.i)	Not provided – response states that "Severe Accident Analysis will commence in 2025 to confirm exposures in accident exposures are ALARP, and no greater than GW scale plants". In the original application, comparisons are made of likelihood of accident as compared to similar reactor types (page 53). However, there is no comparison to other types other than also being PWRs nor discussion of risk for any specific groups.	A quantitative dose is not required. A qualitative description is required of the expected on-site radiological consequences from an informative sub-set of design basis accidents where safety measures work successfully (for example the most onerous faults which could impact multiple workers initiated from within the containment, during shutdown and associated with the fuel route). A qualitative description should also be provided of the expected on-site collective doses as a result of undertaking pre-identified actions in response to design extension conditions/severe accidents. Where useful to illustrate the case made this may include a comparison of whether these would lead to lower or higher expected collective occupational exposures in comparison with existing PWRs. *
4. Maximum individual occupational exposures for accident scenarios (Section 3.i)	Not provided – response states that "Severe Accident Analysis will commence in 2025 to confirm exposures in accident exposures are	A quantitative dose is not required. A qualitative description is required of the expected on-site radiological consequences from an informative

Information point requested (area of additional information request from 19 November shown in brackets)	Information Gap identified	Guidance on level of information required
	ALARP, and no greater than GW scale plants". In the original application, comparisons are made of likelihood of accident as compared to similar reactor types (page 53). However, there is no comparison to other types other than also being PWRs nor discussion of risk for any specific groups.	sub-set of design basis accidents where safety measures work successfully (for example, the most onerous faults which will result in a high dose to an individual worker initiated from within the containment, during shutdown and associated with the fuel route). A qualitative description should also be provided of the expected maximum individual on-site doses as a result of undertaking pre-identified actions in response to design extension conditions/severe accidents. Where useful to illustrate the case made this may include a comparison of whether these would lead to lower or higher maximum individual occupational exposures in comparison with existing PWRs. *
5. Representative person public radiation exposures for accident scenarios (Section 3.ii)	Not provided – response states that "Severe Accident Analysis will commence in 2025 to confirm exposures in accident exposures are ALARP, and no greater than GW scale plants".	A quantitative exposure is not required. A qualitative description is required of the expected off-site radiological consequences from an informative sub-set of design basis accidents, where safety measures work successfully and the

Information point requested (area of additional information request from 19 November shown in brackets)	Information Gap identified	Guidance on level of information required
		effectiveness of in-vessel retention and other safety measures limit the consequences of severe accidents. Where useful to illustrate the case made this may include a comparison of whether these would lead to lower or higher expected representative person exposures based on comparisons with existing PWRs. *
6. Radiological risks to the most exposed members of the public for accident scenarios (Section 3.iii)	No information provided regarding risks to specific groups for accident scenarios. Although the response refers to "Radiological risks to the most exposed members of the public are discussed below" the text below it only relates to reference [49] and doses during 'reactor operation', not accident scenarios nor potential different risks to different categories of persons such as male/females, infants, children and adults.	A quantitative exposure is not required. A qualitative description is required of the risks to the most exposed members of the public from design basis accidents and severe accident scenarios, including how and why the characteristics of the design and anticipated operation would lead to lower or higher expected radiological risks to different groups (e.g. males, females, infants). Where useful to illustrate the case made this may include a comparison to existing PWRs. *
7. (all of 3.i and 3.ii and 3.iii above) as associated with totality of the life cycle,	Insufficient information provided regarding exposures and risks for different parts of lifecycle.	A qualitative description of the radiological detriments associated with all the lifecycle phases. This

Information point requested (area of additional information request from 19 November shown in brackets)	Information Gap identified	Guidance on level of information required
including construction, operation, waste disposal and decommissioning.		may be a high-level commentary highlighting any specific design features or approaches that will impact or limit the radiological detriment.
8. Commentary on the relevance and validity for the RR SMR design of any general / comparator dose values used within the application including the extent to which the representative person annual dose presented for the RR SMR is a fair like for like comparison with the values given for the other reactors (Section 3.v)	The response explains the approach used to assess representative person annual dose in relation to coastal sites. No information is provided in relation to non-coastal sites.	A commentary on the approach for a non-coastal site including a qualitative explanation of the impact of a non-coastal site on dose values (recognising that a generic site may not be coastal-based).
9. Exposure from noble gas/iodine discharges (Section 4)	Noble gas discharges are much higher than for other sites due to a very conservative estimate used in determining the source term – to be refined during GDA 3. The amended figures in Tables 13 and 14 for noble gas discharges are still much higher than for other designs. Amended Table 13 Iodine-131 gaseous discharges are still comparatively high.	A qualitative explanation of the impact of design features that are expected to lead to the relatively high level of noble gas discharges, or rationale for the discharge figures quoted.

Information point requested (area of additional information request from 19 November shown in brackets)	Information Gap identified	Guidance on level of information required
10. Scale of waste produced on a per unit of energy basis (Section 4)	Response presents GDA Disposability Case which describes waste stream characteristics, but the scale of waste produced on a per unit of energy basis is not presented.	An estimate or description of the scale of waste produced on a per unit of energy basis.

*While such a comparison is not a requirement of justification, it may provide a useful point of reference for the analysis.

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Thursday 15 May 2025

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Dear Mr Powell

Rolls-Royce SMR Regulatory Justification Application: Notice requiring additional information

We write in response to your letter dated 3rd April 2025. This letter and our updated application contain the additional information requested. For clarity we have included text from our original application in blue, any text we are removing is highlighted and additional text to be included in our application is in red. A record of change is added to the application to catalogue all amendments.

Additional information required

1. Collective occupational exposures for normal operations (Section 3.i.)
2. Maximum individual occupational exposures for normal operations (Section 3.i.)

Response to questions 1 and 2

Publicly available data from previous GDAs undertaken in the UK, from the US NRC website, and from Constellation Energy Corporation LLC (Constellation), was examined to look at collective and, where available, maximum individual doses received by workers primarily associated with maintenance doses during outage. Due to the nature of maintenance activities these tasks are associated with the high dose uptakes. The available information has enabled RR SMR to determine an initial set of key activities which allow proportionate focus to be applied to those areas of design that will have the highest impact to the reduction of both collective and individual worker dose.

Annual collective dose targets have been set for both power operations and during outage, where key maintenance activities are undertaken, both of 0.02 person-Sv. These limits will apply to the approximately 300 full time employees and during peak outage periods this is expected to increase to approximately 1000 individuals.

Due to various activities being undertaken during different outage periods the following comparisons have been carried out by averaging the collective dose target over a 10-year period. This contains a total of 6 outages assuming an 18-month operating cycle, with this considered the adjusted target will be 0.032 person-Sv per unit per year. Normalised against the stated power output of the RR SMR of 0.47 GW_e, this becomes 0.068 person-Sv per unit per year per GW_e.

Estimated Collective Doses for the RR SMR Compared with Publicly Available Data from Previous GDAs, the US NRC, and Constellation OPEX – Normalised to be per GWe

RR SMR (person-Sv)	HPR1000 (person-Sv)	HPC (person-Sv)	AP1000 (person-Sv)	UK ABWR (person-Sv)	US NRC 2020 PWR average (person-Sv)	PWR1 (person-Sv)	PWR2 (person-Sv)
0.068	0.308	0.196	0.215[1]	0.444	0.3[2]	0.127	0.387

Using RR SMR normalised dose constraints that incorporate the various outages this allows us to compare doses against OPEX and PWR designs.

The RR SMR is a modern plant design that will incorporate improvements and optimisations over older PWR designs, based on RGP and OPEX from Constellation and EPRI, it is expected that the average dose to employees working with ionising radiation will be below the basic safety objective, set out by the ONR, and will at least be in line with the recent data presented by the US NRC, which gives an average measurable dose per individual of 0.7 mSv in 2020.

Based on the OPEX it is also expected that the maximum individual dose that some workers will be exposed to when performing isolated high dose tasks may lead to them receiving doses in excess of the BSO. Nonetheless, individual doses will remain below statutory limits, and it is anticipated that the maximum individual dose for any worker will not exceed 10 mSv, which is below the regulatory limits.

It is therefore judged that the RR SMR design will be able to meet its collective dose and individual dose criteria, and that the design will drive the collective and individual dose down towards a justified value So Far As Is Reasonably Practicable (SFAIRP) such that collective and individual doses, when normalised against electrical power output, will be ALARP and compare favourably with those of other designs that have already successfully passed through the GDA process in the UK and are currently operating in the US.

Paragraph 10.12.6 removed: Initial operational dose rate assessments undertaken for RI show dose rates in all areas are<0.1 µSv/h and in many cases significantly lower.

Replaced with: The RR SMR is a modern plant design that will incorporate improvements and optimisations over older PWR designs, based on RGP and OPEX. It is expected that the average dose to employees working with ionising radiation will be below the basic safety objective, set out by the ONR, and will at least be in line with the recent data presented by the US NRC, which gives an average measurable dose per individual of 0.7 mSv in 2020.

3. Collective occupational exposures for accident scenarios. (Section 3.i)

Response

[1] The AP1000 value is given for a year containing an outage, whereas the other values are averaged over years with and without outages. It is expected that this value would decrease if such an averaging was performed.

[2] The US NRC value is an average across 64 PWRs in the year 2020 exclusive of outages.

Collective exposures for accident scenarios have not been included in the analysis undertaken. However, design features implemented to mitigate exposures to individuals have been included in the RR SMR design. These features have shown that individual doses are below project dose targets. Reliance on passive safety features will ensure that collective project dose targets are met.
The only accident scenarios where pre identified actions will have to be undertaken are associated with Local Ultimate Heat Sink, Spent Fuel Pool and Essential Services Water Supply top up. These scenarios will require operator action after the first 24 hours of an accident scenario. These activities are carried out at all PWRs and the exposures from RR SMR will be no worse than at other PWRs. It is envisaged that they would, in fact, be lower due to the smaller reactor size (source term) of RR SMR.
Top up of the emergency diesel generators sits outside of these scenarios as they have fuel tanks that have seven day capacity, which is outside of the essential 72 hour emergency period.

Extra paragraph added after 10.12.12 (The new paragraph becomes 10.12.13 and all subsequent paragraph numbers are updated to the end of section 10.12): Due to the passive safety features employed in RR SMR the only accident scenarios where pre identified operator actions will have to be undertaken are associated with Local Ultimate Heat Sink, Spent Fuel Pool and Essential Services Water Supply top up. These scenarios will require operator action after the first 24 hours of an accident scenario. These activities are carried out at all PWRs and the exposures from RR SMR will be no worse than at other PWRs, it is envisaged that they would, in fact, be lower due to the smaller reactor size of RR SMR. The reactor of the RR SMR contains 40% of the inventory of Sizewell B and on a per unit basis would be expected to have a significantly smaller radiological impact during normal operation and in the event of any incident or severe accident.

4. Maximum individual occupational exposures for accident scenarios (Section 3.i)

Response

Radiological consequence calculations for maximum individual exposures and members of the public have been undertaken for a set of postulate accident scenarios. Results are reported for four accident scenarios to demonstrate the radiological consequence calculations can be applied to design basis assessment. These scenarios include:

1. Large Break Loss of Coolant Accident (LB LOCA)
2. Main Steam Line Break (MSLB)
3. Steam Generator Tube Rupture (SGTR)
4. Spurious Main Steam Isolation (MSIV) Closure

Currently, the radiological consequence calculations focus on the onsite doses received by Main Control Room (MCR) operators, during seven analysis cases, considered representative, that are based on the four fault scenarios above.

The highest effective dose is predicted for a LB LOCA and the result is within project dose targets (equivalent to ONR Target 4). This is equivalent to existing PWRs, which are already justified in GB. The adoption of additional measures, such as charcoal filters to reduce exposures further, is being investigated. The current MCR design features a 72 hour endurance period which isolates the MCR from the external environment. This safety measure eliminates exposure in the MCR for design basis faults with releases durations < 72 hours. Work is ongoing to expand calculations to severe accidents and other types of design basis faults.

The only expected local to plant action to mitigate design basis and design extension conditions is LUHS tank up. Radiological consequences analysis of this activity is ongoing. It is expected that this analysis will demonstrate that relevant radiological consequences targets are met or otherwise identify the necessary design modifications to ensure they can be achieved.

5. Representative person public radiation exposures for accident scenarios (Section 3.ii)

Response

Radiological consequence calculations for maximum individual exposures and members of the public have been undertaken against a set of accident scenarios. Results are reported for four accident scenarios to demonstrate the radiological consequence calculations can be applied to design basis assessment; these scenarios include:

1. Large Break Loss of Coolant Accident (LB LOCA)
2. Main Steam Line Break (MSLB)
3. Steam Generator Tube Rupture (SGTR)
4. Spurious Main Steam Isolation (MSIV) Closure

Offsite consequences have been calculated for several representative design basis reactor faults and DEC-B scenarios conservatively assuming a residence located at 300 m from the discharge point (approximately at the site boundary). For the design basis faults, the LB LOCA leads to the largest offsite effective dose and the result is within project dose targets (equivalent to ONR Target 4) again equivalent to existing PWRs. Results for DEC-B scenarios consider core melt with successful in-vessel retention and containment isolation. The offsite effective dose for DEC-B scenarios is also within project targets, and sufficiently low that the requirement for and geographic extent of offsite countermeasures (such as evacuation) are expected to be reduced for the RR SMR relative to other PWRs (i.e. SZB). The only offsite protective action considered in these analyses are legally mandated food bans.

Additional paragraph after 10.12.17 (Now 10.12.18 because of an earlier paragraph change, and new paragraph becomes 10.12.19): RR SMR accident scenarios consider core melt with successful in-vessel retention and containment isolation. The offsite effective dose for these scenarios is within project targets, and sufficiently low that the requirement for and geographic extent of offsite countermeasures (such as evacuation) are expected to be reduced for the RR SMR relative to other PWRs. The only offsite protective action considered in these analyses are legally mandated food bans which would also apply in accident scenarios for existing justified practices.

6. Radiological risks to the most exposed members of the public for accident scenarios (Section 3.iii)

Response

Application amended:
Paragraph 5.8.66 (Now 5.8.68 because of an earlier paragraph change): In the assessment of a modern reactor design against these BSOs, the ONR concluded in their assessment of the EPR™ reactor design (a Gen III PWR) under the GDA process [60] that the Probabilistic Safety Assessment ("PSA") results presented by EDF and AREVA meet the BSOs presented in Table 10. This is an example of how the ONR applies its expectations. We would expect other modern evolutionary type reactors such as the RR SMR (a Gen III+ PWR) to have a broadly similar risk profile, albeit with a significantly smaller source term.
Paragraph 5.8.74 (Now 5.8.76 because of an earlier paragraph change) removed:
In the UK there are substantial provisions that ensure a high level of nuclear safety is maintained, including effective and independent regulation of any UK operator of the Proposed

Practice. If an accident were to occur, its consequences would be mitigated. As a result, the risk of detriment is considered to be low. These provisions continue to evolve and are subject to on-going review and improvements.

Replaced with:

In the UK there are substantial provisions that ensure a high level of nuclear safety is maintained, including effective and independent regulation of any UK operator of the Proposed Practice. If an accident were to occur, its consequences would be mitigated.

Additional paragraphs added (The new paragraphs become 5.8.77 and 5.8.78):

In addition to the risk of an accident being low, the RR SMR described in the Proposed Practice has a reactor core inventory 40 % lower than Sizewell B. The postulated release during any accident is therefore lower than that from existing LWRs justified in GB. Coupled with advanced, passive features, the risk of release is also considered to be lower for the Proposed Practice than existing designs. Conservative values have been described in this document which will bound the final values once the design is complete.

The discharge of iodine in a postulated accident is lower for any event in the Proposed Practice than in existing LWRs justified in GB. Iodine is a product of the nuclear fission reaction and is particularly volatile. Uptake of iodine into the thyroid gland, where unmitigated, can lead to a disproportionate effect on children and nursing mothers. With a smaller source term and advanced, passive safety measures, the risk of release and quantity of release with respect to iodine is lower; reducing any potential impact on this vulnerable population.

7. (all of 3.i and 3.ii and 3.iii above) as associated with totality of the life cycle, including construction, operation, waste disposal and decommissioning.

Response

Radiological detriments for RR SMR will be either lower or similar to existing PWRs. During construction, for example, the modular approach and use of factory manufactured structures along with the reduction of radiography reduces dose to workers. Operational doses are comparable or lower as demonstrated above in questions 1-3. Waste categories and quantities for disposal will be broadly similar given that much of this irrespective of technology or unit size, noting the significantly lower tritium discharges for the RR SMR due to the boron free chemistry. Design for Decommissioning has been included in the RR SMR from its concept this ensures that radioactive wastes and exposures of radiation to workers from decommissioning activities will as a minimum be as in line with the best performing PWRs and in all cases ALARP.

Additional paragraph added to Application after 10.18.1 (The new paragraph becomes 10.18.2 and all subsequent paragraph numbers update to the end of section 10.18):

Rolls-Royce SMR Ltd is looking to significantly reduce the use of radiography required during fabrication and construction by utilising alternative methods. Additionally, the fabrication of modules within a factory environment and construction in a Site Factory should ensure any radiography that is required can be carried out in significantly more controlled (and shielded) environments, reducing the radiation dose to construction workers.

Paragraph 10.19.1 amended:

New nuclear power stations must be considered to facilitate future decommissioning in a safe and environmentally acceptable way at the early stage. This includes design principles and fulfilment of IAEA requirements related to decommissioning. The incorporation of decommissioning considerations into the RR SMR has been applied by lessons learnt from decommissioning work all over the world. Furthermore, the RR SMR has been designed with features to facilitate decommissioning of the plant to keep doses to workers ALARP and to minimize radioactive waste arising from decommissioning. Design for Decommissioning has been included in the RR SMR from its concept this ensures that radioactive wastes and exposures of radiation to workers from decommissioning activities will as a minimum be as in line with the best performing PWRs and in all cases ALARP.

8. Commentary on the relevance and validity for the RR SMR design of any general / comparator dose values used within the application including the extent to which the representative person annual dose presented for the RR SMR is a fair like for like comparison with the values given for the other reactors (Section 3.v)

Response

Additional paragraphs inserted after 5.8.29 (The new paragraphs become 5.8.30 and 5.8.31, and all subsequent paragraph numbers update to the end of section 5.8):
Radiological impact for the Public from the Proposed Practice is expected to be significantly reduced from existing PWRs. The reactor of the RR SMR contains 40 % of the inventory of Sizewell B and on a per unit basis would be expected to have a significantly smaller radiological impact during normal operation and in the event of any incident or severe accident. The major contributors to radiological dose in a PWR are those due to C-14 and Tritium (H-3). The RR SMR will produce comparable (on a dose per MW basis) levels of C-14 to existing, justified PWRs. Existing PWRs use boron for duty reactivity and power control.

When boron is irradiated in a nuclear reactor such as a PWR, tritium is produced. Tritium cannot be removed in waste treatment plants and periodic dilution of coolant is required to maintain tritium levels below particular criteria prior to maintenance. This tritium is then discharged to the environment, within regulated limits. The RR SMR does not use boron for reactivity control and as such the amount of tritium produced by the Proposed Practice is significantly reduced compared to existing LWRs justified in GB. As tritium is a significant contributor to total dose, so the total dose from the Proposed Practice is significantly reduced.

Paragraph 5.8.36 (Now 5.8.38 because of an earlier paragraph change) amended:

This last source of exposure has been optimised in the RR SMR design. By using a non-borated cooling circuit and potassium hydroxide chemistry, the production of tritium is greatly reduced. This measure is combined with the knowledge of decades of experience from currently operating PWRs in the reduction in use of cobalt based materials and stellite. Along with continued optimisation of primary water chemistry resulting in a reduction in production and transport of CRUD will result in a reduction in dose to workers during operation and decreasing activation of components, resulting in less radioactive material during commissioning. Following on from existing PWRs, the RR SMR in the Proposed Practice is seeking to significantly reduce the amount of cobalt present in components such as hard wearing valve seats and in base material. Cobalt, when activated, can contribute significantly to operator and maintenance doses. Reduction of the amount of cobalt in the design, coupled with the use of zinc dosing in the reactor coolant system which displaces cobalt from corrosion films such that it can be cleaned up in the plant's waste systems will significantly reduce operational and maintenance doses. The use of a potassium hydroxide chemistry will further reduce operational doses from the Proposed Practice in comparison to existing LWRs justified in GB and reduce overall chemical use.

Should a non-coastal site be selected for the RRSMR, alternative modelling will be carried out to determine the "Representative Person". Discharges will be minimised to ALARP and employ BAT, whilst remaining within permitted legal limits. If required, the design will be modified to include additional filtration measures (such as additional Ion Exchange beds) to further reduce permitted discharges to account for the alternative site environment.

9. Exposure from noble gas/iodine discharges (Section 4)

Response

Conservative values for noble gas discharges have been described in the Application which will bound the final values once the design is complete. Despite the conservatism in these values the discharges still meet the BSO. As the design is finalised RR SMR will continue to apply and demonstrate BAT and ALARP with respect to radiological dose and waste, which is expected to significantly reduce these conservative values, as has been demonstrated by other justified practices.

10. Scale of waste produced on a per unit of energy basis (Section 4)

Response

Our January response revised aqueous and gaseous discharges, noting these are still conservative figures as explained under question 9.
Extra paragraph added after 6.7.17 (The new paragraphs become 6.7.18, and all subsequent paragraph numbers update to the end of section 6.7):
Current estimates for the RR SMR spent fuel arisings (averaged over 60 years lifetime) are 2.79 tHM/TWh(e)or 1.22 m^3/TWh_e. Compared with an AP1000, this is roughly 6 % higher (on a mass basis) and 13 % higher (on a volumetric basis). This broadly similar result is expected since the RR-SMR, although classed as an SMR, has a relatively large core size meaning neutron leakage (as a result of size) should be similar. Note the RR SMR core size is almost identical to Ginna, USA. However, unlike an AP1000 and most PWR designs (other than VVER and EPR), the RR-SMR does utilise a heavy radial reflector that improves neutron economy and therefore spent fuel accumulation rates. However, as a result of operating boron-free and unlike a standard PWR that could operate with a low-leakage loading pattern, core safety (in particular the requirement to maintain adequate shutdown margin at cold-zero-power) necessitates a larger proportion of higher-reactive fuel to be loaded on the core periphery. Loading pattern changes and radial neutron reflector design tend to 'cancel out' resulting in similar spent fuel accumulation rates as shown in this calculation. The slightly higher volumes of spent fuel, can be safely managed both on site and eventually in a GDF. The RR SMR discharges virtually no tritium as a result of the boron free chemistry regime, this is a significant improvement over existing LWRs justified in GB.

Record of Change

Additional Row:

Date	Revision Number	Issue	Reason for Change
May 2025	3	Issue	Third issue of NIA Report Regulatory Justification Application Rolls-Royce SMR Limited in response to request for additional information from the justifying authority. Additional information is added to:

			• Chapter 5 to clarify differences between the RRSMR and other comparable justified practices.
			• Chapter 6 to quantify spent fuel arisings.
			• Chapter 10:
			    o clarifying the minimisation of radiography during construction of the RRSMR, and
			    o to emphasise the inclusion of passive safety features and their affect on exposures to workers and people offsite.
			Also minor template/editorial updates for overall consistency and accuracy.

We trust that this information provides adequate additional information and look forward to receiving further details of the applications' progress.

Yours sincerely

Tom Greatrex
Chief Executive