GE Hitachi Nuclear Energy

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BWRX-300 UK Preliminary Safety Report (PSR) Chapter 27 – ALARP Evaluation

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EXECUTIVE SUMMARY

This chapter describes GE-Hitachi's (GEH) structured approach to demonstrating that radiological risks associated with the BWRX-300 design are reduced to a level that is As Low As Reasonably Practicable (ALARP), in accordance with United Kingdom (UK) legal and regulatory expectations. In keeping with the two-step Generic Design Assessment (GDA) process, the chapter does not offer a complete ALARP demonstration at this stage but provides a clear and evidence-based strategy for developing one through subsequent licensing.

The methodology is structured into three phases. Phase 1, completed during Step 2 of GDA, comprises a holistic review of the reference design using three inputs: the design evolution baseline; a systematic comparison with relevant good practice and operating experience; and insights from deterministic and probabilistic safety assessments. Phases 2 and 3, to be conducted post-GDA, will apply formal optioneering and sentencing processes to specific candidate improvements identified through Phase 1, and will then evaluate whether the integrated design meets ALARP expectations for the UK context.

The current BWRX-300 design incorporates a number of passive and simplified features that contribute materially to risk reduction. These include: natural circulation cooling that removes the need for external recirculation loops; isolation valves integral to the reactor pressure vessel that reduce the frequency and consequences of large-break loss-of-coolant accidents; and a passive Isolation Condenser System within a compact dry containment. These features reflect lessons learnt from previous Boiling Water Reactor designs and have been embedded through established configuration and change control arrangements.

The chapter also sets out how ALARP considerations interface with environmental, security and safeguards risks. Where the evidence base remains incomplete or sentencing is deferred, appropriate actions have been recorded in a Forward Action Plan (Appendix B) to ensure traceability into future licensing stages. Claims and arguments relevant to this chapter are laid out in Appendix A, whilst Appendix C provides additional detail on the aspects of the GEH design process relevant to the demonstration of ALARP.

In summary, GEH has adopted a proportionate and traceable approach to ALARP that reflects the maturity of the design, the scope of GDA, and the forward programme for UK deployment. The methodology is designed to align with United Kingdom Office for Nuclear Regulation expectations for international designs entering GDA and provides a credible foundation for the development of a complete ALARP demonstration at a later licensing stage.

ACRONYMS AND ABBREVIATIONS

Acronym	Explanation
ABWR	Advanced Boiling Water Reactor
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
BAT	Best Available Technique
BL	Baseline
BoP	Balance of Plant
BWR	Boiling Water Reactor
C&S	Codes and Standards
CB	Control Building
CDF	Core Damage Frequency
CFS	Condensate and Feedwater Heating System
CHS	Conventional Health and Safety
CIS	Containment Inerting System
CNSC	Canadian Nuclear Safety Commission
CRD	Control Rod Drives
CUW	Reactor Water Cleanup System
D-in-D	Defence-in-Depth
DBA	Design Basis Accident
DC	Direct Current
DCWG	Design Center Working Group
ELM	Engineering Lifecycle Management
ERB	Engineering Review Board
ESBWR	Economic Simplified Boiling Water Reactor
FPC	Fuel Pool Cooling and Cleanup System
FW	Feedwater
GDA	Generic Design Assessment
GEH	GE Hitachi Nuclear Energy
HCU	Hydraulic Control Unit
HP	High Pressure
IAEA	International Atomic Energy Agency
IC	Isolation Condenser
ICS	Isolation Condenser System
IEC	International Electrotechnical Commission

Acronym	Explanation
LfE	Learning from Experience
LOCA	Loss-of-Coolant Accident
LP	Low Pressure
MCR	Main Control Room
MPL	Main Parts List
MS	Main Steam
NBS	Nuclear Boiler System
NISR	Nuclear Industries Security Regulators
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
ONR	Office for Nuclear Regulation
OPEX	Operational Experience
PCCS	Passive Containment Cooling Systems
PLM	Product Lifecycle Management
PSA	Probabilistic Safety Analysis
PSR	Preliminary Safety Report
RB	Reactor Building
RCPB	Reactor Coolant Pressure Boundary
RGP	Relevant Good Practice
RI	Regulatory Issue
RIV	Reactor Pressure Vessel Isolation Valves
RP	Requesting Party
RPV	Reactor Pressure Vessel
RWB	Radwaste Building
SAP	Safety Assessment Principle
SBWR	Simplified Boiling Water Reactor
SCCV	Steel-Plate Composite Containment Vessel
SDC	Shutdown Cooling
SFAIRP	So Far As Is Reasonably Practicable
SRV	Safety Relief Valve
SSCs	Structures, Systems, and Components
UK	United Kingdom
UPR	Ultimate Pressure Regulation
US	United States of America

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REVISION SUMMARY

Revision #	Section Modified	Revision Summary
A	All	Initial Issuance
B	All	Update to provide additional detail on GEH design processes and to reflect learning from GDA Steps 1 and 2

27 ALARP EVALUATION

Introduction

GE-Hitachi (GEH) entered the BWRX-300 design into Generic Design Assessment (GDA) with the United Kingdom (UK) Office for Nuclear Regulation (ONR), the Environment Agency (EA) and Natural Resources Wales (NRW) with the objective of gaining regulatory confidence on the acceptability of a conceptual full plant design for deployment in England and Wales[1]. GEH, referred to in the GDA process as the 'Requesting Party' (RP), will exit GDA at the end of Step 2.

It is a statutory requirement in the UK to demonstrate that risks to workers and the public have been reduced to as low as reasonably practicable (ALARP). This requirement arises from the "Health & Safety at Work etc. Act 1974" (HSWA74) (Reference 27-1) and is enforced through the ONR's licensing process. Nuclear site licences are granted by ONR under the "Nuclear Installations Act 1965" (NIA65) (Reference 27-2). Under Licence Condition 14, "Licence condition handbook" (Reference 27-3), a licensee must produce a safety case, and ONR expects this safety case to include demonstration that risks are ALARP.

GEH's design processes drive risk reduction and design optimisation, including minimising radiation exposures to as low as reasonably achievable (ALARA). GEH and its partners are taking part in licensing reviews of the BWRX-300 in the United States of America (US) and Canada. Meeting stringent regulatory requirements and expectations in the US and Canada has further encouraged risk reduction across the design. As design development prior to GDA entry for the BWRX-300 has primarily taken place in the US and Canada, the concept of reducing risk to ALARP (as understood in the UK) was not part of GEH's design process. GEH recognise the need to adapt this design process to incorporate UK expectations and to allow for a complete demonstration of how risks have been reduced to ALARP at a suitable point during post-GDA licensing of the BWRX-300.

Purpose

This chapter presents how GEH is approaching the demonstration of ALARP for the BWRX-300. This includes:

- How the BWRX-300 incorporates risk reduction achieved through the design evolution of Boiling Water Reactors (BWRs)
- How GEH's design processes drive risk reduction and design optimisation at both system and plant-wide levels[2]
- GEH's three-phase ALARP methodology for the BWRX-300
- What aspects of the ALARP methodology will be completed during GDA
- How the two-step GDA shows a viable path to demonstrating that risks are ALARP post-GDA

GEH recognises that environmental, security and safeguards risks must be considered alongside safety risks in an integrated manner. This is treated at various points in this chapter as well as in NEDC-34162P, "BWRX-300 UK GDA BWRX-300 UK GDA Safety, Security, Safeguards and Environment Summary", (Reference 27-4).

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[1] Note that, in places, this document makes reference to the UK or "UK requirements", for example when discussing certain nationally applicable law. However, only sites in England and Wales are being considered for the BWRX-300.
[2] The need to consider risks at a plant-wide level is sometimes referred to as 'holistic ALARP'.

Objective

The fundamental objective for the BWRX-300 design is summarised in the Level 1 Safety Claim (the claims, arguments, evidence (CAE) structure is discussed in detail in Appendix A):

"1. The BWRX-300 is capable of being constructed, operated and decommissioned in accordance with the standards of environmental, safety, security and safeguard protection required in the UK."

The primary claim that this chapter supports is:

"2.4 Safety risks have been reduced as low as reasonably practicable."

This claim captures GEH's goal to reduce risks to operators and members of the public to ALARP. Claim 2.4 is supported by four sub-claims, all of which are discussed in this chapter:

"2.4.1 Relevant Good Practice (RGP) has been taken into account across all disciplines.

2.4.2 Operational Experience (OPEX) and Learning from Experience (LfE) has been taken into account across all disciplines.

2.4.3 Optioneering (all reasonably practicable measures have been implemented to reduce risk)

2.4.4 Residual risks are compared with numerical targets and no event sequences are disproportionately dominant."

GEH's GDA submission does not intend to demonstrate that all claims are substantiated. Instead, it aims to demonstrate that there is a **viable path towards substantiation for all claims**, and that GEH's current and planned activities are consistent with achieving such substantiation.

The objective of this chapter is not to demonstrate that risks have been reduced to ALARP, and no 'ALARP justification' or 'ALARP evaluation' is offered. Instead, the objective of this chapter is to present a viable path towards such a demonstration, and to show that the first steps on this path have already been taken by completing Phase 1 of our ALARP methodology.

Interfaces with other chapters

The need to reduce risks ALARP applies to all topic areas, therefore this chapter supports all other chapters in the Preliminary Safety Report (PSR).

Key supporting documents for this chapter are:

- NEDC-34137P, "BWRX-300 UK GDA BWRX-300 Design Evolution," (Reference 27-5)
- NEDC-34148P, "BWRX-300 UK GDA Scope of Generic Design Assessment" (Reference 27-6)
- NEDC-34154P, "BWRX-300 UK GDA Design Reference Report" (Reference 27-7)
- 007N1411, "BWRX-300 Operating Experience Report" (Reference 27-8)
- 005N9036, "BWRX-300 Requirements Management Plan" (Reference 27-9)
- 006N3139, "BWRX-300 Design Plan" (Reference 27-10)
- 006N5081, "BWRX-300 As Low As Reasonably Achievable Design Criteria for Standard Design," (Reference 27-11)
- CP-03-100, "Design Control," (Reference 27-12)
- CP-03-113, "Engineering Change Control," (Reference 27-13)

Further information of relevance to this PSR chapter is provided in the Appendices. Appendix A describes the Claims, Arguments and Evidence pertinent to this chapter, Appendix B includes the Forward Action Plan items associated with an ALARP evaluation, and Appendix C provides additional detail on the aspects of the GEH design process relevant to the demonstration of ALARP.

27.1 Legal, Regulatory and Policy Context

27.1.1 What is ALARP?

Based upon the requirements of HSWA74, it is necessary to show that the risks to the workers and the public are ALARP[3]. This requires that all reasonable measures are taken in the design, construction, commissioning and operation of the plant to minimise the radiation dose received by workers and public, unless such measures are grossly disproportionate to the risk avoided.

In simple terms, this means taking all measures to reduce risk where doing so is reasonable. Typically, this is not done through an explicit comparison of costs and benefits, but rather by applying established RGP and standards. ONR considers standards, approaches or guidance to be RGP if they have judged compliance with it as a means of satisfying the law. Sources of RGP are listed in Section 27.1.1.1 below.

The BWRX-300 CAE structure sets out the four main aspects to the demonstration of ALARP via sub-claims:

- Demonstration that RGP has been applied, including codes and standards comparison/justification *(sub-claim 2.4.1)*
- Demonstration that international reactor OPEX has been taken into account in the overall design philosophy and in specific system designs *(sub-claim 2.4.2)*
- Identification and evaluation of options (Optioneering) *(sub-claim 2.4.3)*
- Risk assessment, as a way of understanding the significance of the issue to the holistic demonstration of ALARP i.e. to identify the severity of shortfalls against numerical targets, RGP, and/or deterministic rules *(sub-claim 2.4.4)*

Considering these aspects together is what allows an assessment of whether risk has been reduced ALARP or whether there are further reasonably practicable measures that could be taken.

27.1.1.1 Note on Relevant Good Practice

Typical sources of RGP are identified by ONR in NS-TAST-GD-005, “Technical Assessment Guide on ALARP”, (Reference 27-14) and other ONR publications and communications, and include:

- Guidance within Approved Codes of Practice; for example, the Provision and Use of Work Equipment Regulations 1998
- Office for Nuclear Regulation (ONR) guidance including ONR’s Safety Assessment Principles, Technical Assessment Guides and Technical Inspection Guides
- Standards produced by standards making organisations, for example British Standards Institution, International Electrotechnical Commission (IEC), International Atomic Energy Agency (IAEA) and Western European Nuclear Regulators’ Association
- Guidance agreed by a body representing an industrial/occupational sector
- Well defined and established standard practice adopted by an industrial/operational sector

[3] Note that the legal requirement in HSWA74 is to reduce risk ‘So Far As Is Reasonably Practicable’ (SFAIRP). ONR guidance mostly uses the term ‘ALARP’; for all intents and purposes, these two terms can be used interchangeably.

The development of RGP and standards includes ALARP considerations so in many cases meeting them may be sufficient to demonstrate that risk is ALARP. Where standards and RGP are less evident or not fully applicable, the onus is on implementing measures to the point where the costs of additional measures (in terms of money, time or trouble – i.e. the sacrifice) would be grossly disproportionate to the further risk reduction that would be achieved (the safety benefit).

As part of the GDA process, the RP must establish and justify its choices of RGP. GEH understands that practices that have previously received regulatory approval in the UK or overseas may not always be considered RGP, although they may still be considered as relevant OPEX. When considering the relevance of RGP and OPEX, account must be taken for the inherent features and characteristics of the design, for example some RGP and OPEX from older BWR or nuclear power plant designs may not apply to the BWRX-300 due its passive safety features.

27.1.2 Sources of guidance on ALARP

The legal requirement to reduce risk ALARP arises from HSWA74 (Reference 27-1) but the Health and Safety Executive (HSE) and ONR provide guidance that amounts to regulatory expectations on how to apply this requirement to nuclear installations:

- ONR: “Safety Assessment Principles for Nuclear Facilities,” (Reference 27-15)
  - Provides guidance to ONR inspectors in their assessment of nuclear safety cases. Describes how the need to demonstrate risks are ALARP is the core function of a safety case. For example, SC.4 (“Safety case characteristics”) states that a safety case should show why risks are ALARP, and how they will remain so over time. This applies to normal operation as well as accident conditions, including severe accidents.
- ONR: NS-TAST-GD-005, “Technical Assessment Guide on ALARP,” (Reference 27-14)
  - ONR’s main guidance to inspectors on how to judge whether a licensee’s (or licence applicant’s or RP’s) safety case sufficiently demonstrates that risks are ALARP.
- ONR: ONR-RD-FW-001, “Risk-informed regulatory decision-making,” (Reference 27-16)
  - General guidance on how ONR carries out risk-informed decision-making, which includes consideration of whether risks have been reduced ALARP.
- ONR: ONR-GDA-006, “Guidance to Requesting Parties,” (Reference 27-17) and “Licencing nuclear installations” (Reference 27-18)
  - General guidance on the licensing of nuclear installations and GDA includes some discussion of risk and ALARP.
- HSE “The Tolerability of Risks from Nuclear Power Stations,” (TOR) (Reference 27-19) and HSE “Reducing Risks, Protecting People: HSE’s Decision-Making Process,” (R2P2) (Reference 27-20)
  - Guidance from HSE establishes the tolerability of risk framework that ONR expects to be applied to nuclear installations, as interpreted via the nine numerical targets in the ONR Safety Assessment Principles (SAPs).

27.1.3 Integrated risk reduction

In addition to the concept of ALARP in nuclear safety, UK regulations require that nuclear operators must maintain all radioactive discharges to the environment at a level which is ALARA.

The need to reduce discharges to ALARA in the environmental context is generally referred to as the ‘optimisation requirement,’ “Radioactive Substance Regulations - Principles of optimisation in the management and disposal of radioactive waste,” (Reference 27-21). The optimisation requirement places the requirement on the permit holder to demonstrate the design can: *best meet the full range of relevant health, safety, environmental and security (including safeguards) principles and criteria, taking into account all relevant factors, e.g. social and economic considerations*.

In England and Wales, the requirement to apply Best Available Techniques (BAT) is the means to demonstrate compliance with the optimisation requirement. This means critically assessing the design to confirm whether the proposed solution meets this requirement or whether further measures are required. As a result, BAT also forms an integral part of defining, selecting and justifying the most appropriate design option.

The potential conflicts between reducing safety risk ALARP and environmental risk ALARA is discussed in Section 27.2.5.2. Environmental risks in general are assessed in the Preliminary Environmental Report (PER), NEDC-34223P, “BWRX-300 UK GDA Preliminary Environmental Report Chapter 6: Demonstration of BAT Approach,” (Reference 27-22), with an explanation of how safety and environmental risk (as well as security and safeguards) are assessed in an integrated manner provided in NEDC-34162P (Reference 27-1).

27.2 Methodology

27.2.1 Design reference

The scope of the BWRX-300 GDA is set out in NEDC-34148P, "BWRX-300 UK GDA Scope of Generic Design Assessment," (Reference 27-6). NEDC-34154P, "BWRX-300 UK GDA Design Reference Report," (Reference 27-7) defined the Design Reference and Design Reference Point. A summary of the two-step GDA scope of the BWRX-300 assessment can be found in Section 2 of NEDC-34162P (Reference 27-1).

GEH adopts a four-phase design process that extends from Baseline 0 (where functional requirements are defined) up to Baseline 3 (where the design is ready for construction). For the Design Reference Point, the systems and structures within the Power Block are at least at Baseline 1, whilst the Balance of Plant is at Baseline 0. Baseline 2—completion of standard design— was underway at the time of the GDA Design Reference Point. Baseline 3 is the site- and country-specific design phase, which can begin once the standard design (Baseline 2) is complete.

27.2.2 General approach to ALARP

As set out in this chapter's Objective, GEH's GDA submission aims to demonstrate that there is a viable path towards substantiation for all claims, including claim 2.4 and supporting sub-claims, and that GEH's current and planned activities are consistent with achieving such substantiation. For safety, this means that this chapter does not aim to demonstrate that risks have been reduced to ALARP, and no 'ALARP justification' or 'ALARP evaluation' is offered. Instead, the chapter presents a viable path towards such a demonstration and shows that the first steps on this path have already been taken. This position reflects GEH's decision to carry out a two-step GDA and to enter into GDA while work on the standard design (Baseline 2) remains ongoing.

Consistent with other chapters in this PSR, GEH considers that the arguments and evidence provided within this chapter show that efforts have been taken where practicable to:

1. Optimise the design to reduce risks
2. Record this process, and
3. Set out next steps, including the path to a complete ALARP demonstration

By demonstrating a design process that has consistently driven risk reduction and that a suitable ALARP process has been established, GEH aims to provide confidence that there is a path to reaching an 'ALARP position'.

The level of detail in this chapter will increase as licensing progresses beyond the two-step GDA and the design and supporting analyses mature. Given the level of design maturity is not uniform across the plant (see Section 27.2.1), this also applies to the level of risk optimisation. Should GEH take the BWRX-300 through to site licensing and construction, a mature demonstration that risks have been reduced ALARP will be made available to the regulatory bodies.

Notwithstanding that a complete ALARP justification will not be available during GDA, GEH's approach to demonstrating that risks are ALARP for the BWRX-300 is as follows:

- Risk reduction prior to GDA entry *("Phase 0", pre-GDA)*
- Phase 1: Holistic review of the BWRX-300 design and design process *(during GDA)*
- Phase 2: Specific review of potential improvements *(post-GDA)*
- Phase 3: Holistic evaluation of the ALARP position *(post-GDA)*

The objective of Phase 1 is to determine the baseline risk profile. Phase 2 of the methodology is the identification of reasonably practicable improvements to safety *at the component and system level*. Phase 1 and 2 are to be carried out for all technical topic areas that have safety risk impacts (e.g., civil engineering, electrical engineering, internal hazards). Phase 3 then provides a 'holistic' review that confirms the *plant-wide* impact on risk of implementing all proposed improvements together. At the end of Phase 3, the BWRX-300 Design Reference is re-baselined, and the process is iterated. This method will be used to prepare the evidence and narrative to meet UK expectations, building on the established design principles and processes applied by GEH. This methodology will be applied within GEH's existing design process, which is discussed in the following Section 27.2.3.

It is not anticipated or claimed that a 'final' ALARP position will be reached in GDA. This revision of this document provides the first iteration of Phase 1. While work on Phase 2 will not be completed during GDA, forward actions have been identified throughout the PSR chapters and are summarised in NEDC-34274P, "BWRX-300 UK GDA Forward Action Plan" (Reference 27-23) for post-GDA sentencing.

While the technical topic areas of the BWRX-300 (as summarised in other chapters of this PSR) do not include complete ALARP justifications, efforts have been made to begin collating relevant RGP and OPEX that will inform a formalised ALARP position post-GDA.

27.2.3 Risk reduction prior to GDA entry (pre-GDA)

Although the first BWRX-300 projects to be announced were in Canada and the US, the intention since its conception has been for a 'standard plant design' for the BWRX-300 that is suitable for deployment in any market internationally. Therefore, the BWRX-300 standard plant design is based wherever possible on meeting the requirements and guidance of the IAEA Safety Standards, recognising that there are country-specific requirements and regulatory expectations to be met that go beyond those in the IAEA Safety Standards. The BWRX-300 licensing strategy is described in more detail in NEDC-34162P (Reference 27-1).

Design development up to now on the BWRX-300 standard design has primarily taken place in North America (US and Canada). As UK-specific concepts, ALARP and BAT were therefore not explicitly addressed in the GEH design process prior to entry into GDA. This does not mean that the work carried out prior to GDA entry is irrelevant to ALARP; GEH has a robust set of design and review processes that drive risk reduction and dose optimisation in design activities. Although not part of a formal ALARP methodology, this pre-GDA work has driven risk reduction, as demonstrated by the findings from the safety analysis (see Section 27.3.3). Some of the most important processes that support risk reduction are set out in APPENDIX C. GEH's intention is to integrate the ALARP methodology into its existing design processes, for example CP-03-100, "Design Control," (Reference 27-12) and CP-03-113, "Engineering Change Control," (Reference 27-13).

27.2.4 Phase 1: Holistic review of the BWRX-300 design and design process (during GDA)

The objective of Phase 1 is to provide the foundation of the ALARP evaluation. It is a holistic review of the BWRX-300 design, as well as the design process and evolution over time. It comprises three steps:

- Step 1: BWRX-300 Design Evolution Review
- Step 2: Systematic Review of Design Against RGP & OPEX
- Step 3: Risk Assessment Insights

Phase 1 has been completed for all systems in scope during GDA.

27.2.4.1 Step 1: BWRX-300 Design Evolution Review (during GDA)

This step supports sub-claims:

2.4.1 Relevant Good Practice (RGP) has been taken into account across all disciplines.

2.4.2 Operational Experience (OPEX) and Learning from Experience (LfE) has been taken into account across all disciplines.

GEH's BWR designs have evolved over time to incorporate changes to the design that improve safety and reduce risk. These changes either took advantage of improvements in technology, of learning from OPEX or a need to align with the latest RGP and regulatory requirements and expectations. This step therefore intends to provide evidence of how evolutionary changes to the design of GEH's BWRs have reduced risk and brought the design closer to an ALARP position. Unlike the remaining steps in the methodology, which are iterative, Step 1 is undertaken only once and informs the baseline of the ALARP evaluation.

Step 1 is addressed in this revision of the document – see Section 27.3.

27.2.4.2 Step 2: Systematic Review of Design Against RGP & OPEX (during GDA)

This step supports sub-claims:

2.4.1 Relevant Good Practice (RGP) has been taken into account across all disciplines.

2.4.2 Operational Experience (OPEX) and Learning from Experience (LfE) has been taken into account across all disciplines.

Consideration of RGP forms an early stage of the design review and informs the identification of reasonably practicable risk reduction measures. The importance of RGP and OPEX to the demonstration of ALARP is discussed in Section 27.1.1. Step 2 is therefore a systematic review that ensures:

- That all applicable RGP has been identified and that the design is assessed against this RGP to inform potential design improvements
- That a comparison is done against RGP from similar designs, the broader nuclear sector and, where relevant, other high hazard industries

Examples of the main sources of RGP are listed in Section 27.1.1. In general, the review shall be undertaken primarily against codes and standards applied and acknowledged in the UK, engineering design principles, and approved codes of practice, while noting that some of the unique features of the BWRX-300 may be inconsistent with existing RGP. With justification, the design standards that GEH has employed may represent RGP for this technology.

Information from BWRX-300 GDA regulatory interactions can also inform the review of RGP. The same applies to regulatory interactions during the GDAs of other designs, where these have relevance to the design, construction, commissioning, operation or decommissioning of the BWRX-300.

27.2.4.3 Step 3: Risk Assessment Insights (during GDA)

This step supports sub-claim:

2.4.4 Residual risks are compared with numerical targets and no event sequences are disproportionately dominant.

The risk analysis topics for the BWRX-300, including chemistry, conventional fire safety, external hazards, fault studies, human factors, internal hazards, radiological protection, severe accident analysis, structural integrity and Probabilistic Safety Assessment (PSA) provide insights into the main contributors to the safety risk.

In this step, insights from risk assessment are used to inform the design, including any aspects of the design where the contribution to risk is relatively high and may therefore be a candidate for improvement via changes to the design.

27.2.5 Phase 2: Specific review of potential improvements (post-GDA)

Phase 2 of the methodology is the identification of reasonably practicable improvements to safety *at the component and system level*. As discussed in Section 27.2.2, Phase 2 is to be carried out for all technical topic areas. This is opposed to Phase 3, which provides a 'holistic' review that confirms the *plant-wide* impact on risk of implementing all proposed improvements together. A key part of Phase 2 is therefore the optioneering and decision-making process that supports reducing risk to ALARP.

A robust and traceable decision-making process exists within GEH Common Procedure CP-03-100 (Reference 27-12) which codifies the GEH design change process. During the design change process, questions, deviations and requests, among other things, may be identified that could potentially affect the design and require a design change.

As described in GEH Common Procedure CP-03-113 (Reference 27-13), engineering change control is invoked once a set of engineering-controlled documents that define a specific product such as a component, system, or plant, are verified and released with no limitations on use. The Engineering Change Authorization is the overall process used to control and authorise changes in engineering-controlled documents to, among other things, ensure the impact is considered before a change is approved and that the affected documents are identified and changed as approved. Additionally, CP-03-113 provides the authority for a change and ensures all pertinent interfaces are identified, as well as the stakeholder at each interface. The procedure ensures accurate and traceable records of the change are maintained.

Reminder: No substantive work will be undertaken on Phase 2 during GDA.

27.2.5.1 Step 4: Optioneering – Assessment of Potential Improvements (post-GDA)

This step supports sub-claim:

2.4.3 Optioneering (all reasonably practicable measures have been implemented to reduce risk)

The output of Phase 1 will be used—with a graded approach—to establish a list of potential improvements for later project stages. This should be carried out for each technical topic area, accepting that, for some topic areas, it is possible that no reasonably practicable improvements will be identified. If no potential improvements are identified—or if none is claimed to exist—adequate justification must be provided. This justification should show why the existing design is considered to reduce risk ALARP and remains aligned with the overall BWRX-300 design intent (see also Phase 3). The intention is to provide an auditable trail of the decision-making process, which is why Phase 2 will be integrated into the existing GEH decision-making process (see Section 27.2.3 and APPENDIX C)

Initial prioritisation should consider the safety significance of each potential improvement, as well as the degree of uncertainty in terms of its complexity and feasibility. The prioritisation may consider insights from the risk assessment (Step 3).

A degree of engineering judgement is required, in particular if there is a lack of direct evidence. In such circumstances, judgements made are to be risk-informed from available evidence or relevant OPEX. Further evidence gathering may be required in order to adequately support an assessment of the specific shortfalls.

For prioritisation guidance in this step, specific consideration should be given to:

1. Safety Significance (covering conventional and nuclear safety, security, environment)

   a. Does the shortfall have the potential to challenge the safety and design principles?

   b. Are the implications significant if the improvement is inadequately conceived or executed?

2. Complexity/Feasibility

   a. Complexity of the Safety Case (is the improvement likely to be complex or novel?).

   b. Consideration of the time, trouble and effort likely to be involved.

   c. Does it have the potential to adversely impact future site licensing (e.g. supply chain, quality assurance requirements).

When potential improvements are identified, these may be grouped for convenience and then an individual assessment for each potential improvement (or group of potential improvements) undertaken.

Once the decision to undertake an ALARP review has been made, an owner should be identified, relevant information gathered, and the scope and type of assessment to be undertaken determined.

Optioneering is the process of generating and evaluating options which could address the specific potential improvement and the understanding of potential impact on interfacing systems. It is necessary to understand the risk profile associated with the issue so that the extent and level of detail during optioneering is proportionate to its safety significance and potential implications.

The optioneering process will use the existing design control and modification processes at GEH (References 27-12 and 27-13, and see also APPENDIX C) to ensure familiarity with key stakeholders within GEH. These processes follow standard practices across the nuclear industry to drive safety improvements and reduce the risk profile of designs.

Achieving a 'balanced' design is a key objective of optioneering. A balanced design is one where no single component or group of components makes a disproportionate contribution to overall risk; the failure of any component or group of components should make a relatively small contribution to the overall risk. Understanding whether a design is 'balanced' is one of the objectives of the PSA, as described in NEDC-34184P, "BWRX-300 UK GDA Chapter 15.6: Probabilistic Safety Assessment," (Reference 27-24). The PSA should therefore be used to inform the optioneering[4].

The following steps will be integrated into the existing GEH design process at each baseline design maturity gate to meet UK expectations for the optioneering process:

A. Define and characterise the specific potential improvement. The fundamental issue, including the problem statement, safety significance and potential implications, should be understood and established. To help understand and establish the fundamental issue, it is necessary to understand the risk profile associated with the issue.

B. Develop the potential options to address the problem. Consider as broad a range of options as reasonably achievable. If possible consider options that address different levels of defence in depth (i.e., options that use prevention, protection and mitigation approaches to eliminate/manage risks).

C. Assess the options, including their benefits and dis-benefits. Each option should be evaluated systematically and their relative merits identified. The evaluation may use

[4] Insight from the PSA has already influenced the design – see Section 27.3.3.2.

qualitative and/or quantitative techniques. If options have been considered and screened out, an explanation should be provided with appropriate justification. This step may require a number of iterations, and optioneering may need to be approached in stages.

The need to keep adequate records is addressed in IAEA Safety Standards Series No. GSR Part 2, "Leadership and Management for Safety," (Reference 27-25) ONR Licence Condition 6 (Reference 27-3) and within HSWA74 (Reference 27-1). Therefore, the ALARP review and the justification for the preferred design must be adequately documented to provide a record of the reasoning for design decisions and to support regulatory safety submissions. Key decisions related to optioneering (and ALARP in general) will be recorded via the Product Lifecycle Management (PLM) system, which is discussed in APPENDIX C.

27.2.5.2 Step 5: Interface with Best Available Technique/Security & Safeguards (post-GDA)

The application of BAT is the subject of a separate methodology, as described in NEDC-34223P (Reference 27-22). The requirements of BAT have many commonalities with those of ALARP and, in many cases, application of both methodologies will lead to complementary design development. However, the requirements of ALARP and BAT can conflict e.g., in the approach to management of spent fuel, where techniques could be used which reduce discharges and doses to the public but increase doses to operators.

The goal is to achieve holistic (integrated) design optimisation; the need to reduce risks ALARP is considered alongside the needs to minimise environmental, security and safeguards risks.

A potential advantage of the BWRX-300 design process is that it encourages integrated assessment of safety and environmental risks through the ALARA design criteria and optimisation process, which is discussed in APPENDIX C. Where tension between BAT and ALARP does arise, a subject matter expert on environmental aspects and BAT should have input into the ALARP decision making process, e.g., through involvement in an option review meeting. Any sensitivity analysis applied to a quantitative ALARP assessment should also consider changing the weighting given to the importance of radiological versus environmental and conventional hazards to assess the impact that this change will have on the preferred option.

Should they arise, conflicts between safety, security and safeguards should be managed in a similar way to BAT/ALARP conflicts.

27.2.5.3 Step 6: Decision Making (post-GDA)

The overall decision making and governance processes (Reference 27-13) that control the design ensure evidence-based decision-making and adequate oversight of changes. The ALARP review should consider all relevant factors to allow selection of the ALARP option, and ensure the decision is fully justified as part of the input to a design change management process.

Decisions will be made by GEH personnel with suitable authority and accountability for the design of the BWRX-300, taking into account the output of the assessment process and opinions of relevant subject matter experts. A record of design decisions and the basis for such decisions will be produced and recorded in GEH's 'Confluence' document management system.

The decision-making entity for GEH is the Engineering Review Board (ERB). The ERB is a technically oriented, multi-disciplined team composed of representatives from multiple disciplines with GEH. The ERB membership consists of GEH Principal Engineers and focuses on safety and regulatory issues (including those issues that arise from any regulatory body) associated with the BWRX-300 design. An ERB is convened when a design change results in one or more of the following: 1) plant architecture decision, 2) multiple affected Main Parts Lists, 3) operational concept changes and 4) significant changes to the design/operating philosophy. The ERB convenes to ensure the appropriate significance and rigor is applied to the design change prior to further evaluation and implementation.

Where ALARP analysis involves consideration of costs and benefits, the criterion is not one of simple balance but gross disproportionality. For example, the costs associated with any further improvement action must be demonstrably ‘grossly disproportionate’ to the safety benefit achieved for the action if that action is not to be implemented. The depth of demonstration of this should be proportionate to the risk level.

Decisions that have a significant impact on cost or scope of the BWRX-300 Standard Plant are reviewed by the Design Center Working Group (DCWG). The DCWG is a technically oriented, multidisciplined team composed of representatives from prospective BWRX-300 owners and GEH. The DCWG focuses on resolving design and regulatory issues associated with the BWRX-300 design that are common to all sites. The DCWG approves BWRX-300 Standard Design and its interface with site-specific design features, allowing for an economically viable next-of-a-kind deployment. An important role of the DCWG is to inform the lead project (Darlington, Canada) and subsequent project Risk Registers and aid in developing appropriate mitigation strategies consistent with the complexity and level of risk involved.

Through a standardised design approach, the DCWG promotes safety and standardisation of the BWRX-300 design through harmonisation of regulatory and engineering practices where there may be a safety and design benefit.

27.2.5.4 Step 7: ALARP Position Justified for Potential Improvement (post-GDA)

Once optioneering has been completed, it is considered that the ALARP position for the specific potential improvement has been reached. Where relevant, the safety case should be updated and all commitments tracked to completion in compliance with configuration control arrangements.

27.2.6 Phase 3: Holistic evaluation of the ALARP position (post-GDA)

In Phase 3, the output of Phase 2 is evaluated in a holistic manner to determine if an ALARP position has been reached across the design or if further work is necessary.

Within the BWRX-300 GDA it is anticipated that Phase 1 will be completed but that detailed work on Phases 2 or 3 will be completed post-GDA as part of preparation of the Pre-Construction Safety Report. An update to NEDC-34274P (Reference 27-23) will include plans for post-GDA work.

27.2.6.1 Step 8: Holistic Review of All Implemented Improvements (post-GDA)

The process of optioneering and implementation of the practicable options shall continue whilst there are potential areas for improvement.

Once all of the potential improvements have been assessed for a stage of design maturity and scope of assessment, and a suitable solution implemented for each potential improvement, the design shall be subject to a further holistic review, i.e. a proportionate check of Step 2 & 3, to identify any further potential improvements.

The need to ensure that the risks associated with a design are ALARP applies throughout the lifecycle of design and operation. Reviews of the ALARP evaluation should therefore be undertaken on a regular basis during design development.

27.2.6.2 Step 9: Implementation of Reasonably Practicable Option (post-GDA)

Where the decision making undertaken in the previous steps concludes that there are one or more options that would be considered reasonably practicable (even if that is the ‘null’ option) then that shall be implemented into the BWRX-300 design and collated with other improvements to a new reference design as per applicable design configuration control processes (Reference 27-12 and 27-13). Consideration must be given to how proposed options in one area might impact other areas to ensure a holistic ALARP justification can be made.

All documentation that relates to the design, including drawings and calculations, should be updated to reflect the implementation of the preferred option. This includes identification of any requirements for examination, inspection, maintenance and testing that will be required to ensure the chosen design remains ALARP throughout the lifetime of the plant.

All improvements considered reasonably practicable shall be implemented until no further reasonably practicable options remain.

27.2.6.3 Step 10: Assessment of New As Low As Reasonably Practicable Position (post-GDA)

Once detailed safety analysis of the design has been developed, the ALARP justification should also be reviewed as part of safety case development to enable comparisons against the safety assessment criteria for normal operations and accidents.

Assessment of the design should consider whether risk is adequately shared across the plant; no single area should dominate risk.

This step completes once it can be shown that the plant-wide risk is ALARP.

27.3 Implementation – Phase 1 (during GDA)

The following is a summary of how Phase 1 of the ALARP methodology has been implemented during GDA Steps 1 and 2.

27.3.1 Phase 1, Step 1: Summary of BWRX-300 Design Evolution (during GDA)

This step supports sub-claims:

2.4.1 Relevant Good Practice (RGP) has been taken into account across all disciplines.

2.4.2 Operational Experience (OPEX) and Learning from Experience (LfE) has been taken into account across all disciplines.

A review of the evolution of the BWRX-300 design is presented in NEDC-34137P (Reference 27-5). This provides evidence that the evolutionary modifications have been reducing risk and the modifications have brought the design closer to an optimised position.

Major modifications through design evolution that have contributed to safety are described in detail in NEDC-34137P (Reference 27-5). The process starts with the evolution of BWR technology (Section 27.6) and identifies major modifications (Section 27.7) during subsequent design evolution, with the following subsequent design evolution including the ABWR previously assessed in a UK GDA and the more recent SBWR and ESBWR designs leading finally to the BWRX-300.

The BWRX-300 is GEH's tenth generation BWR design and represents GEH's simplest BWR yet. The BWRX-300 is an evolution of the US Nuclear Regulatory Commission (NRC)-licensed, 1,520 MWe ESBWR. The design includes passive safety features and benefits from decades of GEH BWR design and in-service OPEX.

There have been 115 BWRs built and operated around the world with two ABWRs currently under construction in Japan. Currently there are 63 BWRs operational worldwide. The highest concentration of BWRs is in the US where 31 of the 94 operating reactors in the country are BWRs. Many are among the best operating plants in the world, performing with high availability factors. In April 2025, the Canadian Nuclear Safety Commission (CNSC) issued a construction licence for the BWRX-300 at Darlington, Canada.

The BWRX-300 benefits from design optimisation and OPEX from previous designs. For example, including more reliance on passive systems increases the reliability of the system due to a reduction in piping lengths and moving parts (i.e. pumps), reduces maintenance burdens and therefore reduces operator dose uptakes during maintenance. This also reduces both the burden of safety-related operator actions and inadvertent operator errors. GEH considers that these processes demonstrate its drive for risk reduction across the design.

The above points are expanded on in the following sections.

27.3.1.1 Boiling Water Reactor Evolutions

The first BWR nuclear plant built was the 5 MWe Vallecitos plant (1957) located near San Jose, California. The Vallecitos plant confirmed the ability of the BWR concept to produce electricity successfully and safely for a grid.

A major extrapolation from that first test facility was the Dresden 1 plant, located near Morris, Illinois. Construction of this 180 MWe plant began in 1959, with commercial power production achieved in 1961.The BWR design has subsequently undergone a series of evolutionary changes with each one incorporating greater levels of simplification.

The BWR design has been simplified in two key areas - the reactor systems and the containment design. Figure 27-1 describes the development of the BWR and Table 27-1 shows the timeline with a summary of major plant features at each evolution.

The first step in BWR simplification was the elimination of the external steam drum. This was achieved by introducing two technical innovations – the internal steam separator and dryer (KRB, 1962). This practice of simplifying the design with technical innovations has been repeated many times over.

The first large direct cycle BWRs, e.g. Oyster Creek, appeared in the mid-1960s and were characterised by the elimination of the steam generators and the use of five external recirculation loops. Later, reactor systems were further simplified by the introduction of internal jet pumps. These pumps sufficiently boosted recirculation flow so that only two external recirculation loops were needed. This change first appeared in the Dresden-2 BWR/3 plant. BWR/4, BWR/5 and BWR/6 designs continued the path to simplification.

The use of reactor internal pumps in the ABWR design represented another large step in the process of simplification. By using pumps attached directly to the vessel itself, the jet pumps and the external recirculation systems, with all the associated pumps, valves, piping, and snubbers, were eliminated.

The ESBWR, and its smaller predecessor, the SBWR, took the process of simplification to a logical conclusion with the use of a taller vessel and a shorter core to achieve effective natural recirculation flow without the use of any pumps.

The BWRX-300 uses the same tall vessel design to achieve effective natural circulation flow but is designed without the need for a shorter core. This allows the BWRX-300 to use the same fuel bundle designs that are currently in use in the operating BWR fleet. Challenges to the system are minimised by the large water inventory above the core in the Reactor Pressure Vessel (RPV).

Figure 27-1 illustrates the evolution of the reactor system design. Most of the BWRs deployed to date have used forced circulation, including the BWR/1s through BWR/6s and the ABWR. Natural circulation plants have a separate linage from the Vallecitos plant through Humboldt Bay and Dodewaard to the SBWR, ESBWR and now the BWRX-300.

The first BWR containments were spherical ‘dry’ structures. Dry containments in spherical and cylindrical shapes are still used today in Pressurised Water Reactor designs. The BWR, however, quickly moved to the ‘pressure suppression’ containment design for its many advantages, as discussed below.

The Mark I containment used with BWR/3 and most BWR/4 plants was the first of the new containment designs. The Mark I design has a characteristic light bulb configuration for the steel drywell, surrounded by a steel torus that houses the large pool of water for pressure suppression. The conical Mark II design used with BWR/5 and some late BWR/4 plants has a less-complicated arrangement allowing simplified construction. The Mark III containment design used with BWR/6 plants represented a major improvement in simplicity. Its containment structure is a right-circular cylinder that is easy to construct while providing ready access to equipment and ample space for maintenance activities.

The ABWR containment is significantly smaller than the Mark III containment, as elimination of the recirculation loops allows for a significantly more compact containment and reactor building. The ESBWR containment is similar in construction to the ABWR, but is slightly larger to accommodate the passive ECCS.

The BWRX-300 containment is small and simple. This is achieved through the use of RPV isolation valves to rapidly isolate the flow from pipe breaks and an Isolation Condenser System (ICS) to remove energy from the RPV rather than directing that energy into a suppression pool. Figure 27-2 illustrates the history of BWR containment (outlined in red) and reactor building development. The simplification of the containment has resulted in the removal of the suppression pool with all the suppression pool benefits being delivered by the ICS.

27.3.1.2 Operational Experience

The design process incorporates applicable operating experience and lessons learned to mitigate nuclear design and construction risk, in accordance with CP-16-101, “Lessons Learned/Operating Experience Program,” (Reference 27-26). Operating experience sources include the Institute of Nuclear Power Operations, Electrical Power Research Institute (including the Material Reliability Program), and other applicable sources. Construction experience and improved construction methods from previous large projects are used to improve the quality and efficiency of the construction effort.

GEH has undertaken extensive and systematic OPEX reviews for the BWRX-300, including a plant-wide review described in 007N1411, “BWRX-300 Operating Experience Report,” (Reference 27-8). System-specific OPEX reviews have also been carried out, for example for the Nuclear Boiler System, DBR-0072077, “BWRX-300 Operating Experience (OPEX) Review for the Nuclear Boiler System,” (Reference 27-27), and for the ICS, DBR-0072078, “BWRX-300 Operating Experience (OPEX) Review for the Isolation Condenser System,” (Reference 27-28).

The BWRX-300 design approach leverages nine previous generations of GEH BWR technology, with more than 2,000 reactor-years of operating experience. The design is based on the US NRC certified ESBWR but using the commercially proven GNF2 nuclear fuel.

The nuclear core uses the proven GNF2 fuel assemblies that are manufactured and sold to over 80% of the BWR fleet. Over 18,000 GNF2 fuel assemblies have been delivered worldwide as of 2019. GEH’s BWR operating experience also includes the following:

- GEH has approximately 40 BWR plants currently in service with hundreds of years of reactor operating experience.
- GEH administers and coordinates a Boiling Water Reactor Owners’ Group (BWROG) which deals with fleet-wide issues and concerns and operating experience.
- Previous GE BWR designs have been licensed worldwide, including in the US, Japan, UK, Taiwan, Switzerland, Italy, and Spain.

The ability of BWROG to collect OPEX from around the world and to disseminate learning to the global BWR fleet is a strong differentiator for the BWRX-300 design. As learning from OPEX is a key part of the ALARP demonstration, BWROG’s extensive databases and reports serve as powerful tools in the GEH design process and will play an important role in a future ALARP demonstration for the BWRX-300. This role will not be limited to supporting the demonstration of ALARP for the Pre-Construction Safety Report; BWROG meets regularly to discuss emergent issues allowing it to support continuous improvement in safety over the BWRX-300’s lifetime.

The BWRX-300 leverages the US NRC approved ESBWR design, proven in-use materials, off-the-shelf components, and design pressures and temperatures within the range of the existing BWR design and experience base.

The BWRX-300 core design includes established GNF2 fuel bundles because of their low hydraulic resistance, which is beneficial for natural circulation. The core lattice configuration provides a greater shutdown margin as desired for reload design to accommodate variations in burnup history imposed by load following. The reactor lattice configuration and fuel element design for the BWRX-300 are similar to those employed in operating BWRs around the world. The BWRX-300 fuel handling and refuelling process is essentially unchanged from historical BWR practices.

The types of radioactive waste discharge during normal operations are well understood for BWRs. The BWRX-300 incorporates decades of lessons learned from the operating fleet to minimise these amounts.

The BWRX-300 employs a conventional Rankine steam cycle, consistent with those used in existing and historical BWRs, allowing it to leverage established balance-of-plant (BoP) designs and operational experience. The lower gross power (compared to e.g. ABWR) of 300 MWe eliminates the need for custom designs for turbines and generators as existing, industry-standard frame sizes are available from the major turbine generator set manufacturers (typically with extensive OPEX).

27.3.1.3 Designed for Safety

The following key design decisions have driven improved safety:

- Use of a single reactor coolant loop that passes through both the reactor pressure vessel (RPV) and turbines, eliminating the need for steam generators.
- Use of Reactor Pressure Vessel (RPV) isolation valves (integral to the RPV) that reduce the potential for unisolable Loss-of-Coolant Accidents (LOCAs).
- Use of an extended-height RPV to enable effective natural circulation without the need for forced-flow pumps.
- Elimination of internal pumps, jet pumps, and external recirculation loops through the adoption of natural circulation cooling.
- Integration of internal steam separators and dryers, removing the need for an external steam drum.
- Use of proven fuel bundle designs that are already deployed in the operating BWR fleet.
- Provision of a large water inventory above the core within the RPV, reducing the challenge to the system under postulated fault conditions.
- Retention of removable core internals—fuel assemblies, control rods, chimney head, steam separators and dryers, and in-core instrumentation—that are consistent with ESBWR practice, thereby benefiting from established design pedigree and operating experience.
- Large capacity ICS that provides overpressure protection without the need for safety relief valves, and allowing for a dry containment volume.

The ICS represents a key design simplification in the BWRX-300, replacing the suppression pool used in earlier BWRs and enabling a containment architecture with the following benefits:

- Increased heat capacity to absorb energy from containment transients and pipe break LOCAs.
- Reduced containment design pressure requirements due to passive heat rejection.
- Enhanced capability to accommodate rapid system depressurisation.
- Integrated filtration capability to retain fission products within the containment boundary.
- Availability of a large passive inventory of makeup water for use in accident conditions.
- Inclusion of a containment vent system to mitigate low-frequency pressurisation events.

As well as decisions relating to the primary circuit and key safety systems, GEH’s general approach to the design and construction of the BWRX-300 presents other advantages:

- A risk-informed approach to design, where insights from the PSA are used iteratively to improve safety in the design

- Simplified design supporting increased reliability e.g. reduction in the number of components and pipework lengths
- Reduced requirement for operator control or intervention
- Modularisation with constructability integrated into the design
- Reduced external event risk from optimised site layout and plant structural integrity
- Designed in accordance with internationally accepted codes, standards and guidance to support international deployment with minimum changes
- Ability to use non-safety classified and commercial off-the-shelf equipment in some areas (e.g. BoP)

The BWRX-300 has been developed with a focus on achieving high safety margins through simplification, functional diversity, and passive systems, rather than through reliance on complex active safety systems. The design reduces reliance on operator action, electrical power, and mechanical components while ensuring alignment with applicable US NRC, IAEA, and IEC guidance.

In line with IAEA guidance on Defence-in-Depth (D-in-D), the BWRX-300 design incorporates all five Defence Lines, supported by redundant, diverse, and segregated systems as appropriate to each safety function. This structure provides multiple layers of protection against internal faults and external hazards.

The RPV is equipped with integral double isolation valves, eliminating the potential for non-isolable LOCAs and enabling a compact, dry containment. The removal of Safety Relief Valves (SRVs)—which are a known LOCA contributor in legacy designs—is made possible by the passive overpressure protection provided by the Isolation Condenser System (ICS), in combination with the inherent steam volume of the RPV. In addition, an Ultimate Pressure Regulation (UPR) line has been incorporated based on insights from preliminary PSA, offering a pressure relief path in the event of unlikely pressurisation events (see Section 27.3.3.2 and APPENDIX C).

The ICS provides the primary passive means of decay heat removal, removing decay heat after any reactor isolation and shutdown event during power operations. The ICS decay heat removal limits increases in steam pressure and maintains the RPV pressure at an acceptable level. The ICS consists of three independent loops that each contain a heat exchanger with capacity of approximately 33 MW, or approximately 3.7% of rated thermal power.

The ICS is initiated automatically and will also be initiated if a loss of Direct Current (DC) power occurs (fail-safe). The ICS can also be initiated manually by the operator from the Main Control Room (MCR). The heat rejection process can be continued beyond seven days by replenishing the ICS pool inventory. The ICS pools are located at ground level and are not pressurised, so replenishment can be easily accomplished using readily available transportable sources such as a fire truck. Full-scale ICS prototype testing was performed for the ESBWR, which provides confidence in the ability of this triple-redundant system to function as required.

Reactivity control is delivered through a diverse set of shutdown mechanisms. In addition to hydraulic scram, the Fine Motion Control Rod Drives can insert all control rods via electric motor. A chemically-based Boron Injection System provides a further independent and diverse shutdown path, intended to terminate extremely low-probability events where mechanical rod insertion proves ineffective.

The layout of safety-significant structures, systems and components (SSCs) further contributes to hazard resilience. The RPV, Primary Containment Vessel and other important safety related systems and components are located in the below grade (i.e. below ground level) reactor building vertical right cylinder shaft to mitigate effects of possible external events, including aircraft impact, adverse weather, flooding, fires, and earthquakes.

The spent fuel pool is located at grade in the reactor building and has a capacity of eight years of used fuel plus a full core offload. Since the spent fuel pool is at grade, spent fuel casks can be removed without the use of a heavy crane, which mitigates potential dropped load hazard risks. This reflects learning from the GDA for the UK ABWR, where concerns were raised over the UK ABWR spent fuel pool's relatively high elevation within the Reactor Building. Exporting spent fuel casks from the UK ABWR Reactor Building would have involved lowering the casks down a tall, vertical shaft, introducing a dropped load hazard.

The Instrumentation and Control (I&C) and electrical power systems have been simplified consistent with the reduced need for active safety intervention. Lower complexity and reduced classification of I&C SSCs have been achieved by design, supported by the elimination of operator action requirements for 72 hours following any Design Basis Accident (DBA). RGP is followed by ensuring that all I&C is designed to applicable US NRC, IAEA and IEC guidance.

Safety-class electrical supply is provided by battery-backed DC systems with a 72-hour autonomy envelope, removing the traditional reliance on AC power sources such as diesel generators during Design Basis Accidents. Natural circulation cooling is maintained without forced flow, such that loss of offsite power does not result in a loss of core cooling.

Finally, the BWRX-300's chemistry regime reflects decades of BWR operating experience and relevant good practice. The approach maintains structural integrity and fuel performance through controlled chemical dosing, impurity control and material selection, and supports ALARP demonstration by minimising radiological source term, routine discharges and occupational exposure. The regime also contributes to long-term maintainability of both fuel- and non-fuel-related systems, supporting lifecycle safety and operational performance.

27.3.1.4 BWRX-300 Design Evolution Review Summary

The material presented in Sections 27.3.1.1 to 27.3.1.3 demonstrates that the BWRX-300 design evolution has delivered substantive risk reductions through simplification, increased use of passive systems, and the elimination of high-consequence failure modes. These changes are underpinned by extensive BWR operating experience, guided by RGP, and supported by preliminary PSA insights. Collectively, they minimise reliance on operator action and complex safety-class systems. Together, these features constitute the outcome of Phase 1 Step 1 of the ALARP methodology. Table 27-2 provides a system-level traceability map showing how these design developments support future ALARP sentencing, including the application of OPEX, RGP, and formal optioneering.

27.3.2 Phase 1, Step 2: Summary of Systematic Review of Design Against RGP and OPEX

This step supports sub-claims:

2.4.1 Relevant Good Practice (RGP) has been taken into account across all disciplines.

2.4.2 Operational Experience (OPEX) and Learning from Experience (LfE) has been taken into account across all disciplines.

During GDA Step 1, one of the primary tasks undertaken was a Codes and Standards (C&S) review, NEDC-34139P, "BWRX-300 UK Codes and Standards Assessment," (Reference 27-29), for the design of the BWRX-300. This assessment compares the US / Canadian to European / UK C&S equivalents across a GEH defined suite of Safety and Control Areas and identified potential design compliance risks in terms of:

- Areas where the existing C&S currently used is likely to be fully acceptable within the UK
- Areas potentially at risk of design or operational change, and / or
- Areas where further justification of the existing C&S currently used was likely to be required to support their acceptability in the UK, and / or
- Areas where the BWRX-300 may be required to demonstrate compliance against European or UK-specific C&S

This C&S review has been undertaken for the physical design covering systems and structures important to safety within the 'Power Block', i.e. the Reactor Building, Turbine Building, Radioactive Waste Building, Control Building, Service Building and Reactor Auxiliary Structures. The discipline areas covered by these C&S reviews were:

- Fire
- Environmental Qualification
- Human Factors
- Civil
- Electrical
- I&C
- Refuelling Equipment and Services
- Mechanical

These topic areas were considered those with the most risk of design change associated with adoption of alternative C&S for the UK.

The preliminary findings are as follows:

- Of the 532 C&S reviewed, ≈50% were considered likely to be acceptable in the UK without any further justification, a further ≈20% were likely to be acceptable in the UK with additional justification whilst only ≈30% were considered not to be acceptable.

The C&S identified as not likely to be acceptable were predominantly local C&S associated with building regulations in the specific country and province. The key C&S used in the design of the BWRX-300 (American Society of Mechanical Engineers, IEC, Institute of Electrical and Electronics Engineers, etc.) are considered RGP in the UK.

As part of the future licensing phase review of the proposed codes and standards for the UK, a reconciliation will be performed with the revision of the BWRX-300 Applicable Codes, Standards, and Regulations List current at that time.

The legal requirement to apply and demonstrate the ALARP principle also applies to conventional industrial risks which are addressed in the BWRX-300 design under Conventional Health and Safety (CHS) and Conventional Fire Safety risk. An assessment of these requirements was included in the RGP review of UK codes and standards. It is considered that the CHS/ Conventional Fire Safety UK regulatory expectations, that constitute UK RGP, are well understood and that plant designers are able to apply their knowledge and experience of these expectations appropriately. Initial reviews of these CHS/ Conventional Fire Safety regulatory expectations have been performed during GDA Step 1 and where potential gaps to such expectations have been identified then forward actions have been raised to manage these in future. The BWRX-300 design is based upon decades of BWR operating experience, which is expected to support CHS/ Conventional Fire Safety risk reduction.

In terms of RGP review of analysis, the approach to safety, including fundamental objectives, applying defence in depth principles, categorisation of safety functions, and classification of safety features to deliver those functions is derived from IAEA guidance and internationally recognised good practice. The approach adopted for the BWRX-300 is fully described in NEDC-34165P, “BWRX-300 UK GDA Preliminary Safety Report Chapter 3: Safety Objectives and Design Rules for Structures, Systems and Components,” (Reference 27-30), providing confidence and context that the application of ALARP principles is embedded in the approach taken and aligns with UK expectations.

A comparison of application of safety category and SSC classification for the BWRX-300 and UK expectations has been undertaken in NEDC-34161P, “BWRX-300 UK Generic Design Assessment (GDA) Comparison of BWRX-300 Approach to Categorization & Classification with UK expectations,” (Reference 27-31). The BWRX-300 approach to categorisation of safety functions and classification of SSCs broadly aligns with UK expectations and are aligned with ONR’s high-level objectives of a scheme for categorisation of safety functions and classification of SSCs. In addition, UK Subject Matter Experts have reviewed the classifications of equipment in the BWRX-300 design and found them in general alignment with their experience of similar plant in the UK, which supports this judgement.

Two areas have been identified where there are potential gaps or weaknesses in the BWRX-300 approach for categorisation and classification when compared with UK expectations:

- Subjectivity in the categorisation of functions that provide Fundamental Safety Functions or maintain key reactor parameters in normal operations
- Classification of components whose failure could impact delivery of categorised safety functions or have nuclear consequences

The identified gaps and weaknesses in the BWRX-300 approach to categorisation of safety functions and classification of SSCs are unlikely to lead to any deficiencies in the acceptability of the design in the UK. However, a Forward Action Plan item has been raised to address these in NEDC-34161P (Reference 27-31).

27.3.3 Phase 1, Step 3: Risk Assessment Insights

This step supports sub-claim:

2.4.4 Residual risks are compared with numerical targets and no event sequences are disproportionately dominant.

27.3.3.1 Deterministic Analysis

The design is informed by analysis of safety functions. Explicit SSC functional requirements are then derived to meet these safety needs. These SSC functional requirements set clear criteria that the engineered systems must meet, and allow quantification of potential shortfalls in safety. Analysis topics include internal hazards, external hazards, deterministic safety analysis and probabilistic safety analysis.

NEDC-34187P, “BWRX-300 UK GDA Preliminary Safety Report Chapter 15.9: Safety Analysis - Summary of Results,” (Reference 27-32), shows that implementation of the D-in-D concept ensures multiple, independent layers of protection against unacceptable radiation releases.

The chapter concludes that none of the bounding Anticipated Operator Occurrences, DBAs, or Design Extension Condition Events Without Core Damage analysed approach the regulatory limits for radioactive releases.

At this stage, the results of the deterministic analysis are preliminary and will mature along with the design development of the BWRX-300.

27.3.3.2 Probabilistic Safety Assessment

PSR Chapter 15.6 (Reference 27-24) reports how a Level 1 PSA has been developed for internal events in all modes of operation with a Level 2 PSA for full power. Full power hazard Level 1 PSAs, including internal fire, internal flooding, seismic, high wind and heavy load drop have been developed, with some Level 2 analyses for certain hazards. A spent fuel pool PSA has also been produced and is discussed. The chapter is supported by a summary report and methodology report, which go into more detail regarding the assumptions, input data, task outputs and analysis of the results.

The chapter demonstrates that the PSA results have been, and will continue to be, used to risk-inform and support design optioneering to ensure that the risk is ALARP. In addition, given the low risks calculated from the analysis to date, it is expected that the final risk results will continue to show the site risk to be very low relative to traditional safety goals and numerical targets.

The PSA is an iterative process and will continue to be developed as the design develops. The scope and level of detail in the PSA is commensurate with the stage of design development and with a two-step GDA. There are Forward Actions related to PSA, including future work commitments such as the development of numerical dose and risk-based targets against which a full scope Level 3 PSA will be assessed.

The development of the BWRX-300 PSA is an iterative process; the results will be updated as more detailed design information becomes available and more analyses are performed. As such, the current PSA results do not present the full site risk from a full scope PSA. They do, however, show the order of magnitude of expected risk, which can be seen to be very low compared to traditional BWR plants. At this stage in design development, the most important use of the PSA is to provide risk insights to inform design.

The overall calculated risk is very low compared to historical Core Damage Frequency (CDF) values calculated for existing plants. There is significant margin to the targets typically applied by IAEA member states as documented in IAEA-TECDOC-1874, “Hierarchical Structure of Safety Goals for Nuclear Installations,” (Reference 27-33). The total plant CDF, including Fuel

Damage Frequency from the spent fuel pool contribution, is 8.73E-07/yr. Almost 94% of this is from the seismic analysis. This early version of the seismic analysis is known to be conservative, due to the limitations given the early phase of the design.

The early results from the PSA have been used to inform the design. At the time of writing, insight from the PSA has:

- Shown a need for an alternative RPV depressurisation mechanism in addition to the ICS, referred to as the UPR (currently under design development)
- Shown a need for a filtered containment vent system, and informed its sizing
- Supported the decision to provide a boration mechanism as a diverse means of reactivity control
- Precluded the need for a new RPV nozzle to accommodate the boration mechanism
- Influenced the sizing/operation of CRD injection to provide reactor inventory makeup
- Supported development of seismic capacity requirements for some equipment
- Shown the importance of spatial separation in some areas during certain fire scenarios
- Influenced the development of shutdown nuclear safety strategies
- Suggested that the feasibility and effectiveness of a seismic anticipatory trip function should be investigated
- Showed the risk reduction benefit of developing diverse makeup functions to the pools

The PSA will continue to provide risk insights to support design optioneering and risk reduction in future licensing phases.

27.4 Conclusions

This chapter has set out GEH's strategy for meeting UK legal requirements and regulatory expectations on the need to reduce risks ALARP. Design development prior to GDA entry for the BWRX-300 has primarily taken place in North America. As such, the concept of reducing risk to ALARP (as understood in the UK) was not part of GEH's design process, although many elements of the design process do encourage risk reduction and design optimisation, especially for risks from ionising radiation. GEH acknowledges the need to adapt this design process to incorporate UK expectations and to allow for a complete demonstration of how risks have been reduced to ALARP at a suitable point during post-GDA licensing of the BWRX-300.

This chapter has set out how GEH is approaching the demonstration of ALARP for the BWRX-300, including:

- The main claims related to reducing risks ALARP
- How the BWRX-300 incorporates risk reduction achieved through the design evolution of BWRs
- How GEH's design processes have driven holistic risk reduction and design optimisation at both system and plant-wide levels
- The three-phase GEH ALARP methodology for the BWRX-300
- What aspects of the ALARP methodology will be completed during GDA
- How the two-step GDA shows a viable path to demonstrating that risks are ALARP post-GDA
- How safety, environmental, security and safeguards risks are considered in an integrated manner that minimises conflicts.

Section 27.2 of this chapter set out the three-phase methodology, as well as describing how work carried out prior to GDA drove risk reduction across the design. Only Phase 1 of the three-phase methodology is being implemented during GDA, and this is recorded in Section 27.3. Phases 2 and 3 will be completed as part of the Pre-Construction Safety Report licensing phase.

The implementation of Phase 1 shows that GEH design processes are designed to drive risk reduction across the design and can be adapted to align with UK expectations on reducing risk to ALARP post-GDA. This is supported by the evidence of how the design evolution of the BWRX-300 has led to risk reduction, including the addition of passive and inherent safety features. As the tenth generation BWR, the design of the BWRX-300 makes use of many decades of OPEX. The BWROG is a powerful tool for the gathering and dissemination of OPEX among the global BWR fleet and differentiates GEH's offering, particularly related to continuous improvement and the need to periodically evaluate whether plant risk remains ALARP.

GEH's GDA submission does not intend to demonstrate that all claims are substantiated. Instead, it aims to demonstrate that there is a **viable path towards substantiation for all claims**, and that GEH's current and planned activities are consistent with achieving such substantiation. The objective of this chapter has therefore not been to demonstrate that risks have been reduced to ALARP (as per claim 2.4) and no 'ALARP justification' or 'ALARP evaluation' is offered. Instead, the objective was to show that there is a viable path towards such a demonstration, and that the first steps on this path have already been taken (Phase 1).

This position reflects GEH's decision to carry out a two-step GDA and to enter into GDA while work on the standard design (Baseline 2) remains ongoing. GEH intends to complete GDA without additional design changes beyond the Design Reference (as described in Section

27.2.1). Instead, any design changes beyond the GDA will be tracked for implementation using Forward Action Plans in the UK as part of future site-specific licensing and development of Baseline 3 design for the UK. GEH will provide periodic updates on design maturity as part of completion of the Baseline 2 BWRX-300 standard design. Moreover, commitments are being formally identified within the consolidated end of the Step 2 GDA Safety, Security, Safeguards and Environments cases. GEH considers that this staged approach ensures the ALARP demonstration remains proportionate to design maturity, traceable through future licensing, and aligned with the expectations of a two-step GDA.

Table 27-1: Development and Deployment of Boiling Water Reactors

Product Line	First Commercial Operation Date	Representative Plant / Characteristics
BWR/1	1960	**Dresden1** Initial commercial-size BWR
BWR/2	1969	**Oyster Creek** Plants purchased solely on economics Large direct cycle
BWR/3	1971	**Dresden 2** First jet pump application Improved Emergency Core Cooling System (ECCS): spray and flood capability
BWR/4	1972	**Vermont Yankee** Increased power density (20%)
BWR/5	1978	**Tokai 2** Improved ECCS Valve flow control
BWR/6	1981	**Kuosheng 1** Compact control room Solid-state nuclear system protection system
ABWR	1996	**Kashiwazaki-Kariwa 6** Reactor internal pumps Fine-motion control rod drives Advanced control room, digital and fibre optic technology Improved ECCS: high/low pressure flooders
ESBWR	not applicable	Natural circulation Passive ECCS
BWRX-300		LOCA mitigation Reactor building built from second generation steel-concrete composite modules

Table 27-2: System Design Evolution Summary

System	Function	Design Development
Nuclear Boiling System (NBS)	• Deliver steam from the RPV to the turbine Main Steam (MS) system. • Receive Feedwater (FW) from the Condensate and Feedwater Heating System (CFS) to the RPV. • Provide overpressure protection of the Reactor Coolant Pressure Boundary (RCPB). • Provide core support structure to enable the control rods to stop the nuclear reaction when driven into the core by their respective Hydraulic Control Units (HCUs). • Provide the flow path to enable the core coolant to keep the core cooled using natural circulation.	RGP - Improved LOCA mitigation through reduction of the number and size of penetrations below and above the core. RGP - Maintaining core water cover during LOCAs and FW flow interruptions.
Reactor Pressure Vessel (RPV) and Internals	• Major part of the RCPB, contains the path for reactor coolant flow through the fuel, and generates steam to drive the High Pressure (HP) and Low Pressure (LP) turbines.	OPEX/RGP - ABWR forced coolant circulation removed in favour of passive natural circulation which is not reliant on continuous supply of power. OPEX - Removal of reactor internal pump maintenance operator dose uptakes and potential mis-operation. OPEX - Reduction in LOCA risks due to removal of ABWR pump penetrations in the bottom of the reactor and external pumping loops in older BWR designs. OPEX - Improved material selection to reduce corrosion and improving pressure vessel reliability.
Reactor Pressure Vessel Isolation Valves (RIV)	• Limit the loss of coolant from large and medium pipe breaks.	OPEX/RGP - Removal of non-isolable pipework between the RPV and RIVs which were present on the ABWR, thus reducing LOCA risks. RGP - Passive fail-safe design during loss of power scenarios.
Control Rod Drive (CRD) System	• Reactivity control and shut down.	RGP - Diverse means of insertion of control rods into the reactor, i.e. electrical driven and hydraulic driven.

System	Function	Design Development
		OPEX for the control rod arrangement in BWRs which support continued application in the BWRX-300.
Isolation Condenser System (ICS)	• Heat removal to ultimate heat sink for protecting the reactor core when the main condenser is not available, and the RPV becomes isolated.	OPEX - Smaller volumes of water located at higher elevations with minimised pipework length. OPEX/RGP - Removal of major LOCA SRV sites. OPEX - Closed loop within containment depressurisation and cooling ICS function replacing ABWR suppression pool functions. RGP - Passive depressurisation and cooling function during accident scenarios.
Primary Containment System (PCS)	• Encloses the RPV and some of its related systems and components. • Provides radiation shielding, and • Provides a boundary for radioactive contamination released from the NBS or from portions of systems connected to the NBS inside the containment system.	OPEX - Dry containment which contains steam, water and fission products. RGP - Reduces the volume of potentially contaminated water within the PCS. RGP - PCS composite material which simplifies construction and provides a more robust structure.
Containment Inerting System (CIS)	• Provides dilution of hydrogen and oxygen gases that can be released in a post-accident condition by radiolytic decomposition of water and the released hydrogen from water and fuel cladding (zirconium) reaction during a severe accident condition. • Minimising long-term corrosion and degradation of the Steel-Plate Composite Containment Vessel (SCCV) and the contained components by limiting the exposure to oxygen during plant operating service life.	OPEX - ABWR had a similar proven CIS design which has benefitted the BWRX-300.

System	Function	Design Development
Passive Containment Cooling System (PCCS)	• Heat transfer from the containment to the equipment pool to maintain containment pressure and temperature within the design limits during accident conditions.	OPEX - Passive, dry containment cooling replaces wet, active spray in the ABWR. RGP - Redundant trains of equipment. OPEX/RGP - Removal of pumped spray sources, associated pipework and penetrations. OPEX - Remove the requirement for suppression pool source for containment spray. RGP - Reduced maintenance burden of active equipment and operator dose uptake over the ABWR.
Reactor Water Cleanup System (CUW)	• Provides blowdown-type cleanup flow for the RPV during reactor power operating mode. • Cleanup or filtration and ion removal is performed by the Condensate and Feed System. • Provides an overboarding flow path to the condenser hotwell or liquid radwaste directly from the RPV lower region to control water level during startup. • Suction piping can be used to reduce reactor temperature stratification with reverse flow from the Shutdown Cooling System.	RGP/OPEX – Reduction in LOCA risk from RPV penetrations further above core.
Shutdown Cooling System (SDC)	• Provides for decay heat removal when shutting down the plant for refuelling or maintenance. • Also used to reduce RPV inventory and can be used in conjunction with CUW piping to reduce RPV thermal stratification.	RGP – SDC is not safety system so leads to a reduction in the number of trains required, therefore reduce LOCA risk contribution. RGP/OPEX - Reduced maintenance burden and operator dose uptake over the ABWR.

System	Function	Design Development
Fuel Pool Cooling and Cleanup System (FPC)	• Provide continuous cooling of the water volume in the fuel pool to remove decay energy from spent fuel. • Provide replacement coolant inventory from a variety of sources to ensure spent fuel is kept cool and submerged throughout the life of the plant. • FPC includes demineralisation and particulate filtration to maintain coolant quality and to reduce general area dose. • FPC can be realigned to provide cooling and cleanup to the reactor cavity and equipment pools as necessary.	ABWR OPEX is being used to implement a proven FPC design as there have been no further practicable options to reduce risk further when compared with the ABWR.
Fuel Assembly and Core Configuration	• The core uses GNF2 fuel assemblies due to their low hydraulic resistance which benefits natural circulation. • Equal spacing between the control rod and non-control rod sides of the fuel bundle (N-lattice) provides a greater shutdown margin for variations in burnup histories imposed by load following.	OPEX - Well understood fuel with significant operational history.
Fuel handling and refuelling process	• Provides for safe handling and movement of new and spent fuel. • Provides for safe storage of spent fuel.	OPEX/RGP - Reduced fuel cask lift heights on export of the fuel from the Reactor Building (RB). OPEX - Commonality in previous BWR operations which leverage OPEX and RGP.

System	Function	Design Development
Plant Layout and Arrangement	• Provide protection and mitigation of internal and external hazard consequences and coupling. • The RPV, SCCV, and SSCs are in the below-grade portions of the RB which mitigates the effects of external events including aircraft impact, adverse weather, flooding, fires and earthquakes.	OPEX - Improved external hazard protection compared to the ABWR, in particular aircraft crash, due to major SSCs with nuclear functions being below grade. RGP - Improved external and internal human induced hazard protection due to the steel-plate composite modules with diaphragm plates (DP-SC) structure e.g. turbine missiles, vehicle impacts, dropped load, internal missiles. RGP - Minimisation of seismic category 1 structures to the RB. RGP - Adjacent RB structures (Turbine Building (TB), Control Building (CB) and Radwaste Building (RWB)) are designed such that structural failure will not degrade the functions provided within the RB. OPEX - Similar to ABWR principles where the occupants of the CB control room are protected from incapacitating injuries. OPEX/RGP - Improvements on environmental factors e.g. minimising volumes of concrete and steel, minimising excavation volumes, minimising backfill volumes, etc.

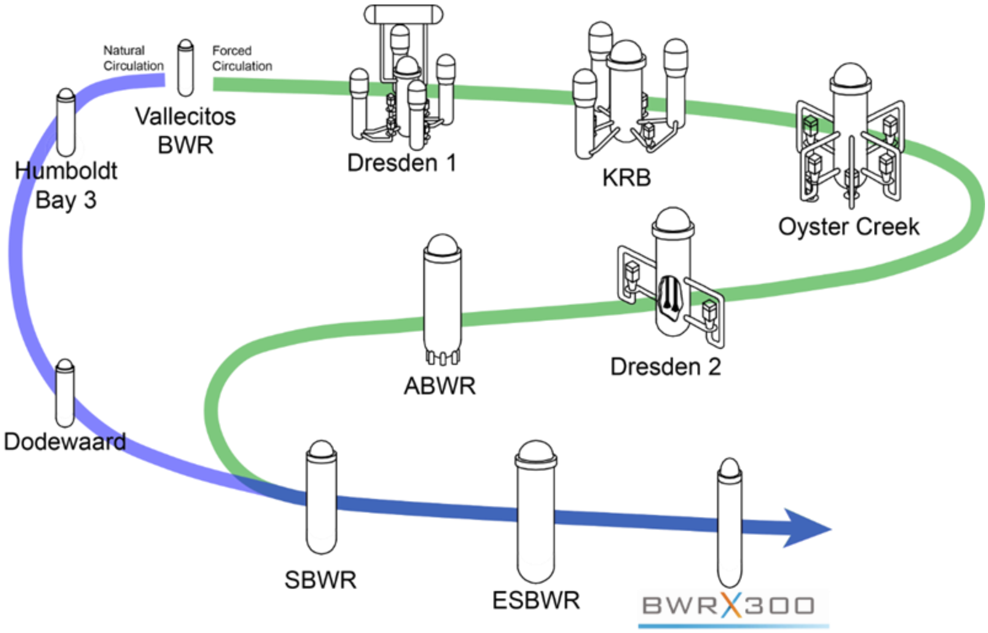

Figure 27-1: Boiling Water Reactor Design Evolution

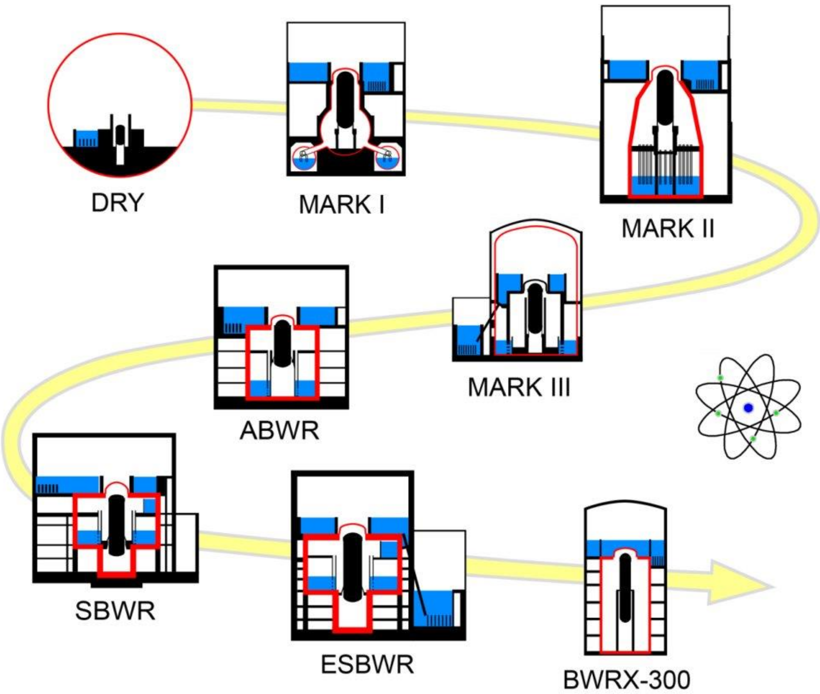

Figure 27-2: GE Hitachi Nuclear Energy Containment Designs

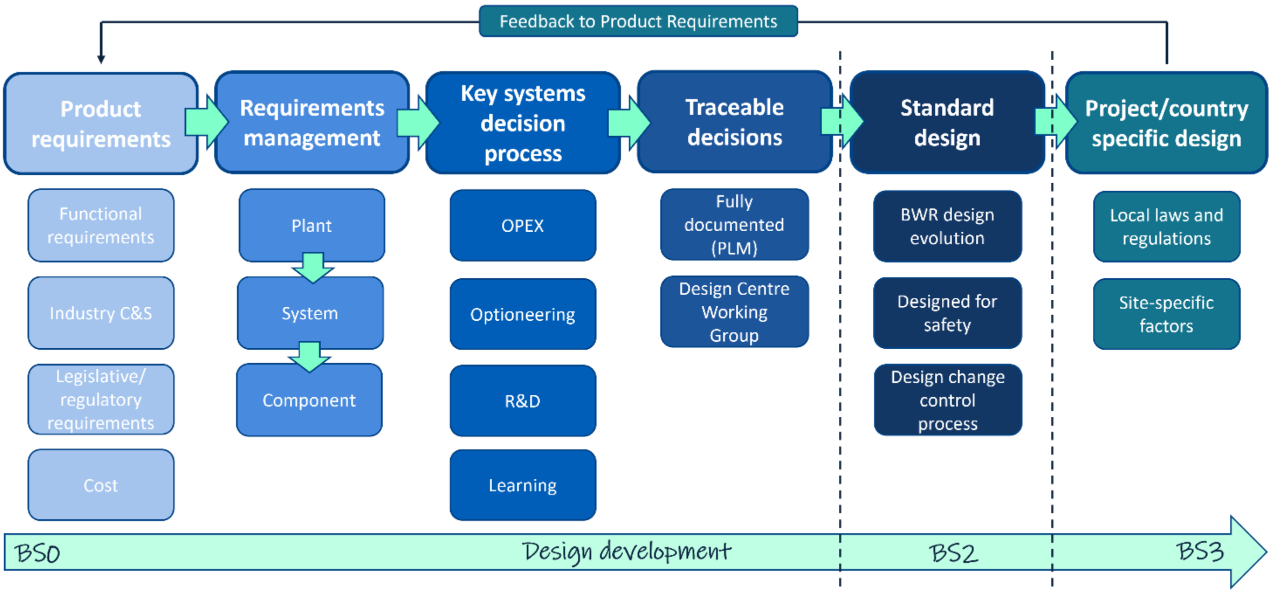

Figure 27-3: Illustrative pathway of the GEH Integrated Design Process

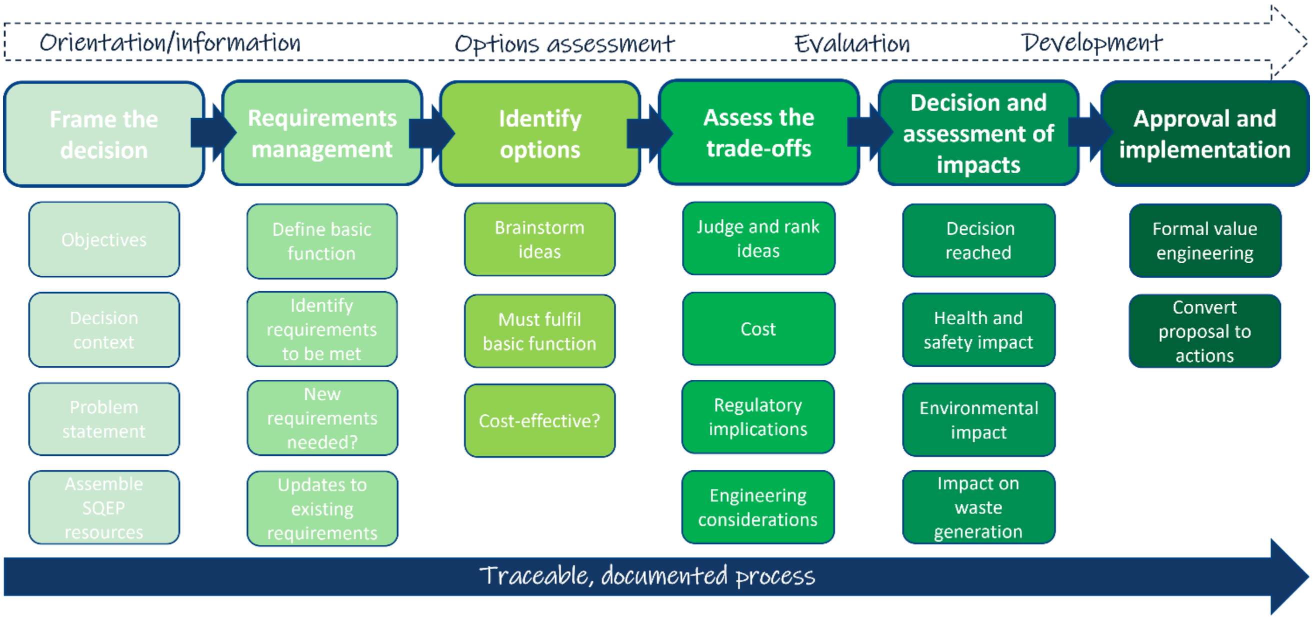

Figure 27-4: Key Systems Decision Process

27.5 References

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APPENDIX A CLAIMS, ARGUMENTS AND EVIDENCE

The ONR SAPs 2014 (Reference 27-15) identify ONR's expectation that a safety case should clearly set out the trail from safety claims, through arguments to evidence. The CAE approach can be explained as follows:

1. Claims (assertions) are statements that indicate why a facility is safe
2. Arguments (reasoning) explain the approaches to satisfying the claims
3. Evidence (facts) supports and forms the basis (justification) of the arguments

The GDA CAE structure is defined within the Safety Case Development Strategy (SCDS) (Reference 27-34) and is a logical breakdown of an overall claim that:

"The BWRX-300 is capable of being constructed, operated and decommissioned in accordance with the standards of environmental, safety, security and safeguard protection required in the UK".

This overall claim is broken down into Level 1 claims (Table A-1) relating to environment, safety, security, and safeguards, which are then broken down again into Level 2 area related sub-claims and then finally into Level 3 (chapter level) sub-claims.

The primary claim that Chapter 27 supports is:

2.4 Safety risks have been reduced as low as reasonably practicable.

The Level 3 sub-claims that this chapter demonstrates compliance against are identified within the SCDS (Reference 27-34) and are as follows:

2.4.1 Relevant Good Practice (RGP) has been taken into account across all disciplines.

2.4.2 Operational Experience (OPEX) and Learning from Experience (LfE) has been taken into account across all disciplines.

2.4.3 Optioneering (all reasonably practicable measures have been implemented to reduce risk)

2.4.4 Residual risks are compared with numerical targets and no event sequences are disproportionately dominant.

ALARP considerations inherently underpin all of the claims in the safety case but the focus for Chapter 27 is geared specifically to those above.

Table A-1: As Low As Reasonably Practicable Claims and Arguments

Chapter 27 Claim	Chapter 27 Argument	Sections and/or Reports that Evidence the Arguments
2.4 Safety risks have been reduced as low as reasonably practicable		
2.4.1 Relevant Good Practice (RGP) has been taken into account across all disciplines	RGP has been considered in the design of the BWRX-300 incorporated into the principles of hazard elimination and reduction of risk across the BWRX-300 design.	Sections 27.2.4.1 and 27.3.1 Phase 1 Step 1 Sections 27.2.4.2 and 27.3.2 Phase 1 Step 2
2.4.2 Operational Experience (OPEX) and Learning from Experience (LfE) has been taken into account across all disciplines	OPEX from previous BWR NPP has been incorporated into the BWRX-300 resulting in key design improvements. Ongoing review of OPEX and LfE will be undertaken.	Sections 27.2.4.1 and 27.3.1 Phase 1 Step 1 Sections 27.2.4.2 and 27.3.2 Phase 1 Step 2
2.4.3 Optioneering (all reasonably practicable measures have been implemented to reduce risk)	The BWRX-300 has been subject to GEH design control and design change management processes. Specific ALARP optioneering is yet to be implemented formally by GEH but the GEH processes contain the key aspects expected of optioneering aligned with UK expectation.	Section 27.2.5.1 Phase 2 Step 1
2.4.4 Residual risks are compared with numerical targets and no event sequences are disproportionately dominant	The risk insights are currently preliminary and based on analysis performed for the reference design plant. However, the risks show significant reduction compared with previous BWR designs and are expected to meet regulatory expectations.	Sections 27.2.4.3 and 27.3.3 Phase 1 Step 3

APPENDIX B FORWARD ACTION PLAN

Table B-1: As Low As Reasonably Practicable Evaluation Forward Action Plan Items

The Forward Action Plan (Table B-1) identifies ALARP related work.

Action ID	Finding	Forward Actions	Delivery Phase
PSR27-5	Current GEH procedures do not explicitly address ALARP. To meet UK expectations a demonstration and establishment of an ALARP process needs to be suitably incorporated into the GEH process.	Demonstrate ALARP evaluation process application in GDA Step 2 (by examples not comprehensive, including an ALARP/BAT/Security deconfliction example if possible)	Within GDA Step 2

APPENDIX C DESIGN PROCESS

The GEH design process includes many aspects that drive risk reduction in the design of the BWRX-300. An overview of the integrated design process employed for the BWRX-300 is shown in Figure 27-3.

Design begins by defining requirements, as documented in 005N9036, “BWRX-300 Requirements Management Plan” (Reference 27-9). Each plant, common system, or component requirement in the BWRX-300 must have a basis attribute, which provides the rationale and justification for that requirement. Traceable decisions are determinations made about the plant design used to meet a set of higher-level requirements. Retaining this information within the Engineering Lifecycle Management (ELM) software (a computer programme used for requirements management) allows identification of the flow down of inputs and design bases. This allows decision traceability when it comes to those decisions which have basis in ALARA. Section C.2 provides more details on the use of ALARA design criteria/requirements in BWRX-300 design.

Examples of the processes which support risk reduction in the BWRX-300 design are outlined in the sections below.

C.1 Key Systems Decision Process

GEH utilises a robust and traceable decision making process, 006N3139, “BWRX-300 Design Plan” (Reference 27-10). The process focusses on making and documenting key systems decisions, which are specifically those which involve issues with a significant cost, schedule or regulatory risk, or which could affect plant operation or stakeholder reputation. Figure 27-4 illustrates the components involved in the GEH key systems decision process. Design decisions and their basis are recorded in the GEH Confluence tool (a collaborative design process portal).

Decisions which have a significant impact on cost or scope are reviewed by the DCWG. The DCWG is a technically-oriented, multidisciplined team composed of representatives from prospective BWRX-300 owners and GEH. The DCWG focuses on resolving design and regulatory issues associated with BWRX-300 design that are common to all sites. Through a standardised design approach, the DCWG promotes safety and standardisation of BWRX-300 design through harmonisation of regulatory and engineering practices, where there may be a safety and design benefit.

Implementation of, and future adherence to, the GEH key systems decision process allows optioneering for design choices, which is a critical aspect of an ALARP demonstration. Examples of system decisions subject to this process where dose reduction and/or safety consideration occurred include:

- Adoption of the Zinc Addition System
  - During BWRX-300 design options for use of zinc addition were subject to the decision process regarding including of an injection system in the standard design. Despite increased engineering and hardware costs, depleted zinc oxide injection was incorporated into the standard BWRX-300 design to help ensure out of core dose rates are kept ALARA.
- Inclusion of RPV Ultimate Pressure Regulation
  - An additional means of pressure relief, referred to as UPR, was added to each ICS steam supply line in order to protect RPV integrity during a failure to scram event. This decision process need was triggered by PSA insights as to the dependency on ICS as the sole means for RPV depressurisation from full power. The final design choice was made based on balancing the need for

further overpressure mitigation (risk reduction) with simplicity and cost minimisation requirements.

- Use of corium shield in lower SCCV and RPV pedastal
    - Subjected to a decision process between use of a corium shield or BiMac (core catcher). A corium shield was selected to prevent contact between the molten core and the containment concrete/shield. The decision accounted for removing the unacceptable structural integrity and containment issues associated with having no shield or core catcher, whilst choosing a proportionate design option considering RGP and OPEX (a BiMac was deemed unnecessary based on lessons learned from Fukushima and given the smaller size of the BWRX-300 compared to the ESBWR).

C.1.1 Product Lifecycle Management System

The results of the key systems decisions are logged in the PLM as decision objects. The PLM acts as an interface for the recording of GEH-developed customer deliverables. Each BWRX-300 customer will have its own PLM structure consisting of both standard design documents and project-specific documents. Project-specific changes which are made relative to the Standard Design will be evaluated to determine whether they should be incorporated into the Standard Design (i.e. they should represent a change enacted for all future BWRX-300 projects) or form a new variant of the Standard Design.

C.2 ALARA Design Criteria and Optimisation

The requirement to reduce radiation exposures to ALARA is incorporated into 006N5081, “BWRX-300 As Low As Reasonably Achievable Design Criteria for Standard Design,” (Reference 27-11). Within GEH, this consideration translates into a series of criteria, proposals, and activities, with the aim of providing design requirements which act as a basis for the systematic application of ALARA throughout design. Ultimately, adherence to these requirements is intended to reduce occupational and public exposures to ALARA throughout the plant lifecycle.

GEH have established 17 ALARA objectives, Section 5.0 of 006N5081 (Reference 27-11), which have bases in the IAEA, US NRC and CNSC regulatory requirements and recommendations. These objectives provide the justification for the BWRX-300 design considerations/requirements/criteria with respect to ALARA, listed in Section 5 of 006N5081 (Reference 27-11). The expectation is that the ALARA objectives are subject to revisions as needed during the design process. This affords GEH the opportunity to consider all possible actions involving the radiation sources, radiation devices and/or prescribed equipment, and the way workers operate with or near the radiation sources, radiation devices and/or prescribed equipment, and to regularly review information on new technologies and procedures that may enhance radiation protection design.

Detailed descriptions of the radiation protection design features in the BWRX-300 are given in Section 3.0 of 006N5081 (Reference 27-11). These features are already implemented in the BWRX-300 design and thus are evidence of how the GEH ALARA objectives have been acted on during the design process, representing an approach implicitly compatible with the ALARP philosophy in the minimising of risks related to radiation. Future integration of the ALARA objectives is a consequence of continued adherence to the ALARA design process.

C.2.1 ALARA Optimisation Process

The SD-03-J004, “BWRX-300 Standard Design Optimisation to Keep Radiation Exposures As Low As Reasonably Achievable” (Reference 27-35) work instruction establishes the process to optimise radiation protection design of the BWRX-300 Standard Design to ensure doses to persons are ALARA. Given the BWRX-300 design is ongoing, the approach to fulfilling ALARA must be flexible and continuously optimised as design progresses. The ALARA optimisation process is used for reviewing the impact on ALARA from, for example, proposed design changes, periodic ALARA reviews, cost reduction initiatives, or any other radiation protection design decision with high safety significance or high cost. There are three categories of 'ALARA decision levels' for design decisions:

- Level 1: Design choices associated with such high risk that no such activities are tolerable unless the risk can be reduced to below a certain threshold. For exmaple, something that affects the Fundamental Safety Functions – escalate to Engineering Change Control.
- Level 2: Design decisions associated with tolerable risk provided that the risk has been reduced to ALARA. Must demonstrate that expenditures for risk mitigation are at a point where any further spending is disproportionate relative to the incremental risk reduction benefits.
- Level 3: Design decisions associated with low risk such that the risk is deemed by all stakeholders to be broadly acceptable. Generally do not require cost/benefit analysis since the bases for decisions are well known engineering good practices.

C.2.2 ALARA Design Process

The systematic approach to ALARA implementation for the BWRX-300 encompasses a number of multi-pass design reviews, technical assessments, and administrative reviews. ALARA objectives and design requirements are carefully considered in each step of the design process, and compliance with the requirements is enforced by adherence to GEH's design processes and requirements management.

The ELM software acts to efficiently store, organise, and manage requirements or design basis information, including those with a foundation in ALARA. Major systems in the BWRX-300 are assigned an identifier in the project Main Parts List (MPL) within the ELM tool.

The ALARA design process is as follows:

1. The ALARA design team reviews the design of an MPL periodically before a design change is implemented and qualitatively assesses it against the ALARA objectives. If the main part or design change meets the objectives collectively, no further actions are needed.
2. If the MPL or design change fails to meet any ALARA objective or set of objectives, the ALARA design team develops options to bring the main part or design change into alignment with the objectives.
3. The ALARA design team conducts a design review of the MPL or design change with the MPL stakeholders to discuss the options to bring it into alignment with ALARA objectives. Consideration is given to any new options identified in the design review.
4. If the design review identifies a solution that is not associated with significant cost or significant impact on the safety of the design, then determine the best way to ensure it is implemented. This is typically implemented through a design change or the addition of, or adjustment to, an ALARA requirement.
5. If the design review identifies a solution associated with high cost or safety impact, escalate the decision to the formal decision process and involve the cost team, as necessary.
6. The ALARA design team reviews the impacts of the decision made in the formal decision process. If the decision results in a significant increase in dose or risk to

workers or the public during any mode of plant operation or in an accident, then the decision will be reopened and escalated to the wider design team.

7. Repeat the process until a reasonable compromise is identified and implemented in the design, as necessary.

ALARA design decisions enter the key systems decision process (described in Section C.1 above) should they be found to have an associated high cost or safety impact. The ALARA design requirements are allocated to the various MPLs to ensure that they are incorporated into the plant design.

C.3 Technical Design Review

Technical Design Reviews occur at the key reactor design stages (BL 1 through to BL 3) and incorporate multi-disciplinary checks to determine system readiness and aid risk management. A description of the Technical Review Process can be found in CP-03-100-G330, “Technical Reviews” (Reference 27-36).

As described the in CP-03-100-G330 (Reference 27-36), the objectives of the GEH Technical Review Process include the following, with respect to safety:

- Ensuring product requirements (including functional, operational, regulatory, interface, and safety requirements) are properly identified and understood.
- Assessing design status, open design inputs, and capability (including robustness and design optimisation) versus product and design practice requirements to identify gaps and/or risks.
- Evaluating mitigation actions taken to address previously identified risk (including those identified in Condition Reports) and determine if current mitigation plans are still adequate
- Identifying any new risk, including First-of-a-Kind and First-in-a-While items,and ensuring appropriate resolution or mitigation actions are planned and resourced appropriately

By incorporating these objectives, Technical Reviews act as a means of communicating technical challenges within wider GEH leadership, including those risks pertinent to safety. The process also provides an audit trail for technical, risk-informed decision making, including Technical Review Reports and recorded actions and risk insights; this is an important aspect of a retrospective ALARP justification.