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

The purpose of this chapter is to describe the As Low As Reasonably Practicable (ALARP) evaluation of the BWRX-300. It supports the demonstration of the fundamental objective 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 United Kingdom (UK). A key component of this demonstration in the UK is that risks to operators and members of the public have been reduced to ALARP.

This chapter presents how the ALARP principle is intended to be incorporated into the justification of the safety of the BWRX-300 through a three-phase approach utilising established GE Hitachi Nuclear Energy (GEH) processes for design control and modification. It is anticipated that only the first phase will be addressed in the scope of Generic Design Assessment (GDA). The first phase is a holistic review of the status of the design against UK expectation and a justification that Relevant Good Practice (RGP) has been applied and informed by relevant operational experience.

The chapter describes how the BWRX-300 design has taken advantage of the evolution of Boiling Water Reactor (BWR) design to incorporate significant simplification of Structures, Systems, and Components (SSCs) promoting the benefit of passive and inherent safety systems. As the tenth generation of BWR, the BWRX-300 leans on significant relevant Operational Experience (OPEX) to build confidence in the design concepts to ensure safe deployment and operation through the lifecycle of a BWRX-300 plant construction, commissioning, operation, decommissioning, and end of life. The design simplifications introduced since the Advanced Boiling Water Reactor (ABWR) demonstrate a commitment to delivering the ALARP principle by reducing risk and eliminating hazards in an ongoing process.

GEH intends to complete GDA Steps 1 and 2 without additional design changes beyond the Design Reference, 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.

The good practices established in GEH, coupled with the evidence of application presented in the design evolution of the BWRX-300 demonstrate a clear commitment to the ALARP principle aligned with UK expectations.

These outputs will be further refined in GDA Step 2, and an implementation plan established to ensure the ALARP principle is embedded in the BWRX-300 design development.

The chapter presents a level of detail commensurate with a 2 Step GDA. This chapter is a specific UK context chapter so does not have a direct correlation to the structure and contents of SSG-61.

Claims and arguments relevant to GDA step 2 objectives and scope are summarised in Appendix A. Appendix B provides a Forward Action Plan, which includes future work commitments and recommendations for future work where ‘gaps’ to GDA expectations have been identified.

ACRONYMS AND ABBREVIATIONS

Acronym	Explanation
ABWR	Advanced Boiling Water Reactor
ACoPs	Approved Codes of Practice
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
AOO	Anticipated Operator Occurrence
BAT	Best Available Technique
BIS	Boron Injection System
BL	Baseline
BoP	Balance of Plant
BWR	Boiling Water Reactor
C&S	Codes and Standards
CB	Control Building
CFS	Condensate and Feedwater Heating System
CHS	Conventional Health and Safety
CIS	Containment Inerting System
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
DEC	Design Extension Conditions
DL	Defence Line
ERB	Engineering Review Board
ESBWR	Economic Simplified Boiling Water Reactor
FMCRD	Fine Motion Control Rod Drive
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
HX	Heat Exchanger
IAEA	International Atomic Energy Agency
IC	Isolation Condenser

Acronym	Explanation
ICS	Isolation Condenser System
IEC	International Electrotechnical Commission
LC	Licence Condition
LfE	Learning from Experience
LOCA	Loss-of-Coolant Accident
LOOP	Loss-of-Offsite Power
LP	Low Pressure
MCR	Main Control Room
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
PSA	Probabilistic Safety Analysis
PSR	Preliminary Safety Report
PWR	Pressurized Water Reactor
RB	Reactor Building
RCPB	Reactor Coolant Pressure Boundary
RGP	Relevant Good Practice
RI	Regulatory Issue
RIV	Reactor Pressure Vessel Isolation Valves
RO	Regulatory Observation
RPV	Reactor Pressure Vessel
RQ	Regulatory Query
RWB	Radwaste Building
SAP	Safety Assessment Principle
SBWR	Simplified Boiling Water Reactor
SCA	Safety and Control Area
SCCV	Steel-Plate Composite Containment Vessel
SDC	Shutdown Cooling
SFAIRP	So Far As Is Reasonably Practicable
SSCs	Structures, Systems, and Components
TAG	Technical Assessment Guide
TB	Turbine Building

Acronym	Explanation
UK	United Kingdom
USNRC	US Nuclear Regulatory Commission
WENRA	Western European Nuclear Regulators Association

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Revision #	Section Modified	Revision Summary
A	All	Initial Issuance

27. ALARP EVALUATION

The fundamental objective that will be demonstrated through the Generic Design Assessment (GDA), is that the proposed BWRX-300 could be constructed, operated and decommissioned in accordance with the standards of environmental, safety, security and safeguard protection required in the UK. A key component of this demonstration is that risks to operators and members of the public have been reduced to ALARP. Following on from GDA, to be granted a nuclear site licence to deploy the BWRX-300 in the UK, a demonstration that risks are reduced to ALARP would be a legal requirement.

Application of design principles in development of BWRX-300 drives the reduction in risk and elimination of hazards from the design. Industry OPEX and learning from experience also drives improvements to design in application of Relevant Good Practice (RGP) such as in reducing operational exposure through improved plant layout and task design for operator tasks.

This chapter presents the ALARP evaluation of the BWRX-300 and will demonstrate that the design can reduce holistic risk as far as reasonably practicable to operators and members of the public.

The maturity of the ALARP evaluation for a two-step GDA is proportionate to the status of the BWRX-300 design and safety analysis underpinning that design.

In this chapter, ‘holistic' ALARP is defined as the consideration of all contributors to the overall ALARP evaluation of the BWRX-300 design. The ALARP principle relates specifically to reducing risk of harm to potential exposure groups i.e., operators and members of public.

Consideration of the overall balance of the ALARP evaluation with the principle of minimising environmental impact by application of Best Available Technique (BAT) and application of secure by design, and safeguards by design principles are discussed in NEDC-34162P, “BWRX-300 UK GDA BWRX-300 UK GDA Safety, Security, Safeguards and Environment Summary,” (Reference 27-1).

The chapter will:

- Explain the holistic ALARP evaluation strategy of BWRX-300
- Summarise ALARP demonstration results within each technical topic area
- Describe the ALARP documentation hierarchy
- Set out the forward action plan for the ALARP evaluation of the BWRX-300

27.1 Scope of As Low As Reasonably Practicable Evaluation

The ALARP evaluation of the BWRX-300 requires consideration of the overall risks rather than just the risks from the individual system design. Therefore, the holistic ALARP evaluation of BWRX-300 is based on the overall design and the ALARP evaluation for each Preliminary Safety Report (PSR) chapter (i.e., for each technical topic). By demonstrating that a suitable ALARP process has been established and that the organisation is capable of implementing the process with examples of this: a holistic ALARP position that is proportionate for the design maturity in GDA can be justified.

The scope of the BWRX-300 ALARP evaluation for GDA is limited to the scope of the SSCs and the associated scope of analysis of the technical assessment topics as defined in the GDA scope for the BWRX-300 (Reference 27-1).

The SSCs in scope are reviewed to identify potential shortfall against relevant good practice and consideration of operational experience. The safety analysis of the design identifies aspects of the design which may have dose and or risk profiles which require further ALARP evaluation and justification and potentially a modification to reduce risk further.

SSCs within the scope of GDA have different design maturity and the associated analysis are also more mature for some parts of the design. This means that the ALARP evaluation of BWRX-300 is more developed for some aspects of the design than others.

The proposed approach to demonstrating ALARP evaluation for BWRX-300 is broadly split into three phases which is then linked to design development in an iterative process:

- Phase 1: Holistic review of BWRX-300
- Phase 2: Specific review of potential improvements
- Phase 3: Holistic evaluation of ALARP position

Following Phase 3, the BWRX-300 Design Reference is re-baselined and the ALARP evaluation iterates back to Phase 1. This iterative process allows the ALARP principle to be embedded in the design development process and realise benefits earlier rather than making changes to constructed or assembled SSCs which takes longer, is more expensive, and more troublesome.

It is not anticipated or claimed that a ‘final’ ALARP position will be reached in GDA. It is intended that the first iteration of Phase 1 will be completed in the two-step GDA. It is not anticipated that detailed work will be undertaken in Phase 2 during GDA but forward actions will be identified for post-GDA licensing. A confidence statement and forward plan can be provided for Phase 3 for future iteration of the ALARP process with design development phases.

A high-level summary of why there is confidence that a holistic ALARP demonstration of the BWRX-300 can then be articulated.

For this version of the ALARP evaluation, a description of the ALARP process that will be applied to BWRX-300, a description of the design evolution will be set out, a description of potential shortfalls identified so far as part of Phase 1 works, and forward actions identified to be undertaken in GDA Step 2.

Environment and waste management related potential improvements and justification of design require a BAT demonstration. Where these are considered, there is a need to balance ALARP and BAT principles in the optioneering process. Identification of potential implications for environmental impact should be considered for all modifications using appropriate criteria.

Security and safeguards related implications must be considered as part of the ALARP demonstration to ensure that impacts to security and safeguards are identified and well managed.

Each topic area of BWRX-300 will perform a specific ALARP assessment during design activities, including identification and preliminary analysis of RGP and OPEX studies that will be summarized in individual PSR chapters where applicable.

As a summary, Chapter 27 together with the safety case documentation provides the holistic view and comprehensive information on the ALARP evaluation of BWRX-300 for its current maturity. It is expected that BWRX-300 systems and hence PSR chapter ALARP demonstrations will develop at different pace reflecting the maturity of each topic area.

27.2 Objective

The fundamental Objective to be demonstrated through the GDA process is:

> 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.

Specifically in this chapter, the demonstration of an ALARP evaluation supports the fundamental objective by underpinning the design and analysis to justify the BWRX-300 as safe aligned with the UK's health and safety legislation. The interface of ALARP and BAT support the demonstration of minimising environmental impact of the BWRX-300.

The objective for this chapter for GDA step 1 is: to demonstrate that the BWRX-300 has incorporated ALARP principles in the development of the design to reduce risks to ALARP. The chapter will also demonstrate the pathway to demonstrating an ALARP evaluation that can meet UK expectations to provide confidence that an ALARP position for the BWRX-300 can be justified in the future.

Reducing risk to ALARP is a 'live' consideration, so the ALARP evaluation is expected to mature and revalidate as the design matures. An ALARP position will only be achieved in phases, and the ALARP position reached for BWRX-300 GDA will be supplemented by an implementation plan to be carried into a potential site licensing phase to further assess the site-specific aspects of construction, commissioning, operation and decommissioning for example.

27.3 Document Route Map

Holistic ALARP demonstration interfaces with all topic areas as it summarises ALARP information from all sources in the PSR.

At this stage the key tier 2 supporting documents are:

- BWRX-300 Design Evolution
- GDA Scope
- Topic area RGP and OPEX reviews

27.4 UK Regulatory Context

The nuclear site licence conditions state that a safety case shall "justify / demonstrate safety." In the UK justification of safety is based on the concept of reducing risk to ALARP.

In simple terms, the concept of ALARP is a requirement to take all measures to reduce risk where doing so is reasonably practicable. In most cases this is not done through an explicit comparison of costs and benefits, but rather by applying established RGP and standards. The development of RGP and standards includes ALARP considerations so in many cases meeting them is sufficient if a demonstration can be made that further improvement is disproportionate to the safety benefit. In other cases, either where standards and RGP are less evident or not fully applicable, the onus is to implement measures to the point where the costs of any 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).

27.4.1 Legislation

The legislative basis of ALARP in the UK is derived from the "Health and Safety at Work etc. Act 1974," (Reference 27-3). The Act places duties on employers to ensure the health, safety and welfare of their employees and to conduct their operations so that persons not in their employment are not exposed to risks to their health and safety. The employer is required to ensure that these duties are met So Far As Is Reasonably Practicable (SFAIRP), which is the basic legal requirement that each employer needs to conform to. In Office for Nuclear Regulation (ONR) guidance, the term ALARP is equivalent to SFAIRP.

27.4.2 Interfacing Requirements

In addition to the concept of ALARP in nuclear safety, European Union and UK regulations require that nuclear operators must maintain all radioactive discharges to the environment at a level which is As Low As Reasonably Achievable (ALARA). This includes consideration of all relevant factors such as protection of the environment and other social and economic impacts.

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 27-4). 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 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.

27.4.3 Guidance

The ONR's "Safety Assessment Principles for Nuclear Facilities," (Reference 27-5), place the expectation that the safety case should provide an analysis of normal operation, potential faults and accidents, and of the engineering design and operations, and demonstrate the risks from all these perspectives have been reduced to ALARP. The ALARP approach should include consideration of the following four aspects:

- Demonstration that international reactor OPEX has been taken into account in the overall design philosophy and in specific system designs.

- Demonstration that RGP has been applied, including codes and standards comparison/justification.
- Identification and evaluation of options (Optioneering).
- 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.

Following on from these is then the implementation of reasonably practicable improvements into the updated design reference.

27.5 Holistic As Low As Reasonably Practicable Evaluation Method

The approach to demonstrating the ALARP justification for BWRX-300 is shown in Figure 27-1, and is broadly split into three phases which is then linked to design development in an iterative process:

- Phase 1: Holistic review of BWRX-300
- Phase 2: Specific review of potential improvements
- Phase 3: Holistic evaluation of ALARP position

After this, the BWRX-300 Design Reference is re-baselined, and the process iterated.

A summary of the method for holistic ALARP evaluation is presented in this chapter that intends to set out a pathway for the ALARP justification of the BWRX-300 to be demonstrated.

This method will be used to prepare the specific evidence and narrative to meet UK expectations building on the established design principles and processes applied by GEH in later steps of GDA and licensing in the UK.

The intention is that the method's application in GEH's existing design process CP-03-100, "Design Control," (Reference 27-6) and CP-03-113, "Engineering Change Control," (Reference 27-7), promotes challenge and ensures risks are reduced ALARP. An overview of the individual steps for each phase are described below.

27.5.1 Phase 1

The objective of Phase 1 is to provide the foundation of the ALARP evaluation and then to identify potential shortfalls in demonstrating an ALARP justification, which are analysed to determine if potential improvements could be implemented.

Phase 1 looks at the design of the whole plant and comprises Steps 1, 2, 3, and 4 which are activities designed to identify the potential shortfalls and improvements.

It is intended that Phase 1 would be completed for all systems in scope during GDA to identify potential improvements and gaps against RGP.

Step 1: BWRX-300 Design Evolution Review

The review of the evolution of the BWRX-300 design is summarised to demonstrate that safety improvements have been incorporated into the design to eliminate hazards and further reduce risks in comparison with previous generations of BWR technology, and that relevant national and international OPEX has been considered. The design evolution review of the BWRX-300 is presented in NEDC-34137P, "BWRX-300 UK GDA BWRX-300 Design Evolution," (Reference 27-8), and summarized in this chapter in Sections 27.6 and 27.7.

The intention of this is to provide evidence that the evolutionary modifications have been reducing risk and the modifications have brought the design closer to a nuclear safety and risk position which can be demonstrated as ALARP.

This means any major modifications through design evolution that have contributed to or to specifically enhance safety are described. The process starts with the evolution of BWR technology (Section 27.6) and identifies major modifications (Section 27.7) with the following subsequent design evolution including the ABWR previously assessed in a UK GDA and the more recent Simplified Boiling Water Reactor (SBWR) and Economic Simplified Boiling Water Reactor (ESBWR) leading to the BWRX-300.

This step is only undertaken once to inform the baseline of the ALARP evaluation, the following steps will be part of the iterative process, however.

Step 2: Systematic Review of Design Against RGP & OPEX

A fundamental part of the ALARP evaluation requires a comparison with RGP and OPEX from other relevant facilities in the nuclear industry and any other relevant industries. The ALARP evaluation needs to ensure that all applicable RGP has been identified and that the design is assessed against this RGP. In the UK, the RP must establish and justify its choices of RGP. Therefore, consideration of appropriate RGP forms an early stage of design review and informs the identification of the risk reduction measures which should be considered and assessment of what is reasonably practicable to implement in the design.

RGP in this context should comprise practices that have been approved for use in nuclear reactor plant designs by recognised authoritative bodies, i.e., ONR in the UK, and are considered relevant and appropriate to the BWRX-300 design. Design solutions are not necessarily considered RGP simply on the premise that they have been implemented by other Licensees, GDA Requesting Parties, or Responsible Designers (they may be considered as relevant OPEX but is not necessarily RGP). In some topic areas, for example reactor chemistry, evidence that the design is based on OPEX shall provide a means to identify potential improvements.

It must be borne in mind that RGP and OPEX for other technologies and reactor designs may not be applicable to the BWRX-300, where nuclear safety is provided by the inherent technical characteristics of the reactor and its passive safety features. Similarly, safety features arising from RGP for other technologies or reactor designs may not provide risk reduction for the BWRX-300. In all cases, RGP must be justified to be applicable to the BWRX-300, and safety features arising from applicable RGP must be subject to ALARP challenge when the provide risk reductions.

The RGP for each topic shall be identified and used as a basis for undertaking a review of the holistic design to identify potential improvements. Sources of RGP include:

- Approved Codes of Practice (ACoPs).
- International Atomic Energy Agency (IAEA) Safety Standards.
- Recognised design codes and standards (e.g., British Standards, Euro Codes).
- Western European Nuclear Regulators Association (WENRA) Safety Reference Levels for reactors, decommissioning, and the storage of radioactive waste and spent fuel.
- Safety Assessment Principles (SAPs) and Technical Assessment Guides (TAGs) of ONR.

In general, the review shall be undertaken primarily against codes and standards applied and acknowledged in the UK, engineering design principles, and ACoPs, while noting that some of the unique features of the BWRX-300 may be inconsistent with existing RGP. In such cases the design standards that GEH has employed may represent RGP for this technology where demonstrated.

In addition, due consideration can be taken of input from the UK Regulators (e.g., through the formal correspondence of Regulatory Queries (RQs), Regulatory Observations (ROs), Regulatory Issues (RIs)) as part of the process of identifying potential improvements.

Additionally, ROs, RIs and GDA Issues from previous GDAs can be considered. The specific technical issues may not be directly applicable to BWRX-300 but the reasons and rationales leading to their creation provide a source of lessons learnt.

Step 3: Risk Assessment Insights

The risk analysis topics for 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.

The insights from risk assessment could inform the design, including any aspects of the design where the contribution to risk is elevated and could therefore be a candidate for improvement via changes to the design.

Commensurate with the current stage of GDA, and the production of a PSR, the fault schedule is in an early stage of development. The GDA gives a snapshot at a level of design maturity to support the understanding of balance of risk for incorporation into the ALARP process and identifying potential areas for improvements. Following on from a GDA phase it is expected that a complete set of risk insights will eventually be subject to the ALARP process and provide sufficient underpinning to a final ALARP evaluation of BWRX-300 at later a later licensing stage.

Step 4: Collate the Potential Shortfalls

The potential shortfall identified in Step 2 and 3 shall be compiled into a register. Each item shall be prioritised using a graded approach to establish a priority list of potential shortfalls for consideration within the scope and timeframe of GDA and later project stages. Initial prioritisation should consider its potential safety significance (if this is a gap) or safety benefit (if this is identified as a safety shortfall) as well as the degree of uncertainty in terms of its complexity and/or feasibility. The prioritisation may require and/or benefit from risk assessment insights.

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 judgement or form a requirement in 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).

27.5.2 Phase 2

The objective of Phase 2 is to undertake an optioneering and decision-making process that considers the ALARP principle when addressing any identified shortfall or potential improvement to determine if a potential modification is required to be made to the design. A proportionate assessment and optioneering process shall be undertaken of each gap, identifying potential improvements that could be implemented, assessing the impact to interfacing systems and overall design, weighed against appropriate criteria, and applying engineering judgement to select option(s) proportionate to the risk level.

It is not anticipated that detailed work will be undertaken in Phase 2 during GDA but forward actions will be identified for post-GDA licensing.

A robust and traceable decision-making process is established within GEH processes. GEH Common Procedure CP-03-100 (Reference 27-6) codifies the GEH design change process. During the design change process, questions, deviations, requests, among other things, may be identified that could potentially affect the design and require a design change for example potential shortfalls identified from Phase 1.

As described in GEH Common Procedure CP-03-113 (Reference 27-7), engineering change control is implemented and this procedure 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 organizations for those interfaces. The procedure ensures accurate and traceable records of the change are maintained.

Step 5: Assessment of Potential Improvements

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

If no areas for potential improvements are identified for a topic area or if none is claimed to exist, an adequate level of argument and / or justification must be provided with reference to the overall BWRX-300 design intent and understanding why the design is the way it is and maintaining it by exercising engineering judgement. The intention is to provide an auditable trail.

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 generation and evaluation of 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 27-6 and 27-7) to ensure familiarity with key stakeholders within GEH. These processes follow standard practice across the nuclear industry to drive safety improvements and reducing the risk profile of designs.

When performing the optioneering process, the objective of balanced design should always be kept in mind and multiple factors such as interfaces with conventional safety, environmental impact interpreted by BAT, and security etc. should be considered to ensure the design intent is maintained.

The following steps can be followed when performing the optioneering process:

A. Define and characterise the specific potential improvement where the fundamental issue, including the problem statement, safety significance and potential implications (i.e., risk profile), 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 where a broad range of options should be considered, by applying the defence in depth principle, to take account of multiple factors to prevent, protect and mitigate the risk identified in the previous step.

C. Assess the options (their benefits and dis-benefits) where each option should be evaluated systematically and where their relative merits should be identified. It is possible that this step may require a number of iterations as each option may require further information to support judgements made.

For some potential improvements, the evaluation of options is less suited to standard qualitative techniques. In some cases, further information is required, therefore the optioneering can be approached in stages.

After the assessments of all options, the relevant benefits and dis-benefits of each option shall be presented. If options have been considered and screened out, an explanation should be provided with appropriate justification.

The need to keep adequate records to justify safety is a key part of the IAEA requirements for management arrangements and are the subject of ONR Licence Condition (LC) 6 and Health and Safety at Work Act legislation (Reference 27-3). 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.

Step 6: Interface with Best Available Technique/Security & Safeguards

The application of BAT is the subject of a separate methodology, as described in NEDC-34223P, "BWRX-300 UK GDA Preliminary Environmental Report Ch. 6: Demonstration of BAT Approach," (Reference 27-9). 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, it is recognised that, in some instances, the requirements of ALARP and BAT may 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 ALARP argument must be made for the overall design, including the assessment of all radiological, environmental and conventional hazards, and wider considerations about the operability and security of the facility.

Where tension between BAT and ALARP arise, the ALARP assessment must ensure that an appropriate overall balance is achieved in regard to their management. This can be achieved through application of the correct resources and expertise in the relevant decision-making processes. This will ensure that the requirements of BAT and ALARP are considered in each review and allow a fully justified argument to be developed for the ultimate BAT and ALARP position.

To achieve a balanced design there must also be an adequate consideration of the effects of risk reduction measures on the security of the facility and the principle of security and safeguards by design. Deconfliction of safety and security and safeguards considerations requires a similar approach of identification of improvements and inclusion of suitable criteria and expertise in their assessment.

For example, where environmental impacts are a relevant criterion, 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 review the impact that this change will have on the preferred option.

This approach will help ensure the correct balance of risks is achieved in the final design and the approach is supported by a robust justification of the decisions made.

Step 7: Decision Making

The overall decision making and governance processes (Reference 27-7) to control the design must ensure adequate oversight of changes and to ensure that decisions are made on an informed basis. The ALARP review should consider all relevant factors to allow selection of the ALARP option, and for this decision to be 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, opinions of relevant subject matter experts, and producing a record of the basis for the decision taken.

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. The ERB 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, 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 at hand.

As discussed above, the cost of implementing a safety feature is not purely financial and consideration must be given to the effects of proposed design changes on environmental and conventional safety risks, and facility security.

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 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 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 BWRX-300 design through harmonization of regulatory and engineering practices where there may be a safety and design benefit.

Step 8: As Low As Reasonably Practicable Position Justified for Potential Improvement

For the specific potential improvement being addressed, once the process of optioneering of all reasonably practicable options has been completed, it is considered that the ALARP position for the specific potential improvement has been reached.

Once optioneering is complete, the benefit to the overall risk should be included in the safety case with the commitment tracked to completion and in compliance with the configuration control arrangements.

27.5.3 Phase 3

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 BWRX-300 GDA it is anticipated that Phase 1 will be completed but no detailed work will be undertaken in Phase 2 with only forward actions identified for post-GDA licensing. For Phase 3, it is intended that a confidence statement for the ALARP position can be made, and forward plan provided for future iteration of the ALARP process with design development phases during GDA and for later project stages.

A high-level summary of why there is confidence that a holistic ALARP evaluation of the BWRX-300 can then be achieved.

Step 9: Holistic Review of All Implemented Improvements

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 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.

Step 10: Implementation of Reasonably Practicable Option

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 27-6 and 27-7). Consideration must be given to interaction of options where they interact and interface 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 through the lifetime of the plant.

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

Step 11: Assessment of New As Low As Reasonably Practicable Position

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

An assessment of the design should consider that the balance of risk is adequately shared across the plant with no single risk dominating and leading to clear risk vulnerabilities.

At this stage a global view of the design is considered as evaluated that risk is balanced and the risk level of the BWRX-300 is demonstrated to be tolerable and ALARP.

Step 12: UK BWRX-300 As Low As Reasonably Practicable Position Reached

Where there are no further reasonably practicable options to implement, and no further identified areas for potential improvement, the design is considered as optimised, reflecting UK expectations, and the safety risks from the BWRX-300 design are considered ALARP.

At the end of this step, the decisions reached following this ALARP methodology shall be justified, documented and summarised in the safety case suitable for the relative maturity of the design.

It is recognized that the attainment of a truly ALARP position will only be achieved in phases, and the ALARP position reached for BWRX-300 may need to be supplemented by an implementation plan to be carried out over the site licensing phase to refine the site-specific aspects of construction, commissioning, operation and decommissioning as well as consideration of the full scope of risk insights.

27.6 Summary of BWRX-300 Design Evolution

A review of the evolution of the BWRX-300 design has been produced (Reference 27-8) which demonstrates that safety improvements and relevant OPEX have been continuously incorporated into the design.

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 or to specifically enhance safety are described in detail in Reference 27-8. The process starts with the evolution of BWR technology and identifies major modifications with the following subsequent design evolution including the ABWR previously assessed in a UK GDA and the more recent SBWR and ESBWR designs leading to the BWRX-300.

The BWRX-300 is GEH's tenth generation BWR design and represents GEH's simplest yet BWR. The BWRX-300 is an evolution of the U.S. 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.

Key design developments of the BWRX-300, which contribute to reducing risks ALARP, include:

- The adoption of many proven in-service BWR technologies, e.g., fuel, core design and the steam separator system design.
- Inherent and passive safety design over historic active design, with a simplified design supporting increased reliability e.g., reduction in the number of components and pipework lengths.
- Large capacity isolation condensers that provide over pressure protection without the need for safety relief valves, and allowing for a dry containment volume
- The use of Reactor Pressure Vessel (RPV) isolation valves (integral to the RPV) that reduce the potential for unisolable Loss-of-Coolant Accidents (LOCAs).
- Reduced requirement for operator control or intervention.
- Design in accordance with internationally accepted codes, standards and guidance to implement RGP and support international deployment with minimum changes.

There have been 115 BWRs built and operated around the world with two ABWRs currently under construction. Currently there are 63 BWRs operational worldwide. The highest concentration of BWRs is in the USA where 31 of the 94 operating reactors in the country are BWRs. Many are among the best operating plants in the world, performing in the "best of class" category.

The BWRX-300 benefits from design optimization and taking consideration of 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 due to passive systems. The BWRX-300 optimization has common goals which align with the ALARP principles.

27.6.1 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. Table 27-1 chronicles the development of the BWR.

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 over and over.

The first large direct cycle BWRs, e.g., Oyster Creek, appeared in the mid-1960s and were characterized 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.

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 minimized by the large water inventory above the core in the RPV.

Figure 27-2 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 shape are still used today in Pressurized Water Reactor (PWR) designs. The BWR, however, quickly moved to the "pressure suppression" containment design for its many advantages.

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 translates into a significantly more compact containment and reactor building. The containment is similar in construction to the ABWR but is slightly larger to accommodate the passive ECCS systems.

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 27-3 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.

27.6.2 Operational Experience

The BWRX-300 design approach leverages nine previous generations of GEH BWR technology with greater than 2,000 reactor-years of operating experience, based on the U.S. NRC certified ESBWR with commercially proven GNF2 nuclear fuel. The BWRX-300 leverages the main features of the power cycle from Nuclear Power Plants (NPPs) that have been or are in service.

The nuclear core uses the proven GNF2 fuel assemblies that are manufactured and sold to over 80% of the BWR fleet, and 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 which deals with fleet-wide issues and concerns and operating experience.
- Previous GE BWR designs have been licensed worldwide, including in the U.S., Japan, UK, Taiwan, Switzerland, Italy, and Spain.

The BWRX-300 leverages the U.S. 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 practice.

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 minimize these amounts.

The BWRX-300 Balance of Plant (BoP) systems configuration is typical of those in current use throughout the BWR fleet adjusting for the differences in gross power output. The lower gross power of 300 MWe eliminates the need for custom designs for turbines and generators as existing standard frame sizes are available from the major turbine generator set manufacturers, with considerable OPEX.

27.6.3 Key Design Simplifications

Key BWR design simplifications as part of design evolution have been described above and how they have been incorporated into BWRX-300 design, including:

- Single reactor cooling loop, which runs through the RPV/core and also through the turbines, thus eliminating the need for steam generators.

- Use of a taller vessel to achieve effective natural recirculation flow without the use of any pumps.
- The BWRX-300 contains no reactor internal pumps which eliminates the need for external jet pumps and the external recirculation systems, with all the associated pumps, valves, piping, and snubbers.
- Internal steam separator and dryer which eliminates the need for an external steam drum.
- BWRX-300 uses the same fuel bundle designs that are currently in use in the operating BWR fleet.
- Challenges to the system are minimized by the large water inventory above the core in the RPV.
- The fuel assemblies (including fuel rods and channels), control rods, chimney head, steam separators, steam dryer, and in-core instrumentation assemblies are removable when the reactor vessel is opened for refuelling or maintenance. These items are the same as those used with the ESBWR, which brings consequent design pedigree and OPEX.

The ICS is a further design simplification for BWRX-300, which replaces the previously used suppression pool, and facilitates a containment design which includes the following advantages:

- High heat capacity to absorb the energy from containment transients or pipe break LOCAs.
- Lower containment design pressures.
- Superior ability to accommodate rapid depressurization.
- Unique ability to filter and retain fission products.
- Provision of a large source of readily available makeup water in the case of accidents.

However, a containment vent system is included to mitigate potential low frequency containment pressurisation events.

The BWRX-300 has been designed with constructability in mind from the start, beginning with a simplified system layout that has fewer safety systems and safety-related pools of water. Due to its smaller size, the BWRX-300 has been designed to use more commercial off-the-shelf equipment than previous BWRs.

27.6.4 Designed for Safety

The BWRX-300 RPV is equipped with RPV double isolation valves, integral to the RPV, which can rapidly isolate a ruptured pipe, and removes the potential for a non-isolable LOCA. This design feature also supports the design of a more compact and dry containment and eliminates the need for some Safety Relief Valves (SRV). The large capacity ICS provides overpressure protection.

The ICS removes 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 (HX) 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 Isolation Condenser (IC) pool inventory. The ICS pools are located at ground level and are not pressurized, 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.

The RPV, PCV 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 and 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.

In addition to hydraulic-powered scram, the Fine Motion Control Rod Drives (FMCRDs) also provide electric-motor-driven run-in of all control rods as a path to rod insertion that is diverse from the hydraulic-powered scram. The Boron Injection System (BIS) is an independent means of reactivity control to terminate extremely low probability events where the control rod insertion (hydraulic or motor) is not successful.

The BWRX-300 design incorporates five Defence-in-Depth (D-in-D) layers, i.e., Defence Lines (DLs), as promulgated by the IAEA, which include a range of redundant, diverse, and segregated safety measures to prevent, protect and mitigate potential fault and hazard scenarios.

27.6.5 Key Design Development Advantages

The key design development advantages of the BWRX-300 are:

- Reduced LOCA risk e.g., inclusion of Reactor Isolation Valves (RIVs), removal of SRVs.
- Inherent and passive safety design over historic active design.
- Simplified design supporting increased reliability e.g., reduction in the number of components and pipework lengths.
- Flexible energy generation, including Combined Heat and Power (CHP) and hydrogen production capabilities.
- 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.
- Design pedigree / heritage from previous BWR designs, e.g., UK ABWR and ESBWR.
- Use of many proven technologies, e.g., fuel, core design, steam separator system.
- Ability to use non-safety classified and COTS equipment in some areas (e.g., BoP).

Other areas where safety improvements have been made include Instrumentation and Control (I&C) and Electrical Power where simplification of the design has led to lower classification of SSCs in these systems and reduction in complexity.

The BWRX-300 approach is considered to have reduced risks by presenting a simpler, more compact, lower heat load and more flexible design with large safety margins. These safety improvements have reduced plant complexity resulting in the need for fewer automated systems and has eliminated the need for operator actions for Design Basis Accidents for 72 hours. This has reduced requirements for the highest classification of I&C equipment. RGP is followed by ensuring that all I&C is designed to applicable US Nuclear Regulatory Committee (USNRC), IAEA and International Electrotechnical Commission (IEC) guidance.

For Electrical Power systems the BWRX-300 design follows RGP by reducing the reliance on electrical power to support safety functions. Commonly, plant design relies on AC power sources, including diesel generators, to mitigate Design Basis Accidents (DBAs). The BWRX-300 instead relies on battery backed DC power with a coping period of 72 hours for all DBAs which are automatically initiated on loss of power. This feature significantly reduces the importance of grid connection and grid stability for anything other than power production. The reliance of the design on natural rather than forced circulation means that a Loss-of-Offsite Power (LOOP) does not result in a loss of circulation.

The BWRX-300 chemistry regime builds on OPEX and RGP obtained from the historical evolution of BWR chemistry developed over many decades of operation and is an integral part of maintaining plant condition. In particular, the integrity of the reactor cooling circuit SSCs and the fuel by chemical dosing and impurity control (both within specified limits) and material condition. For other SSCs, the chemistry regime will contribute to the maintenance of integrity by combinations of chemical dosing, impurity control and materials selection. In addition, the BWRX-300 chemistry regime will ensure that the source term radiological dose to the workers and public is minimised and that the source term reduces waste accumulation and routine discharges. The chemistry regime achieves these objectives by optimising material selection and through operating practices.

27.7 BWRX-300 Design Evolution Review Summary

The BWRX-300 design choices have been informed by reducing the largest contributors to risk in the PSA, as well as improving deterministic safety performance through increasing passive safety features, elimination of hazards, and reduction in operator interaction, for example. The key BWRX-300 systems are presented below in Table 27-2, highlighting how the systems designs have considered the various aspects of the ALARP methodology, i.e., RGP, OPEX and optioneering, a more detailed description is presented in Reference 27-8.

27.8 Summary of Systematic Review of Design Against RGP and OPEX

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 27-10), for the engineering 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 (SCAs) 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 physical design covering the 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 (HF)
- Civil
- Electrical
- Instrumentation and Control (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 (ASME, IEC, IEEE 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 BWRX-300 is fully described in NEDC-34165P, "BWRX-300 UK GDA Preliminary Safety Report Ch. 3: Safety Objectives and Design Rules for Structures, Systems and Components," (Reference 27-11), providing confidence and context that the application of ALARP principles is embedded in the approach taken and aligns with UK expectation.

A comparison of application of safety category and SSC classification for 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 27-12). The BWRX300 approach to categorisation of safety functions and classification of SSCs broadly aligns with UK expectations and are aligned with the Office for Nuclear Regulation'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 BWRX300 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 categorization of functions that provide Fundamental Safety Functions or maintain key reactor parameters in normal operations.
- Classification of components whose failure could impact delivery of categorized safety functions or have nuclear consequences.

The identified gaps and weaknesses in the BWRX300 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 Reference 27-12.

27.9 Risk Assessment Insights

The design is informed by analysis of safety function, environmental protection function, and security and safeguard functions. Derived from these functional needs to deliver safety, are the explicit functional requirements that the SSCs must meet to deliver the functions, these 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 Ch. 15.9: Safety Analysis - Summary of Results,” (Reference 27-13), 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 (AOOs), DBAs, or Design Extension Condition (DEC) Events Without Core Damage analyzed approach the regulatory limits for radioactive releases. Definition of numerical targets for BWRX-300 will be undertaken in GDA Step 2 to provide greater context of the ALARP position.

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

27.10 Holistic As Low As Reasonably Practicable Evaluation

At this stage, the BWRX-300 has demonstrated the basis of a robust ALARP justification from the elimination of hazards and reduction in risk achieved by the design evolution of the BWRX-300 compared with previous generations of BWR designs. Notably the increase in inherent and passive safety function delivery provides significant benefit.

Phase 1 of the ALARP review is still underway with detailed analysis of C&S comparison for UK application ongoing, once complete an assessment can be made of the safety significance of identified shortfalls and their potential impact to demonstrate that risk is reduced to ALARP. The existing safety analysis demonstrates that the risk levels are below regulatory expectation.

27.11 Future Development of Holistic ALARP Demonstration

In GDA Step 1 and 2 it is intended that the ALARP process will be implemented to identify potential shortfalls during the RGP and OPEX review step. It is not anticipated that detailed work will be undertaken in Phase 2 during GDA but forward actions will be identified for post-GDA licensing.

In the next version of this chapter, further risk insights will be available from new work undertaken as part of the ongoing development of the BWRX-300 as well as more detailed RGP review for the design of BWRX-300.

It is intended that in GDA step 2 an implementation plan will be established, and forward actions identified to progress towards a mature ALARP evaluation of the BWRX-300. Commitments may also be made and logged for actions to be undertaken post-GDA into potential licensing phases for deployment of the BWRX-300 in the UK, NEDC-34140P, "BWRX-300 UK GDA Safety Case Development Strategy," (Reference 27-14).

27.12 Conclusions

The BWRX-300 design has taken advantage of the evolution of BWR design to incorporate significant simplification of SSCs promoting the benefit of passive and inherent safety systems. As the tenth generation of BWR, the BWRX-300 leans on significant relevant OPEX to build confidence in the design concepts to ensure safe deployment and operation through the lifecycle of a BWRX-300 plant construction, commissioning, operation, decommissioning, and end of life.

The design simplifications introduced since the ABWR demonstrate a commitment to delivering the ALARP principle by reducing risk and eliminating hazards in an ongoing process.

GEH intends to complete GDA Steps 1 and 2 without additional design changes beyond the DR, 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. GEH will provide periodic summary reports of major design developments and design maturity developed as part of completion of Baseline (BL) 2 BWRX-300 standard design. Moreover, commitments will be formally identified within the consolidated end of the Step 2 GDA Safety, Security, Safeguards and Environments cases.

GEH processes are intended to be aligned to UK expectations, built upon existing good practice already in place in GEH's design processes.

The good practices established in GEH, coupled with the evidence of application presented in the design evolution of the BWRX-300 demonstrate a clear commitment to the ALARP principle.

These outputs will be further refined in GDA Step 2, and an implementation plan established to ensure the ALARP principle is embedded in the BWRX-300 design development for deployment in the UK.

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		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 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 in 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. OPEX for the control rod arrangement in BWRs which support continued application in the BWRX-300.

System	Function	Design Development
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 • Minimizing 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 demineralization 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 Safety Class Structures, Systems and Components (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, in particular aircraft crash, due to major SSCs with nuclear functions being below grade over the ABWR. RGP - Improved external and internal human induced hazard protection due to the DP-SC structure e.g., turbine missiles, vehicle impacts, dropped load, internal missiles, etc. 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 - Similarly to ABWR principals where the occupants of the CB control room are protected from incapacitating injuries. OPEX/RGP - Improvements on environmental factors e.g., minimizing volumes of concrete and steel, minimizing excavation volumes, minimizing backfill volumes, etc

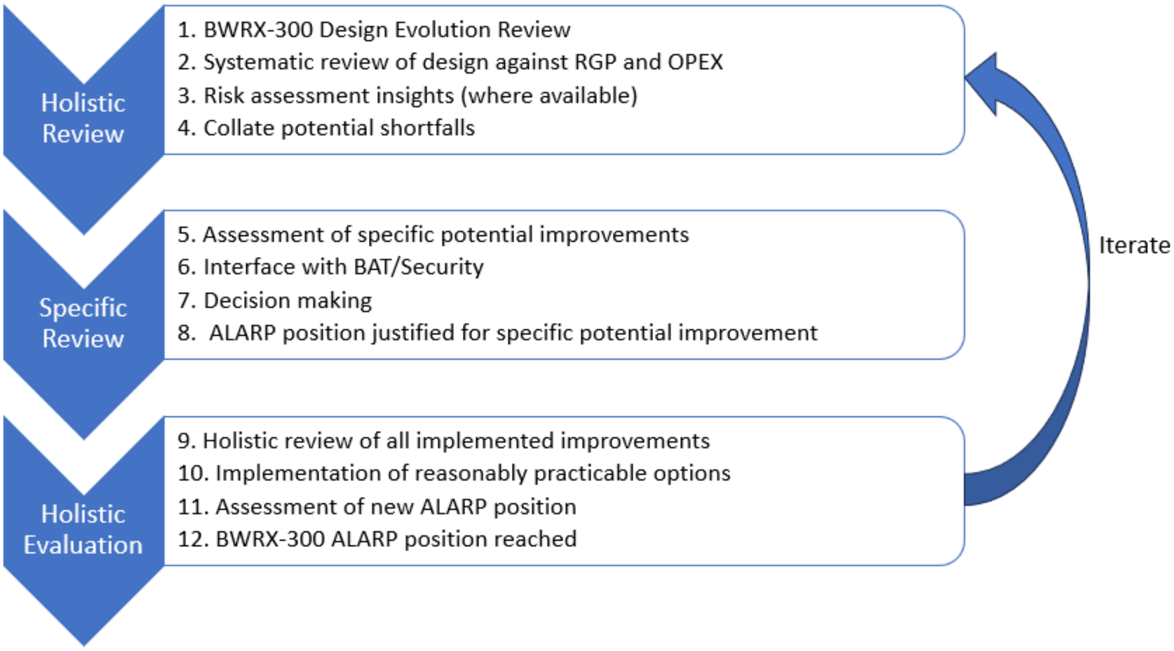

Figure 27-1: Overview of As Low As Reasonably Practicable Evaluation Process

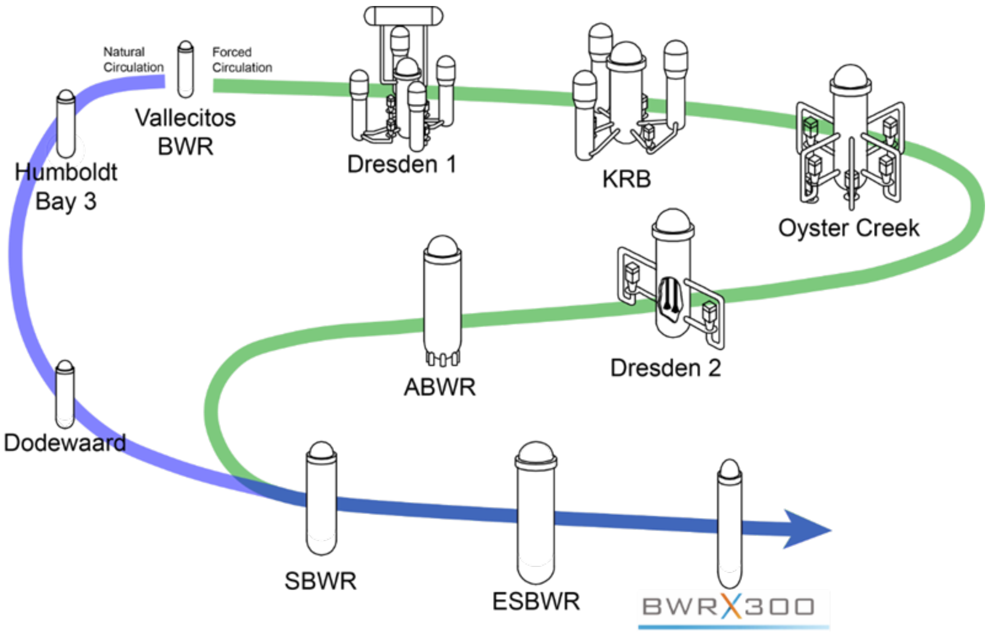

Figure 27-2: Boiling Water Reactor Design Evolution

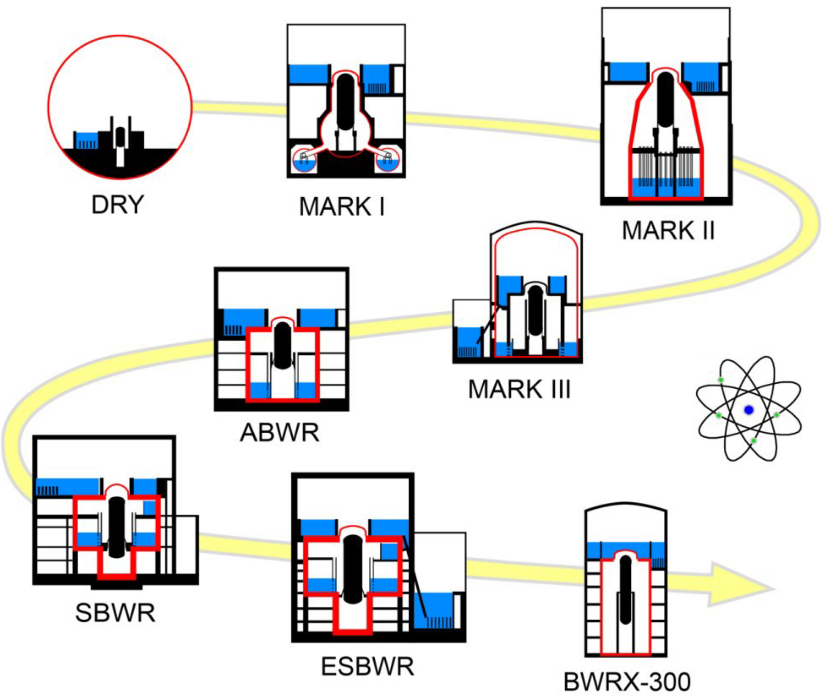

Figure 27-3: GE Hitachi Nuclear Energy Containment Designs

27.13 References

27-1 NEDC-34162P, "BWRX-300 UK GDA BWRX-300 UK GDA Safety, Security, Safeguards and Environment Summary," Rev A, GE-Hitachi Nuclear Energy, Americas, LLC.

27-2 NEDC-34148P, "BWRX-300 UK Generic Design Assessment (GDA) Scope of Generic Design Assessment," Rev 0, GE-Hitachi Nuclear Energy, Americas, LLC, May 2024.

27-3 "Health and Safety at Work etc. Act 1974," The Stationery Office, 1974.

27-4 "Radioactive Substance Regulations - Principles of optimisation in the management and disposal of radioactive waste," Rev 2, Environment Agency, 2010.

27-5 "Safety Assessment Principles for Nuclear Facilities," Rev 1, ONR, 2020.

27-6 CP-03-100, "Design Control," Rev 11, GE-Hitachi Nuclear Energy, Americas, LLC.

27-7 CP-03-113, "Engineering Change Control," Rev 5, GE-Hitachi Nuclear Energy, Americas, LLC.

27-8 NEDC-34137P, "BWRX-300 UK GDA BWRX-300 Design Evolution," Rev 0, GE-Hitachi Nuclear Energy, Americas, LLC, May 2024.

27-9 NEDC-34223P, "BWRX-300 UK GDA Preliminary Environmental Report Ch. 6: Demonstration of BAT Approach," Rev 0, GE-Hitachi Nuclear Energy, Americas, LLC, October 2024.

27-10 NEDC-34139P, "BWRX-300 UK Codes and Standards Assessment," Rev 0, GE-Hitachi Nuclear Energy, Americas, LLC, August 2024.

27-11 NEDC-34165P, "BWRX-300 UK GDA Preliminary Safety Report Ch. 3: Safety Objectives and Design Rules for Structures, Systems and Components," Rev A, GE-Hitachi Nuclear Energy, Americas, LLC.

27-12 NEDC-34161P, "BWRX-300 UK Generic Design Assessment (GDA) Comparison of BWRX-300 Approach to Categorization & Classification with UK expectations," Rev 0, GE-Hitachi Nuclear Energy, Americas, LLC, July 2024.

27-13 NEDC-34187P, "BWRX-300 UK GDA Preliminary Safety Report Ch. 15.9: Safety Analysis - Summary of Results," Rev A, GE-Hitachi Nuclear Energy, Americas, LLC.

27-14 NEDC-34140P, "BWRX-300 UK GDA Safety Case Development Strategy," Rev 0, GE-Hitachi Nuclear Energy, Americas, LLC, August 2024.

APPENDIX A CLAIM, ARGUMENTS AND EVIDENCE

The ONR Safety Assessment Principles (SAPs) 2014 (Reference 27-5) 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 27-14) 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 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 PSR Ch. 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 27-14) 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 PSR Ch. 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.	27.4 Summary of BWRX-300 Design Evolution which summarises reference 27-8 27.6 Summary of Systematic Review of Design against RGP and OPEX
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.	27.4.2 Operational Experience, which summarises Reference 27-8 27.4.3 Key BWRX-300 Design Simplifications, which summarises Reference 27-8 27.6 Summary of Systematic Review of Design against RGP and OPEX
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.	27.3.2.1 Step 5: Assessment of Potential Improvements, linked to References 27-6 and 27-7 27.5 BWRX-300 Design Evolution Summary, which summarises Reference 27-8
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.	27.7 Risk Assessment Insights

APPENDIX B FORWARD ACTION PLAN

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

FAP No.	Finding	Forward Action	Delivery Phase
27.1	Current GEH procedures do not explicitly address ALARP. To meet UK expectations a demonstration and establishment of an ALARP process is necessary to be suitably incorporated into GEH process.	Demonstrate ALARP evaluation process application in GDA Step 2 (by examples not comprehensive, including an ALARP/BAT/Security deconfliction example if possible)	GDA Step 2
27.2	A suitable register of ALARP actions to be undertaken during GDA and post-GDA is to be established to provide an auditable trail.	Produce a log/register of ALARP issues to be addressed post-GDA with justifications	GDA Step 2
27.3	Specific RGP and OPEX reviews in topic areas may identify potential shortfalls and actions in those areas will be handled by responsible engineers in that topic.	Specific ALARP related actions for systems should be identified from individual topic areas.	GDA Step 2

Note: The following Forward Action Plans (FAPs) have been derived in PSR Ch. 27.