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BWRX-300 UK Generic Design Assessment (GDA) Chapter 15.7 – Deterministic Safety Analyses – Analysis of Internal Hazards

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EXECUTIVE SUMMARY

This subchapter provides a description of the internal hazards assessment processes for the BWRX-300 and forms part of the Preliminary Safety Report (PSR) to be submitted in the United Kingdom (UK) for the Generic Design Assessment (GDA) of the BWRX-300 design, presenting a level of detail commensurate with a 2-Step GDA. The document has identified the approach to internal hazards for ensuring that the Fundamental Safety Functions (FSFs) are not impacted. This is primarily through ensuring Fundamental Safety Properties (FSPs), which are integrated into the design to prevent the internal hazards occurring or to mitigate the consequences. The FSPs ensure that all safety functions and measures within Defence Line (DL) 3 are not challenged following an event. The FSPs are identified across a range of individual hazards, including hazards screened out from further deterministic assessment based on probabilistic arguments. The assessment of internal hazards includes methodologies that consider combinations of hazards and cliff-edges.

For those hazards that require further deterministic assessment, hazard-specific methodologies have been identified for the identification of sources, characterisation, and assessment of consequences. These assessments are currently at differing levels of maturity and an illustrative example for internal fire only is included (see Appendix C). Further deterministic assessment for other hazards (e.g. flooding and pressure part failure) are also in development with outputs from the analysis being incorporated as the internal hazards safety case matures.

However, this subchapter has identified a number of areas where the BWRX-300 safety strategy for internal hazards currently represents a gap when compared to the requirements for GDA. These differences originate from the screening of individual hazards or hazard sources from further deterministic assessment based on probabilistic arguments (including turbine-generated missiles and dropped loads hazards). In addition, the BWRX-300 credits design concepts (such a Break Exclusion Zone (BEZ) or 2% operating life) to further screen out specific hazards or hazard sources from deterministic assessment. The use of probabilistic arguments and the design concepts to screen out specific hazards or hazard sources from deterministic assessment does not meet UK GDA expectations, and this forms the basis of a number of Forward Action Plan (FAP) items (see Appendix B) covering either the development of the deterministic assessment methodologies or the scope of the deterministic assessment. The development of the deterministic assessment for internal hazards should consider hazard combinations, consider cliff-edge effects on a hazard-by-hazard basis and ensure the outputs of the assessments align with the wider Safety Case to enable demonstration of the golden thread. In addition, the deterministic assessment methodologies should ensure that identified risks are subject to existing processes for risk reduction and enable an As Low As Reasonably Practicable (ALARP) demonstration to be made that meets UK expectations. To support this, claims and arguments have been developed (see Appendix A), which shall enable the appropriate evidence to be presented.

Given the nature of the items included in the FAP (see Appendix B), it is proposed that addressing many of them is undertaken in steps, which align to the maturity of the design and supporting inputs. For example, development of deterministic assessment methodologies to align with within GDA Step 2 and then the identified scope of work is undertaken during Pre-Construction Safety Report (PCSR) development or at the site-specific stage (especially when there are interactions with external hazards). A Safety Case Manual (SCM) Specification has been produced during GDA Step 2, which outlines the requirements for a SCM for the deployment of the BWRX-300 baseline design in the UK, which the future phases of the project need to consider. Within this specification it highlights an approach to the development of information or methodologies to meet UK regulatory expectations and requirements within the PCSR and provides a level of confidence that identified differences shall be addressed.

While items have been identified that mean certain hazards or hazard consequences have not yet been assessed, the philosophy associated with FSPs and ensuring DL3 safety functions,

provides confidence that the design can deliver FSFs in the event of a design basis internal hazard. In addition, this document supports the overall demonstration that risks associated with the BWRX-300 design shall be identified and appropriately managed to meet the overall national safety objective. Therefore, this subchapter supports the high-level safety objective that the design and intended construction and operation of the UK BWRX-300 shall protect the workers and the public by providing multiple levels of defence to fulfil the FSFs.

ACRONYMS AND ABBREVIATIONS

Acronym	Explanation
3D	Three-Dimensional
ABWR	Advanced Boiling Water Reactor
ALARP	As Low As Reasonably Practicable
BEZ	Break Exclusion Zone
BL	Baseline
BLEVE	Boiling Liquid Expanding Vapour Explosion
BWR	Boiling Water Reactor
C&I	Control and Instrumentation
CRD	Control Rod Drive
D-in-D	Defence-in-Depth
DBA	Design Basis Accident
DEC	Design Extension Conditions
DEGB	Double Ended Guillotine Break
DL	Defence Line
DN	Diameter Nominal
DSA	Deterministic Safety Assessment
FAP	Forward Action Plan
FFA	Functional Failure Analysis
FHA	Fire Hazard Assessment
FMCRD	Fine Motion Control Rod Drive
FSF	Fundamental Safety Function
FSP	Fundamental Safety Property
FSSA	Fire Safe Shutdown Analysis
GDA	Generic Design Assessment
GEH	GE Hitachi Nuclear Energy
GOTHIC	Generation of Thermal Hydraulic Information for Containments
GSR	General Safety Requirements
HCU	Hydraulic Control Unit
HELB	High Energy Line Break
HVAC	Heating, Ventilation and Air Conditioning
I&C	Instrumentation and Control
ICS	Isolation Condenser System
IAEA	International Atomic Energy Agency
IHE	Internal Hazard Evaluation
LBB	Leak-Before-Break
LOCA	Loss of Coolant Accident

Acronym	Explanation
MELB	Moderate Energy Line Break
NPS	Nominal Pipe Size
ONR	Office for Nuclear Regulation
OPEX	Operational Experience
PCSR	Pre-Construction Safety Report
PIE	Postulated Initiating Event
PFD	Process Flow Diagram
PRHA	Pipe Rupture Hazard Analysis
PSA	Probabilistic Safety Assessment
PSR	Preliminary Safety Report
RGP	Relevant Good Practice
RTS	Reactor Trip System
SAA	Severe Accident Analysis
SC	Steel-Plate Composite
SCM	Safety Case Manual
SSC	Structure, System and Component
SSG	Specific Safety Guide
UK	United Kingdom
UPS	Uninterruptible Power Supplies

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

REVISION SUMMARY

Revision #	Section Modified	Revision Summary
A	All	Initial Issuance
B	All	Update for end of GDA Step 2 consolidation

15.7 DETERMINISTIC SAFETY ANALYSES – ANALYSIS OF INTERNAL HAZARDS

Introduction

Subchapter Route Map

The route map for PSR Subchapter 15.7 (Deterministic Safety Analyses – Analysis of Internal Hazards) is presented in Figure 15.7-1. The structure of the route map is based on the internal hazards identification, screening and grouping that has been undertaken in NEDC-34144P, "Internal Hazards Identification", (Reference 15.7-1), the outputs of which are presented in Table 15.7-1.

Subchapter Structure

This subchapter begins by defining the scope of internal hazards, significant buildings and related systems and components that are included within the BWRX-300 PSR. This includes outlining what aspects of internal hazards shall be covered as part of the GDA and what shall be covered in future stages of the BWRX-300 design assessment.

The Internal Hazard Evaluation (IHE) approach is then outlined, following which the approach to implementation of FSPs and internal hazard provisions is discussed. Treatment of certain common aspects of the internal hazards assessment is then discussed including identifying general assumptions and conservatisms within the analyses, reviewing how cliff-edge effects are to be covered, and identifying what specific software tools or computer codes are used in the analyses. The systematic and comprehensive identification and screening process undertaken for internal hazards is then summarised and the outcomes are presented to define the scope of internal hazards that require assessment to support the GDA for the UK BWRX-300 design.

The subchapter then proceeds to provide a high-level summary of the status for each of the internal hazards and credible hazard combinations that are identified as being within the scope. As part of this, internal hazards and hazard combinations are defined and suitable assessment methodologies are presented, following which specific assumptions and conservatisms that exist within each of the hazard analyses are outlined along with consideration of any relevant cliff-edge effects. Where currently available, illustrative analyses are then presented for the internal hazards in order to demonstrate that the associated methodologies are appropriate for future GDA steps. In addition, consideration of any cross-cutting issues in the safety case relevant to each internal hazard or combinations is discussed.

Finally, a discussion is provided on the cross-cutting internal hazards issues that relate to multiple areas of the safety assessment, following which the overall conclusions of the subchapter are presented.

Appendix A outlines the top-level claims for the PSR and shows how these have been evolved for the Internal Hazards topic, with primary arguments outlined to support the demonstration of the relevant sub-claims. These primary arguments are addressed in the sections summarised above, with suitable cross-references identified within the appendix as required.

Appendix B presents the FAP items that have been created for a number of areas where the information for internal hazards currently represents a gap when compared to the UK requirements for GDA.

Appendix C provides a summary of illustrative analyses for the Internal Fire Hazard.

Interfaces with Other Chapters

This Internal Hazards subchapter interfaces with the following PSR Chapters:

- 3 – Safety Objectives and Design Rules for Structures, Systems and Components (SSCs)
- 5 – Reactor Coolant System and Associated Systems
- 9A – Auxiliary Systems
- 9B – Civil Structures
- 10 – Steam and Power Conversion Systems
- 15 – Safety Analysis (including all other subchapters)
- 22 – Structural Integrity
- 24 – Conventional Fire Safety.

NB: Should Topic Reports associated with PSR Subchapter 15.7 be produced in the future, the above information would need to be reviewed and updated accordingly.

Purpose

The purpose of this subchapter is to provide a description of the internal hazards assessment process for the BWRX-300. This subchapter forms part of the PSR to be submitted in the UK for the GDA of the BWRX-300 design and presents a level of detail commensurate with a 2-Step GDA.

This subchapter supports the overall demonstration that risks associated with the BWRX-300 design are identified and appropriately managed to meet the overall national safety objective. This subchapter supports the following high-level objective: the design and intended construction and operation of the UK BWRX-300 shall protect the workers and the public by providing multiple levels of defence to fulfil the FSFs. This subchapter shall demonstrate that a design bases internal hazard event will not prevent the delivery of the FSFs.

Scope

Internal Hazards are defined in the Office for Nuclear Regulation (ONR) Nuclear Safety "Technical Assessment Guide: Internal Hazards", (Reference 15.7-2) as "those hazards to the facility or its structures, systems, and components that originate within the site boundary and over which the duty holder has control in some form. The term is usually limited to apply to hazards external to the process, in the case of nuclear chemical plant *(e.g. sites licenced for fuel manufacturing or waste processing)*, or external to the primary circuit in the case of power reactors."

This subchapter describes the derivation of internal hazards to be considered within the BWRX-300 GDA PSR. The subchapter explains the identification process of internal hazards considered and outlines the methodologies used to assess and demonstrate the tolerance of the BWRX-300 design to the defined internal hazards.

The scope of this subchapter covers only the internal hazards that are required to be assessed in GDA as outlined in the first subsection below; however, it is recognised that other aspects of the Internal Hazards topic shall be covered in site-specific and future work as discussed in the second subsection below.

Generic Design Assessment

The BWRX-300 standard design is developed using a phased design process. In summary, this design process aligns to the following staged design maturity:

- Baseline (BL) 0 – Plant Requirements established; high-level conceptual SSCs design developed; corresponding requirements identified.

- BL1 – System interfaces established; integrated Three-Dimensional (3D) model, Instrumentation and Control (I&C) Simulation Assisted Engineering model, System Design Descriptions developed.
- BL2 – Standard design completed, ready for construction planning, detailed component design and support for preparation for construction activities.
- BL3 – Standard design applied to specific project; all remaining SSC design completed.

NEDC-34144P (Reference 15.7-1) provides a complete list of the Internal Hazards identified for consideration in the assessment of the BWRX-300 design in GDA. It should be noted that although screened in for GDA, the “Fire from Cask Transporter, on-site materials”, “Explosion after pipeline accident” and “Explosion after transportation accident” hazards are deemed to be outside of GDA scope and so have not been included in this subchapter.

For the purposes of the BWRX-300 GDA assessment for Step 2, the assessment focuses on those hazards and their combinations, that may have hazardous consequences to nuclear safety classified buildings and SSCs. In addition, future activities required after GDA Step 2 are identified as an output from the GDA assessment activities. The scope of nuclear safety classified buildings and related SSCs, is described in NEDC-34148P, “BWRX-300 UK GDA Scope of Generic Design Assessment”, (Reference 15.7-3). In summary, this includes the following Power Block buildings at BL1 level of maturity:

- Reactor Building (including Containment)
- Turbine Building
- Control Building
- Radwaste Building
- Service Building
- Reactor Auxiliary Structures.

This includes all corresponding systems and components within Containment and these buildings. Where required, the Internal Hazards assessment shall consider the generic plant layout and remaining Balance of Plant.

A description of the plant within the above listed buildings is outlined in NEDO-34163, “BWRX-300 UK GDA Chapter 1 Introduction”, (Reference 15.7-4).

Site-specific and Future Work

Appendix A of NEDC-34144P provides a complete list of the Internal Hazards identified as outside the scope of GDA and these hazards shall be assessed in future stages of the BWRX-300 design assessment. This includes the following hazard groups:

- Pipeline Accident
- On-site Hazardous Materials
- Transportation Accidents
- Electromagnetic Interference/Radio Frequency Interference
- Vibration
- Static Electricity
- Methane
- Snow Melt

- Biological Agents
- Wildlife.

As noted in the above subsection, although screened in for GDA in NEDC-34144P, the “Fire from Cask Transporter”, “On-site Hazardous Materials”, “Explosion after pipeline accident”, “Ground Washout from Internal Flooding” and “Explosion after transportation accident” hazards are deemed to be outside of GDA scope and so have not been included in this subchapter and so shall be assessed in future stages of the BWRX-300 design assessment.

In addition, buildings other than those listed in the subsection above are also deemed to be outside the scope of GDA and shall be assessed in future stages of the BWRX-300 design assessment.

There is no detailed assessment of maintenance activities during Shutdown and Refuelling (as such, temporary and transient materials are excluded from the scope of GDA); however, any activities that would result in an exception to segregation, and therefore alter the Internal Hazards protection are identified and assessed.

15.7.1 General Approach and Principles

15.7.1.1 Internal Hazard Evaluation

The IHE identifies internal hazards that originate from sources within the boundaries of the site and with potential to damage the plant SSCs and challenge FSFs. The following types of internal hazards are typically considered: fires, explosions, missiles from rotating or pressurised equipment, collapse of structures/falling objects, pipe whip, jet effects and flooding. Explosions include chemical explosions (typically explosions of gas mixtures), Boiling Liquid Expanding Vapour Explosion (BLEVE) induced by fire exposure, oil mist, blast from pressure vessel failure and high energy arcing faults accompanied by rapid air expansion and plasma buildup.

The IHE identifies and evaluates both individual hazard sources and combinations of sources. It should be noted that the internal hazard does not directly challenge the FSFs itself, but is postulated to effect equipment, causing failures that do challenge the FSFs. For example, a break in fire water piping near a plant electrical equipment room is considered an internal hazard. The broken pipe or the depletion of the fire water supply does not directly challenge an FSF or lead to a Postulated Initiating Event (PIE); the reactor could continue operating undisturbed even if the fire water tank was empty. However, the water released into the electrical equipment room could cause short circuits or other failures of the electrical equipment. These electrical failures could then cause a pump trip or reposition a valve that might initiate a PIE or otherwise challenge to an FSF.

The example above contrasts with a broken pipe in a system directly involved in the nuclear or power generation processes. In such a case, depletion of fluid through the break may directly challenge an FSF or cause a PIE. Such a scenario represents a functional failure, which is analysed in the Functional Failure Analysis (FFA), not an internal hazard.

The technical basis for the IHE is as follows:

- International Atomic Energy Agency (IAEA) SSR-2/1, “Safety of Nuclear Power Plants: Design”, (Reference 15.7-5)
- IAEA General Safety Requirements (GSR) Part 4, “Safety Assessment for Facilities and Activities – General Safety Requirements”, (Reference 15.7-6)
- IAEA Specific Safety Guide (SSG) SSG-64, “Protection against Internal Hazards in the Design of Nuclear Power Plants”, (Reference 15.7-7)

The IHE is comprised of the following activities:

- Establish a comprehensive list of internal hazards and their credible sources.
- Group the hazards by their potential effect on the plant. Define “sub-sources” of the hazards if necessary to characterise different magnitudes/intensities and probabilities of the same type of hazard.
- Establish and apply criteria to determine which hazards and sources (and combinations of sources) can be screened from further consideration. For example, screening criteria might include:
  - If a hazard sub-source cannot cause failure of an SSC in such a way that causes a PIE or challenge an FSF (e.g., its intensity is not significant enough to cause damage), it can be screened from further consideration.
  - If a combination of hazard sources or sub-sources is not feasible, for example fire within a building that is also flooded such that fire is not possible, that combination can be screened out.

- Identify the remaining internal hazard sources (and combinations of sources) as the set of hazards to be evaluated in the appropriate Deterministic Hazard Analysis and Probabilistic Safety Assessment (PSA)
- Organise the internal hazard sources/combinations by quantitative frequency, using the frequency ranges

The IHE provides the following outputs:

- Results of the evaluation, including details of the process used to arrive at the credible (i.e., "screened in") internal hazards list and justification for any hazard sources/sub-sources that were screened out.
- List of credible internal hazards, with sub-sources or combinations of sources where applicable, and quantitative frequencies.
- Identification of existing, or specification of new relevant and feasible design requirements that support FSP provisions for Defence Line 1 (DL1) (see Subsection 15.7.1.2); these design requirements should explicitly validate any assumptions in the evaluation and underpin justifications made during the screening process.

15.7.1.2 Fundamental Safety Properties Implementation – Internal Hazard Provisions

FSPs are largely non-functional attributes of the design architecture and its SSCs. They provide assurance that the FSFs will be performed with the expected reliability as, when, and under the conditions required. The FSPs largely involve principles relating to, and features of the design; however, they also include aspects related to the demonstration of design sufficiency by analysis and evaluation.

The approach to internal hazard protection and mitigation differs from that employed in the mitigation of specific PIEs (which establishes required functionality in each of the functional DLs). Specific PIEs are not deterministically postulated to result from internal hazards (Subsection 15.7.1.1 above refers). Instead, various DL1 approaches, layered in a Defence-in-Depth (D-in-D) manner, are employed.

The objectives of these DL1 approaches are to:

- Eliminate, where practicable, or minimise sources of internal hazards.
- Contain or mitigate the consequences of internal hazards to minimise likelihood of causing a PIE or to limit the extent of the consequences of a PIE.
- Ensure continued availability of DL3 functions to provide mitigation of PIEs that result from an internal hazard, including qualification of equipment to function under associated environmental conditions.
- Ensure certain fail-safe features are included in DL3 function implementation such that protective actions are likely to be initiated for a variety of relevant equipment failure causes.
- Ensure adequate provisions within the design to allow plant personnel to monitor FSF performance and physical barrier integrity, to support management of unforeseen conditions or complicating factors associated with impacts of an internal hazard event.
- Ensure that other equipment that does not support DL3 functions is appropriately protected and/or qualified as required to satisfy plant safety goals, with due consideration of its risk-significance for a given hazard.

The balance between elimination, minimisation, containment, and mitigation of internal hazards is specific to each hazard-type. It is influenced by the specific hazard analysis methods employed, established design techniques embodied in codes and standards, design choices regarding equipment location, and various other factors.

Because the specific DL1 approaches are hazard-specific, the FSPs related to internal hazards are also organised on a hazard-specific basis.

The applicable internal hazards are listed below and the related FSPs and design provisions are described in the applicable subsections.

- Internal Fires and Explosions
- Internal Missiles
- Load Drops
- Internal Flooding and Pipe Rupture.

The FSPs identified above do not explicitly identify achieving a Safe Shutdown state as an objective, where the Safe Shutdown state is defined in the PSR Chapter 1 (Reference 15.7-4) as a shutdown with:

a. The reactivity of the reactor kept to a margin below criticality consistent with Technical Specifications.
b. The core decay heat being removed at a controlled rate sufficient to prevent core or reactor coolant system thermal design limits from being exceeded.
c. Components and systems necessary to maintain these conditions operating within their design limits.
d. Components and systems necessary to keep doses within prescribed limits operating properly.

In addition, the individual hazard FSPs and design provisions described in the applicable subsections do not identify this objective. However, achieving a Safe Shutdown state is identified in the success criteria for individual hazard assessments and where appropriate these shall be identified.

15.7.1.3 Assumptions and Conservatisms

The analysis of the individual internal hazards will contain various assumptions (e.g., those related to the design or consequences of the hazards) and conservatisms and these shall be identified in the relevant subsections below.

15.7.1.4 Treatment of Cliff-Edge Effects

A cliff-edge effect is considered to be where a small change in analysis assumptions or parameters, such as those relating to design basis hazard severity, facility response, or design basis analyses, is predicted to lead to a disproportionate increase in the radiological consequence or the event frequency.

Sensitivity analyses are used to demonstrate that the margin to a cliff-edge effect is adequate, during which dominant parameters in the analyses are examined to determine whether small variations in the conservative direction introduce a cliff-edge effect. The Sensitivity analyses are performed on the best-estimate analyses of Design Extension Conditions (DEC) event sequences and the Severe Accident Analysis (SAA). This is supported by PSA uncertainty quantification methodologies which involve perturbing individual facility parameters to understand the effects.

Where appropriate, cliff-edge effects will be taken into consideration within the internal hazards analysis covered in this subchapter and these are to be summarised in the relevant subsections below.

It should be noted that currently cliff-edge effects are not considered on an individual hazard basis, and this is the case for all internal hazards, with the exception of those where it is covered individually as summarised in the relevant subsections below. Therefore, there is a need to ensure that the deterministic assessments for the internal hazards include consideration of cliff-edge effects and this will form the basis of a FAP item, please refer to Action PSR15.7-70 in Appendix B.

15.7.1.5 Use of Software Tools and Computer Codes

This subsection provides a summary of the specific software tools or codes used in the analysis of the individual internal hazards.

The Internal Flooding Hazard methodology discussed below, makes reference to use of the Generation of Thermal Hydraulic Information for Containments (GOTHIC) computer code. The GOTHIC computer code is a state-of-the-art program for modelling multiphase, multicomponent fluid flow for performing both containment Design Basis Accident (DBA) analyses and analyses to support equipment qualification.

The GOTHIC code has a noding structure that allows both lumped parameter and 3D modelling capabilities. The multidimensional analysis capability facilitates the study of non-condensable gas and stratification and the calculation of flow field details within a given volume. The code has undergone extensive review and validation against a large test array. The validation program scope examines the code capability for predicting pressure and temperature as well as hydrogen distribution and mixing under various conditions. GOTHIC is a continuously maintained and improved computer code.

15.7.1.6 Identification of Internal Hazards

The internal hazards that require assessment to support GDA Step 3 or beyond for the UK BWRX-300 design have been identified in NEDC-34144P (Reference 15.7-1). This report outlines the comprehensive internal hazards identification and screening process that was applied to the BWRX-300 generic design for SSCs for any specific candidate site in the UK as part of the GDA Step 2. Using this process, a comprehensive set of internal hazards was derived by reference to regulator guidance, publicly available documents, Boiling Water Reactor (BWR) operating fleet Operational Experience (OPEX), experience from previous UK nuclear plant internal hazards assessments, engineering judgement and Relevant Good Practice (RGP) (as outlined in Section 3 of NEDC-34144P [Reference 15.7-1]), the output of which is shown in Appendix A of NEDC-34144P (Reference 15.7-1). Using this comprehensive list, all foreseeable internal hazards that require assessment to support the GDA were systematically identified using the screening criteria presented in Section 4 of NEDC-34144P (Reference 15.7-1) (as per Section 4.3.2 of NEDC-34143P, “Approach to Internal and External Hazards”, Reference 15.7-9), which notes that a hazard can be screened out on the following basis:

- Consequences – The maximum impact of the hazard does not exceed the plant’s design capabilities.
- Frequency of occurrence – Individual hazards with expected frequencies of less than 1.0 E-07 per reactor year are screened from consideration in the Fault Evaluation.
- Bounded hazard – The failures induced by the hazard are bounded by another hazard of similar consequence and higher frequency.

The screening outputs of NEDC-34144P (Reference 15.7-1) identified the list of individual internal hazards that require further assessment to support GDA Step 2 for the UK BWRX-300 design, as presented in Table 15.7-1.

In addition to the individual internal hazards in Table 15.7-1, relevant hazard combinations are also reviewed within this subchapter as part of the combined hazards assessment presented below.

15.7.2 Outline of Internal Hazards Assessment

This section provides a high-level summary of the status for each of the internal hazards that are within scope as well as credible hazard combinations.

The aim of the assessment of internal hazards shall be in part to demonstrate that the FSFs are not impacted and in addition, that the relevant FSPs are met or are not challenged and that DL3 is not challenged.

For each hazard group, the following information is discussed in the subsections below:

- Definition of the hazard, including a description of the relevant FSPs and design provisions
- Provision of suitable hazard assessment methodologies
- Outline of hazard-specific assumptions and conservatisms within the hazard analyses
- Consideration of relevant cliff-edge effects
- Presentation of illustrative analyses to demonstrate that associated assessment methodologies are appropriate for future GDA steps
- Consideration of cross-cutting issues in the safety case
- Inputs to hazard schedule development and any future engineering substantiation required

It should be noted that in the future, separate Topic Reports for each hazard group may be produced (if deemed required) to provide further detail on the above items as and when the FAP and individual commitment items are addressed.

The methodologies for the assessment of internal hazards should demonstrate deterministically that the FSPs are met or not challenged and that the SSCs performing DL3 functions are not impacted by the hazards. In addition, the methodologies should consider the following: assumptions and conservatisms; consideration of cliff-edge effects; illustrative analyses; and consideration of cross-cutting issues in the safety case. The methodologies should ensure that identified risks are subject to existing processes for risk reduction and enable an ALARP demonstration to be made that meets UK expectations. However, this is not the current position for the internal hazards, and they are therefore required to be developed. This will form part of a FAP, please refer to Action PSR15.7-62 in Appendix B. It should be noted that for certain internal hazards, the current information available is more mature than for others; however, this is discussed in more detail in the below subsections.

Following on from the above FAP item (Action PSR15.7-62 in Appendix B), once suitable deterministic methodologies have been developed for the internal hazards, these will be used to identify inputs for the production of a hazard schedule; this is discussed further below.

It should be noted that the information presented in the above sections aligns with 006N5064, “BWRX-300 Safety Strategy”, (Reference 15.7-8); however, as discussed in the following subsections, there are additional UK regulatory expectations that require other aspects to be considered, which are covered in detail in FAP item PSR15.7-62. To support this, NEDC-34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, (Reference 15.7-

24) has been produced during GDA Step 2 in response to FAP item PSR15-3 (see Appendix B), which shall be complementary to the BWRX-300 Safety Strategy (Reference 15.7-8) to align with UK RGP. This specification outlines the requirements for a SCM for the deployment of the BWRX-300 baseline design in the UK, which the future phases of the project need to consider. Within this specification it highlights an approach to the development of information or methodologies to meet UK regulatory expectations and requirements within the PCSR and provides a level of confidence that identified differences shall be addressed.

15.7.2.1 Internal Fire and Explosion

The following subsections address the Internal Fire and Explosion Hazards and summarises the general approach and methodology used to assess and demonstrate the tolerance of the BWRX-300 design to the defined hazards. These subsections shall include the following aspects of the Internal Fire and Explosion Hazards:

- Internal Fire:
  - Internal fire (flammable sources)
- Internal Explosion:
  - Explosion within the plant
  - BLEVE
  - Electrical explosion, including shockwave from transformer explosion.

15.7.2.1.1 Internal Fire

Definition of the Hazard

An internal fire can result from the oxidation of combustible materials in the presence of an oxidiser, initiated by an ignition source within the plant. An internal fire, in the absence of suitable safeguards, has the potential to cause initiating faults, reduce the availability of plant, damage control functions and/or generate overpressures. Secondary effects such as smoke affecting equipment and elevated temperatures resulting in structural failure. can occur as a result of an internal fire, and in addition, operator effects such as loss of main control room habitability can occur.

In 006N5064, (Reference 15.7-8) it describes the FSPs, and design provisions related to the Internal Fire Hazard. The FSPs that form the DL1 measures for the Internal Fire Hazard are centred around preventing, detecting, and suppressing fires, and limiting their effects, and include:

- Design measures are in place to reduce or eliminate combustible materials and ignition sources. Examples of design measures traceable to this FSP are:
  - Materials used within the plant design, both within SSCs and as consumables, minimise the likelihood of starting or propagating fire such as use of non-combustible and heat resistant material where practicable, minimising use of plastic and utilising finishes within the plant with acceptable flame spread indexes.
  - Lightning protection and electrical grounding design measures which minimise likelihood of lightning strikes igniting electrical fires.
  - System design controls the use of combustible, flammable and explosive materials limiting their leakage and spread throughout the plant.

- Means are provided to quickly detect and extinguish or control fires. Examples of design measures traceable to this FSP are:
  - Fire detection and firefighting systems of appropriate capacity and capability are provided and designed to minimise the adverse effects of fires on SSCs.
  - Firewater standpipes are located such that they are protected from damage and available during an internal fire event (located in concrete stairwells or dedicated concrete chases).
  - Plant design supports firefighting efforts including allowing for a minimum response time, emergency lighting, communication systems and a layout that considers manual firefighting.
- Fire separation or other measures are included in the design where necessary to limit the spread of fire and its effects, thus minimising the impact on the plant and its occupants. Examples of design measures traceable to this FSP are:
  - Physical barriers throughout the plant prevent the spread of fires such as fire barriers, doors, and buildings with approved fire ratings.
  - Construction techniques prevent fire through aspects such as fireproofing and continuity of design for fire rated/proofed areas.
  - Mechanical systems designed to prevent spread of fire such as Heating, Ventilation, and Air Conditioning (HVAC) penetrations through fire barriers equipped with fire dampers, redundant equipment used for achieving and maintaining safe shutdown separated by fire barriers, and systems designed such that their failure does not impair the safety capability of the SSCs.
  - Electrical systems are designed to prevent the spread and impact of fires including electrical cabinet design and cable tray requirements to limit the effect of fires.

Assessment Methodology for the Hazard

The aim of the assessment of internal fire hazards shall be in part to demonstrate that the FSFs are not impacted and in addition, that the relevant FSPs are met or are not challenged. Evaluation of site fire hazards and demonstration of fire safety adequacy at the site are supported by both the Fire Hazard Assessment (FHA) and the Fire Safe Shutdown Analysis (FSSA).

The FHA provides the minimum fire protection requirements for the design and operation of the BWRX-300, including SSCs that directly support the plant and the protected area. The FHA objective is to identify the specific hazards and fire protection capabilities in each area of the plant to demonstrate that the potential damage is limited by various active and passive fire protection measures.

The FHA demonstrates that the plant will maintain the ability to perform safe-shutdown functions and minimise radioactive material releases to the environment in the event of a fire. The FHA evaluates distinct fire areas for the Power Block and other standalone buildings, structures, and equipment in the protected area and establishes fire protection requirements pertaining to each building as described in 006N6567, “BWRX-300 Fire Hazard Assessment Requirements Document”, (Reference 15.7-10) (Note: this reference may be replaced by an associated Internal Fire & Explosion Hazards Topic Report should it be produced in the future). A “fire area” is defined in the FHA as a portion (aggregate floor area) of a building or plant enclosed and bounded by fire walls, fire barriers, exterior walls, fire-resistance rated horizontal assemblies of a building, or other means in order to contain fire within that area. It should be noted that the FHA also identifies some Internal Explosion Hazards within the individual fire areas and requirements for protection. The combustible loading and explosion sources used in the assessment of each room were identified using the anticipated equipment and systems in the various rooms, and the assessment will be updated as the design progresses. Therefore, the inventory of combustible loadings and explosion sources in each room will need to be verified in the final design stage to confirm that the assumed loading is accurate. This will form part of a FAP, please refer to Action PSR15.7-73 in Appendix B.

The FSSA demonstrates the BWRX-300 fire safe shutdown capability for postulated fires involving in-situ and/or transient combustibles that could impact nearby SSCs. This analysis identifies impacts of a fire on the safe shutdown systems and includes a Safe Shutdown Circuit Analysis as documented in 006N7487, "BWRX-300 Fire Safety Shutdown Requirement and Analysis Document", (Reference 15.7-11) (Note: this reference may be replaced by an associated Internal Fire & Explosion Hazards Topic Report should it be produced in the future). The FSSA follows the guidelines in RG 1.189 Section 5, as well as in CSA N293-12 Appendix B.4, and the methodology is illustrated in Figure 15.7-2. These codes were identified as part of NEDC-34139P, "BWRX-300 UK Codes and Standards Assessment", (Reference 15.7-12).

Fire damage is conservatively assumed to occur to components in a fire area regardless of the combustible inventory, material ignition temperatures, ignition sources, or the presence of automatic or manual fire suppression and detection systems. Fire damage is also postulated for all cables and equipment in the fire area that may be used for safe shutdown, even though most fire plant areas do not contain sufficient fire hazards for this to occur.

Assumptions and Conservatisms

The following assumptions are identified in 006N7487 (Reference 15.7-11):

- A single, postulated fire is assumed to occur in any area of the plant containing equipment or electrical circuits that are necessary for safe shutdown except for primary containment, which is inerted with nitrogen during power operations.

  Note: It is acknowledged that this assumption is not consistent with the requirements of Combined Hazards.

- The FHA postulates design basis fires in each fire zone within the protected area and external to the protected area for SSCs that directly support the plant with assessment of damage including impact on safe shutdown equipment.

- The evaluation of secondary effects such as smoke spread and impact to structural supports is considered in the FHA. The spread of fire from a non-safety classroom to a safety classroom is prevented by the appropriate design of fire barriers.

- Design basis fires are assumed not to occur concurrently with non-fire related failures in systems, other accidents, or the most severe natural phenomena.

- The plant is assumed to be in a standard lineup governed by operating procedures, operating modes or administrative controls at the onset of the fire. All components, including manual valves, are assumed to be in their normal position.

  Note: Deterministic assessment may assess in all plant states and take into consideration maintenance and a single active failure, which may challenge this assumption, see Action PSR15.7-62 on the FAP (Appendix B refers).

- Piping, check valves, strainers, tanks, manual valves, heat exchangers, safety relief valves, and pressure vessels are assumed to remain functional during and after a fire. For valves, the fire damage is limited to power-assisted operators such as motors, air operators, hydraulic and/or solenoid operators.

- Fire damage to substantial passive components, such as, piping, heat exchangers, and tanks, is assumed to have no adverse impact on the ability to function as pressure boundaries or as safe shutdown components.
- Spurious operation of control circuits is considered improbable for circuits in fibre-optic cable.

It is also noted in 006N7487 (Reference 15.7-11) that the BWRX-300 Hydraulic Control Unit (HCU) is a fail-safe design that actuates on loss of signal from the Reactor Trip System (RTS) or loss of power. This fail-safe actuation can be credited to eventually limit the fire separation requirements for all the power and control cables for RTS and the HCUs.

In addition to the above, NEDO-34184, “BWRX-300 UK GDA Chapter 15.6: Probabilistic Safety Assessment”, (Reference 15.7-13) identifies the following internal fire related assumption: administrative controls are placed to ensure stored combustibles are not collected in sufficient quantities to impact nuclear safety if ignited. Additional internal fire related assumptions also reside within the probabilistic assessment of the hazard, and these are covered under PSR Subchapter 15.6 (Reference 15.7-13).

Consideration of Cliff-Edge Effects

No cliff-edge effects have currently been identified.

Cliff-edge effects will be considered in the future when the deterministic assessment for the Internal Fire Hazard has further matured, and this is covered by Action PSR15.7-70 on the FAP in Appendix B.

Illustrative Analyses

Should an Internal Fire & Explosion Hazards Topic Report be produced in the future, this shall provide illustrative examples to demonstrate the internal FHA approach for rooms which contain significant combustible inventories and/or plant and equipment that is claimed for nuclear safety. This shall include examples of a fire area where no functions are failed and a fire area where functions are failed, and resolutions have been identified. A summary of this is provided in Appendix C, which provides an example of information captured for each of the steps highlighted in Figure 15.7-2. Further illustrative analyses will be presented in the future when the deterministic assessment for the Internal Fire Hazard matures, and this is covered by Action PSR15.7-62 on the FAP in Appendix B.

It should be noted that the information that would inform the Internal Fire & Explosion Hazards Topic Report and in this subchapter of the GDA submission is based on the latest published version of 006N6567 (Reference 15.7-10); however, the FHA it is currently being updated to include new rooms that were added to the design. Therefore, any updates will need to be reflected in this subchapter and the associated Topic Report (if produced). This will form part of a FAP, refer to Action PSR15.7-73 in Appendix B.

In addition, 006N7487 (Reference 15.7-11) is not yet complete. Cable routing information and assignment of cables to components is currently incomplete. Therefore, there is a need to update this table once the cable routing information and assignment of cables to components are complete. This will form part of a FAP, please refer to Action PSR15.7-73 in Appendix B.

Consideration of Cross-Cutting Issues in the Safety Case

No cross-cutting issues have currently been identified; however, should any be identified in the future once the deterministic assessment for the Internal Fire and Explosion Hazards matures (Action PSR15.7-62 in Appendix B refers), these shall be considered.

15.7.2.1.2 Internal Explosion

Definition of the Hazard

Internal explosions can be caused by rapid combustion of flammable materials, gases, or vapours in confined or congested conditions. Explosive effects (blast) can also occur due to disruptive failure of high-pressure pipework and vessels.

006N5064 (Reference 15.7-8) describes the FSPs and design provisions related to the Internal Explosion Hazard. The FSPs for the Internal Explosion Hazard are centred around preventing and protecting against the impact of explosions within the plant, and these FSPs include:

- The design and layout of the plant and SSCs prevents (wherever possible) or limits the formation of explosive mixtures. Examples of design measures traceable to this FSP include placing explosive gas supply tanks/vessels and their distribution manifolds in well-ventilated locations, preferably external to the Power Block buildings.
- Where risk of explosion cannot be completely eliminated, the plant design includes features which limit the consequences of an explosion. Examples of design measures traceable to this FSP include limiting and reducing the volumes of explosive gas mixtures to the minimum amount necessary to support their functional need.

It should be noted that 006N5064 (Reference 15.7-8) outlines the concept of “practical elimination” and the design considers practical elimination of internal explosions (Note: if produced in the future, this shall be discussed in more detail in an Internal Fire & Explosion Hazards Topic Report).

There is currently limited information available for the deterministic assessment of the BWRX-300 Internal Explosion Hazard. Although explosion hazards and mitigations are identified in some of the Room Data Sheets in 006N6567 (Reference 15.7-10) from, for example, stored gases or hydrogen from battery charging, the details of whether these systems are claimed as SSCs for nuclear safety are not yet available. Therefore, there is a need to update the assessments to either include deterministic assessment of the internal explosion hazards screened in for assessment in the FHA/FSSA or provide evidence that there are no potential sources of the hazard in the design. For any arguments for exclusion based on equipment design (e.g., design of HVAC and hydrogen detection in battery rooms), sufficient evidence needs to be provided for the design strategy and sizing of this equipment to support the arguments. The evidence should make it clear whether any such equipment is claimed in any of the nuclear safety DLs. This will form part of a FAP, please refer to Action PSR15.7-68 in Appendix B.

As part of the FAP item (Action PSR15.7-62 in Appendix B) for developing the methodology for deterministic assessment of the Internal Explosion Hazard, the factors that should be considered include the following:

- Assessment Methodology for the Hazard
- Assumptions & Conservatisms
- Consideration of Cliff-Edge Effects
- Illustrative Analyses
- Consideration of Cross-Cutting Issues in the Safety Case

15.7.2.2 Internal Flooding

The following subsections address the Internal Flooding Hazard and summarises the general approach and methodology used to assess and demonstrate the tolerance of the BWRX-300 design to the defined hazards. These subsections shall include the following aspects of the Internal Flooding Hazard:

- Internal Flooding:
  - Internal flooding sources (High Energy Line Break [HELB], Moderate Energy Line Break (MELB), spurious fire suppression system operation)
- Spray (causing wetting without imparting any energy).

15.7.2.2.1 Internal Flooding

Definition of the Hazard

Internal flooding can be caused by any event that results in the release of a liquid (usually water) that exceeds the drainage capacity in a given area. Flooding can affect multiple SSCs (i.e. those that are not designed to withstand being submerged or exposed to spray).

006N5064 (Reference 15.7-8) describes the FSPs and design provisions related to the Pipe Breaks Hazard. The FSPs for internal flooding, jet impingement and pipe whip comprise measures to eliminate or reduce the likelihood of these internal hazards, and to mitigate the effects or reduce the consequences of them. These FSPs include:

- Internal flooding and pipe whip are prevented within the plant through system design and equipment qualification. Examples of design measures traceable to this FSP are:
  - Robust piping and supports are utilised to reduce likelihood of pipe ruptures for select areas within the plant, using the BEZ methodology. It is recognised that this approach does not align with UK RGP and therefore further consideration is needed to address any gaps or shortfalls. This will form the basis of a FAP item, please refer to Action PSR15.7-63 in Appendix B, and is also included in the SCM Specification, (Reference 15.7-24), which was produced during GDA Step 2 (in response to FAP item PSR15-3, see Appendix B).
  - Qualified tanks and tank-supports that are built to the appropriate codes and standards.
  - System features to prevent flooding through appropriately sized bunding with sump drainage.
  - Leak detection system utilising temperature, pressure, flow, radiation, and level measurements to quickly isolate piping breaks throughout containment with automatic drainage of accumulated liquid.
- The effects of internal flooding, jet impingement and pipe whip are minimised through suitable structural and system design features. Examples of design measures traceable to this FSP are:
  - Redundant and separated equipment to reduce the likelihood that multiple trains are impacted by the same event.
  - Design features to prevent the spread of flooding and aid in recovery of leaked fluids, including drains, sumps, flood-proof doors, barriers, and rooms.
  - Where necessary, building structures are designed to consider jet impingement and pipe rupture impact from certain DEC instances of high energy pipe rupture.

Assessment Methodology for the Hazard

The internal flooding analysis identifies vulnerabilities associated with internal flooding, opportunities for improving flood protection capability, and additional loads on structures associated with a flood event. Areas where potential flooding or spraying can occur are identified and limiting cases are analysed with GOTHIC models to execute a more detailed analysis.

Areas with the potential for flooding are identified through a review of the building layout, elevations, rooms, and openings below ground level and identification of sources of flooding including pipe or tank ruptures, pump seals, and fire sprinklers. The areas identified are then reviewed to evaluate the effect of a given source to identify mitigating actions. Examples of items considered include flow rates, energy of the break, location, and equipment impact. For cases requiring additional analysis, GOTHIC models are used to identify vulnerabilities and hydrostatic loads on the floors and walls to support building design and requirement development.

The flooding methodology is presented in 008N1679, “BWRX-300 Internal Flooding Methodology Specification”, (Reference 15.7-14). This document specifies the methodology and criteria for internal flooding analysis for the BWRX-300 design. The purpose of internal flooding analysis is to establish the specific requirements for protection against the effects of compartment flooding due to internal hazards. This specification applies to the BWRX-300 standard design. Technical requirements and general design criteria are provided.

The methods and criteria in this specification include:

- Flood Source and inventory identification
- Flood zone of influence determination
- Flood protection/Mitigating strategies
- Flood induced hydrostatic loading on floors and walls

The methodology and criteria in this specification exclude the following topics which are covered in separate scopes of documentation:

- System energy classification
- Load combinations, civil/structural acceptance criteria, and load combination methodology for loads such as hydrostatic loading
- Interaction with external flooding sources

The general approach of the internal flooding methodology will follow the guidelines laid out in Figure 15.7-3.

Terminology utilised throughout the methodology should be applied consistently with definitions provided in 006N6938, “BWRX-300 Pipe Rupture Hazards Analysis Criteria”, (Reference 15.7-15).

Assumptions & Conservatisms

A review of the methodology outlined in Figure 15.7-3 highlights a number of assumptions and conservatisms are identified that are directly labelled as such or are implied in the approach taken. These include:

- Step 1A notes buildings that contain Safety Class 1 (SC1) systems and components shall be evaluated for potential flooding or areas where spray wetting can occur. Buildings that do not contain SC1 equipment but house systems which could cause flooding that has the potential to reach SC1 equipment through connecting flow paths shall also be evaluated.

- Also Step 1A identifies that the use of penetration sealants or foam to mitigate hydraulic communications between locations should be considered when reviewing impacts between buildings, rooms, and elevations.
- In Step 1B it notes that all possible sources of flooding shall be identified. Sources of compartment flooding shall not be limited to those systems within the compartment but shall also include the effects of sources external to the compartment.
- Step 1B also identifies that fluid shall be assumed to be released from the postulated source until the rupture or actuated system is isolated, the flow is diverted, or the fluid reservoir is depleted.
- Also Step 1B notes spurious actuation of dry pipe fire suppression systems utilising a closed-head arrangement may be neglected.
- In Step 2 pipe rupture sources identified include:
  - High-energy piping: breaks and cracks
  - Moderate energy piping: through-wall cracks in seismically supported piping
  - Moderate energy piping: breaks and through-wall cracks in non-seismically supported piping

  It should be noted that postulating Double Ended Guillotine Break (DEGB) for moderate-energy pipework to determine if the unmitigated consequences are tolerable, irrespective of the seismic classification, is considered good practice. However, this represents a gap in the BWRX-300 analysis due to the failures of seismically classified pipes only postulating through wall cracks. As a result, the flooding consequences assessed only assume leak rather than DEGB flow rates. Therefore, more onerous consequences (larger flooding rates and flooding volumes) are potentially excluded from the current flooding analysis. This is covered by Action PSR15.7-64 on the FAP (Appendix B refers), and is also included in the SCM Specification, (Reference 15.7-24), which was produced during GDA Step 2 (in response to FAP item PSR15-3, see Appendix B).
- Also, in Step 2 it notes that tanks which are designed to Seismic Category 1B and which have redundant vacuum breakers or an opening to atmosphere, and overpressure protection, may be assumed not to fail.
- Step 2 identifies that the amount of fluid released from the failed tank shall be assumed to be equivalent to the internal volume of the tank. In addition, the effects of automatic make-up systems and attached piping systems shall be included in the determination of subsequent fluid flow rates and released volumes.
- In Step 3 it notes that for all possible flood scenarios, the water level as a function of time should be determined, not only for the room or plant area containing the source of the water but also for all rooms or plant areas to which the water could spread. This should take into account the overall source inventory, discharge rates, and means of isolation. Possible inexhaustible water supplies should also be considered.
- Step 3 identifies that for the purposes of calculating compartment flooding potential and rates, floor drains shall be assumed to be clogged. However, if design provisions, engineering evaluations, and appropriate periodic tests and inspections demonstrate that these floor drains would not clog, they may be assumed open to the degree justified.
- Other conservatism in Step 3 include:

- Drainage flow from upper to lower compartments shall be determined using conservative values for entrance and exit loss coefficients for the drain line.
- Flow through floor sleeves shall be assessed where the flow is conservatively calculated.
- Failure of doors should be modelled in a conservative manner.
- Locations where elevated surfaces exist such that water collection could occur should be considered for flooding.
- Consideration of single failure of a mitigating SSC should be applied consistent with the criterion stated in 006N5064 (Reference 15.7-8).

- Step 4 notes that if the equipment is entirely above the localised water level concluded by analysis performed, it can easily be concluded that water intrusion of the equipment will not occur. Equipment in this situation can be concluded to remain operable throughout the scenario.
- Step 4 also identifies that if the SC1 equipment is not completely located above the zone of influence, it will be subjected to possible water intrusion during the event. In this scenario the equipment shall be evaluated for further operability. If it is deemed that the equipment or a portion of the equipment become inoperable, a mitigation strategy shall be put in place for provide assurance of operability during the event.
- Step 5 notes that possible mitigating strategies for equipment operability assurance include, (but are not limited to):
  - Operator Action
  - Relocation
  - Mitigating Hardware
  - Equipment Environmental Qualification

  Any mitigating strategy shall be appropriately justified in the analysis and design. The mitigating strategy utilised shall completely mitigate the possibility of water intrusion for the given equipment and location.

It is assumed that as the flooding analysis is performed, and the methodology matures, further assumptions and conservatisms may arise. These are to be captured and appropriately recorded as the internal flooding hazard Safety Case evolves.

Consideration of Cliff-Edge Effects

No cliff-edge effects have currently been identified within the methodology outlined in 008N1679 (Reference 15.7-14). The consideration of cliff-edge effects in the deterministic flooding analysis should reflect whether the following aspects can have an adverse effect on the outcome in the event of flooding. This includes:

- Buoyancy of equipment in and around the area of the flooding source
- The hydrodynamic effects during a flooding event
- Debris within the flooded area
- Whether pooling of flooded sources has a localised unintended consequence, where assessments consider only transitory flooding
- The impact of flood durations and the factors that have the potential to extend these times

Cliff-edge effects will be considered in the future when the deterministic assessment for the internal flooding hazard matures and this is covered by Action PSR15.7-70 on the FAP (Appendix B refers).

Illustrative Analyses

At present, no illustrative analysis is available for inclusion, due to the development stage and design maturity. Illustrative analyses will be presented in the future when the deterministic assessment for the internal flooding hazard matures, and this is covered by Action PSR15.7-62 on the FAP (Appendix B refers).

Consideration of Cross-Cutting Issues in the Safety Case

Due to the nature of the FAP items associated with the seismically classified moderate-energy pipes and the application of the BEZ there will be a need for input from Structural Integrity team and applicable Engineering teams. With regards to the assessment of the consequences on SSCs, this will require input from various groups within Engineering (including the Civil Engineering and Control and Instrumentation (C&I) teams) and Safety Analysis (such as the Fault Studies team). In addition, due to the claims made on operators, associated with the isolation of flooding sources, there will be some input required from the Human Factors team. These cross-cutting issues will be identified as the case develops and the appropriate links acknowledged.

15.7.2.2.2 Spray

There is currently limited information available for the deterministic assessment of the BWRX-300 spray hazard. Spray is identified in the internal flooding methodology. Step 1A identifies that areas containing SC1 system and components should be evaluated for potential flooding or areas where spray wetting can occur. This indicates that the internal flooding analysis shall include the assessment of spray in the steps outlined in Figure 15.7-3. However, as the deterministic analysis has yet to be performed it is not clear how Spray is fully addressed in the context of each step. Factors that should be considered for the spray hazard should (if applicable) include the following:

- Assumptions & Conservatisms
- Consideration of Cliff-Edge Effects
- Illustrative Analyses
- Consideration of Cross-Cutting Issues in the Safety Case.

The deterministic assessment of the spray hazard will be presented in the future when the deterministic assessment for the internal flooding hazard matures and Action PSR15.7-62 on the FAP in Appendix B applies.

15.7.2.3 Pressure Part Failure

The following subsections address the Pressure Part Failure Hazard and summarises the general approach and methodology used to assess and demonstrate the tolerance of the BWRX-300 design to the defined hazards. These subsections shall include the following aspects of the Pressure Part Failure Hazard:

- Pipe Breaks:
  - HELB (including pipe whip, jet effects, and steam release)
- Failure of Pumps, Tanks & Vessels:
  - Failures of pumps, tanks, and vessels.

High Energy Fluid Systems are fluid systems that during normal plant conditions, are either in operation or maintained pressurised under conditions where either or both of the following conditions are met (Reference 15.7-15):

a. Maximum operating temperature exceeds 95°C (200°F), or
b. Maximum operating pressure exceeds 1900 kPa (275 psig).

Note: the reference may be replaced by an associated Pressure Part Failure Hazard Topic Report should it be produced.

Moderate Energy Fluid Systems are defined as (from Reference 15.7-15) fluid systems or portions of systems pressurised above atmospheric pressure during normal plant conditions that are not classified as high energy.

Note: Within the current assessments fluid systems are classified as moderate energy when they operate as high-energy for only short operational periods in performing their system function. An operational period is considered short if the total fraction of time that the system operates within the pressure-temperature conditions specified for high-energy fluid systems is less than 2% of the total time that the system operates as a moderate-energy fluid system. It is recognised that this approach is not consistent with current GDA expectations and therefore further consideration of applicable SSCs as High-Energy sources is needed. This will form the basis of a FAP item, refer to Action PSR15.7-21 in Appendix B.

15.7.2.3.1 Pipe Breaks

Definition of the Hazard

Pipe Rupture Hazard Analysis (PRHA) considers the consequences of both dynamic and environmental effects resulting from a postulated pipe rupture.

- Dynamic effects comprise:
    a. Pipe whip
    b. Jet impingement
    c. Fluid decompression transients
    d. Sub-compartment pressurisation

  The dynamic effects, as described above, are analysed for HELBs for both circumferential and longitudinal pipe rupture postulation. Dynamic effects are not analysed for through-wall crack considerations for either high- nor moderate-energy piping. These dynamic effects are assessed as part of the PRHA.

- Environmental effects that are considered from a postulated pipe rupture include:
    a. Temperature
    b. Pressure
    c. Humidity
    d. Chemical exposure
    e. Radiation
    f. Spray wetting
    g. Flooding

  Environmental effects are analysed for HELBs and high-energy and moderate-energy through-wall cracks. These effects are not assessed as part of the scope of the PRHA, but are considered as part of the discrete hazards, such as Flooding.

- Containment effects comprise the rise in pressure and temperature of the containment structure following a postulated break. Containment effects are not addressed within the scope of the PRHA.
- Accident analysis comprises the ability to safely shutdown the reactor and maintain core cooling following a postulated break or through-wall crack. This analysis is not addressed within the scope of the PRHA.

006N5064 (Reference 15.7-8) describes the FSPs and design provisions related to the Pipe Breaks Hazard. The FSPs for internal flooding, jet impingement and pipe whip comprise measures to eliminate or reduce the likelihood of these internal hazards, and to mitigate the effects or reduce the consequences of them. These FSPs include:

- Internal flooding and pipe whip are prevented within the plant through system design and equipment qualification. Examples of design measures traceable to this FSP are:
  - Robust piping and supports are utilised to reduce likelihood of pipe ruptures for select areas within the plant, using the BEZ methodology. It is recognised that this approach does not align with UK RGP and therefore further consideration is needed to address any gaps or shortfalls. This will form the basis of a FAP item, please refer to Action PSR15.7-63 in Appendix B, and is also included in the SCM Specification, (Reference 15.7-24), which was produced during GDA Step 2 (in response to FAP item PSR15-3, see Appendix B).
  - Qualified tanks and tank-supports that are built to the appropriate codes and standards.
  - System features to prevent flooding through appropriately sized bunding with sump drainage.
  - Leak detection system utilising temperature, pressure, flow, radiation, and level measurements to quickly isolate piping breaks throughout containment with automatic drainage of accumulated liquid.
- The effects of internal flooding, jet impingement and pipe whip are minimised through suitable structural and system design features. Examples of design measures traceable to this FSP are:
  - Redundant and separated equipment to reduce the likelihood that multiple trains are impacted by the same event.
  - Design features to prevent the spread of flooding and aid in recovery of leaked fluids, including drains, sumps, flood-proof doors, barriers, and rooms.
  - Where necessary, building structures are designed to consider jet impingement and pipe rupture impact from certain DEC instances of high energy pipe rupture.

Assessment Methodology for the Hazard

PRHA demonstrates the ability of the plant to achieve and maintain safe shutdown conditions following a pipe rupture or leakage crack.

PRHA considers the consequences of both dynamic and environmental effects resulting from a postulated pipe rupture in both high and moderate energy systems. These effects include pipe whip, jet impingement, fluid decompression transients, and sub-compartment pressurisation. The analysis identifies locations and equipment subject to these dynamic effects and evaluates the adequacy of protection measures. Where the consequences of dynamic effects on essential SSCs are unacceptable, mitigative design provisions are suggested. PRHA methodology and information regarding use of BEZs within the design can be found in 006N6938 (Reference 15.7-15).

Due to differences in GDA expectations, some aspects of the Pressure Part Failure Hazard screening will require a different approach to that presented in the baseline documents. Associated with the screening criteria this includes:

- Screening Criteria 2: This is covered by FAP Action PSR15.7-21 in Appendix B
- Screening Criteria 3: This is covered by FAP Action PSR15.7-63 in Appendix B

Following the screening process the assessment then considers the effects of pipe breaks in terms of the dynamic and environmental effects, highlighted previously.

The dynamic effects are analysed for HELBs for both circumferential and longitudinal pipe rupture postulation. Dynamic effects are not analysed for through-wall crack considerations for either high nor moderate energy piping.

Both direct dynamic effects on essential SSCs inside the zone of influence and indirect dynamic effects must be considered. An example of an indirect effect would be the whipping pipe impacting a structural frame to which an essential SSC is attached, or dislodged grating becoming a secondary missile, or missiles from back-face scabbing or front face spalling on reinforced concrete caused by pipe impact.

The pipe whip and jet impingement effects are coupled: The unrestrained pipe whip and the corresponding jet shape are determined. The unrestrained pipe whip and associated sweeping jet define an unrestrained zone of influence. Essential SSCs within the unrestrained zone of influence are identified. The significance of the whip impact or jet thrust and wetting on the target SSCs are evaluated.

When the loading and environmental effects have been evaluated, the required target availability is established. Where either loading or environmental effects on components or structures (directly from the rupture or indirectly from damage propagated from failure of other structures and components due to the rupture) exceed that for which they have been designed to function, the target shall be declared unavailable for providing its intended function. Where target loading and environmental effects do not exceed the design limits, the target may be declared available for its intended function. Required targets which have been declared unavailable shall either be protected or upgraded such that they can perform their intended function under the loading and environmental conditions postulated.

Assumptions & Conservatisms

Assumptions around breaks are discussed in 006N6938, “BWRX-300 Pipe Rupture Hazards Analysis Criteria”, (Reference 15.7-15):

- Pipe ruptures are postulated in high- and moderate-energy systems and describes the location and size of pipe breaks, through-wall cracks, and leakage cracks. In addition, the exclusion criteria applied to the PRHA are discussed.
- Illustrative figures of the breaks are described including the size and types of the pipe ruptures15.7-15.
- It also notes that Leak-Before-Break (LBB) methodology is not being utilised in the BWRX-300 design.

Further assumptions and conservatisms are to be identified as the assessments of the dynamic and environmental effects are developed.

Consideration of Cliff-Edge Effects

The assessments of cliff-edges that may arise during pipe break events, such as the factors listed below, are considered in the PRHA. Factors that may alter the outcome of the event include:

- Lump masses or elbows/bends
- The production of secondary missiles
- Assessment of simultaneous whip and jet effects.

The development of the hazard analysis, in line with criteria for pipe breaks from RGP, from documents such as IAEA SSG-64 (Reference 15.7-7). As the safety case develops, and the analysis considers specific sources and locations, then further factors may be identified.

As identified above the dynamic effects are not considered for through-wall cracks of high or moderate energy pipes, or for moderate energy pipe breaks. For these system flooding is the primary resultant hazard of concern. However, pipe-breaks of moderate energy pipes in the region of the high-energy criteria should consider dynamic effects as part of a cliff-edge assessment. For systems that operate near the high-energy threshold, the potential for some pipe whip or jet impacts could lead to unintended consequences that more adverse or onerous than considering flooding alone. This will form the basis of a FAP item, please refer to Action PSR15.7-65 in Appendix B, and is also included in the SCM Specification, (Reference 15.7-24), which was produced during GDA Step 2 (in response to FAP item PSR15-3, see Appendix B).

Illustrative Analyses

At present, no illustrative analysis is available for inclusion, due to the development stage and design maturity. Illustrative analyses will be presented in the future when the deterministic assessment for the pipe breaks hazard matures and this is covered by Action PSR15.7-62 on the FAP (Appendix B refers).

Consideration of Cross-Cutting Issues in the Safety Case

Due to the nature of the FAP items associated with the PRHA screening criteria there will be a need for input from Structural Integrity team, regarding the integrity of SSCs with the highest safety classification and the application of the BEZ. With regards to the assessment of the consequences on SSCs for the various effects, this will require input from various groups within Engineering (including the Civil Engineering team) and Safety Analysis (such as the Fault Studies team). These cross-cutting issues will be identified as the case develops and the appropriated links acknowledged.

15.7.2.3.2 Failure of Pumps, Tanks & Vessels

The consequences that result from the failure of other pressurised SSCs may differ to those postulated for pipe ruptures as defined above, for instance the direct generation of missiles (not covered by consideration of rotating plant). The failure of the pressurised components may be bound by the consequences (for instance pipe whip and jet of connected pipes) or by other hazards (such as missiles). However, the deterministic assessment of other hazards that may result from pressure part failure are not developed to the same extent as PRHA. Where appropriate FAP items are identified in Appendix B and addressing these will enable this aspect of pressure part failure to be considered further.

It is noted that the scope of hazard sources considered within Pressure Part Failure should include the failure components such as accumulators, where multiple diverse hazard effects such as blast or missiles can occur simultaneously.

15.7.2.4 Internal Missiles

The following subsections address the Internal Missiles Hazard and summarises the general approach and methodology used to assess and demonstrate the tolerance of the BWRX-300 design to the defined hazards. These subsections shall include the following aspects of the Internal Missiles Hazard:

- Turbine-Generated Missiles:
  - Impact on affected plant/unit
- Rotating Plant Missiles:
  - Pumps
  - Fans
  - Compressors
  - Electric Motors
- Non-Rotating Plant Missiles:
  - Valves
  - Tanks
  - Other Pressurised Components

There is currently limited information available for the deterministic assessment of the BWRX-300 Internal Missiles Hazard. This section has been separated out to summarise the generic information currently available across the whole hazard area. Once the information available for the deterministic assessment of the Internal Missiles Hazard is more mature, this section of the subchapter shall be revisited and separated into the following aspects of the hazard: turbine-generated missiles, rotating plant missiles and non-rotating plant missiles. This will form part of a FAP, please refer to Action PSR15.7-67 in Appendix B.

Definition of the Hazard

Internally generated missiles are those resulting from in-plant equipment component failures or other events within the nuclear island. Potential internal missile sources include rotating equipment (e.g. pumps, fans, electric motors, blowers, turbine generators, compressors) and pressurised components (e.g., valves, pressure vessels, pipework) which can fail disruptively ejecting highly energetic fragments, potentially resulting in damage to SSCs important to safety and compromising the delivery of safety functions. In addition, chemical or physical explosions can also produce missiles that have the potential to result in damage to SSCs.

006N5064 (Reference 15.7-8) describes the FSPs and design provisions related to the Internal Missiles Hazard. The FSPs for the Internal Missiles Hazard are centred around ensuring system availability through prevention of and protection from internal missiles, and these FSPs include:

- Wherever possible, any equipment capable of generating internal missiles includes design measures that prevent their generation.
- The impacts of internally generated missiles are minimised by provision of barriers and equipment placement.
- Equipment capable of generating missiles is oriented such that consequences of missile generation are minimised, including, for example, the main turbine orientation and the orientation of pressurised air bottles.

- Missile-proof structures and SSCs designed to withstand missile impact are utilised in the design.
- Redundant equipment is physically separated to minimise common-cause failure due to impact from internally-generated missiles.

Assessment Methodology for the Hazard

The aim of the assessment of internal missiles hazards shall be in part to demonstrate that the FSFs are not impacted and in addition, that the relevant FSPs are met or are not challenged. The missile hazard analysis evaluates missiles resulting from both external and internal sources. The analysis supports the design of barriers that resist internally generated missiles (outside and inside containment), turbine missiles, missiles generated by natural phenomena, and site proximity missiles (except aircraft). It should be noted that PSR Subchapter 15.7 shall focus on internal missiles while missiles generated outside of the site boundary are addressed as part of the external hazards assessment presented in NEDO-34186, “BWRX-300 UK GDA Chapter 15.8: Safety Analysis – Analysis of External Hazards”, (Reference 15.7-16).

Other methods used to protect SSCs from missile impact include physically separating redundant systems or components, orienting the missile source to prevent unacceptable consequences and design features to prevent missile generation at the source.

Missile protection is considered in the design of SSCs based on the pertinent safety class, seismic category, and special hardening requirements for extreme storms.

Requirements supporting missile protection for SSCs inside and outside the Power Block are developed and located in 007N2154, “BWRX-300 Missile Protection Design Specification”, (Reference 15.7-17). The report documents the requirements related to missile protection for the design and evaluates the BWRX-300 Nuclear Power Plant SSCs. It is noted that protection of SSCs from impact from potential missiles shall be afforded by one or more of the following practices:

- Location of the system or component in an individual missile-proof structure
- Physical separation of redundant systems or components of the system from the missile trajectory path or calculated range
- Provision of localised protection shields or barriers for systems or components
- Design of a particular structure or component to withstand the impact of the most damaging missile
- Provision of design features on the potential missile source to prevent missile generation
- Orientation of the potential missile source to prevent unacceptable consequences caused by missile generation

The following criteria shall be met to provide an acceptable design basis for the plant’s capability to withstand the postulated significant missiles:

- No loss of containment function as a result of missiles generated internal to containment
- Reasonable assurance that a safe plant shutdown condition can be achieved and maintained
- Offsite exposure remains within the 10 CFR 52.47(a)(2)(iv) and REGDOC-2.5.2 limits for those potential missile damage events resulting in radiation activity release. However, there is a need to justify the appropriateness of these targets for the UK; this

forms part of the FAP, please refer to Actions PSR3-1 and PSR15-3 in Appendix B. These FAP actions have been addressed during GDA Step 2 via the production of the SCM Specification, (Reference 15.7-24), which includes an outline of the approach to developing a radiological criterion suitable for defining the set of faults subject to design basis analysis and judging the effectiveness of the safety measures designated in the design basis analysis (as identified in FAP item PSR15.5-32 in NEDO-34183, "BWRX-300 UK GDA Chapter 15.5: Deterministic Safety Analysis", Reference 15.7-25).

- The failure of non-safety classified equipment, components, or structures, whose failure could result in a missile, do not cause failure of nuclear safety classified equipment
- No high energy lines shall be located near the Off-Gas Charcoal Bed Adsorbers (located in the Radwaste Building)

In some cases of rotating and pressurised components generating missiles, credit for missile-consequence mitigation may be taken for structural walls and slabs. Where this occurs, these walls and slabs shall be designed to withstand internal missile effects in order to preclude perforation by internally generated missiles (Note: in addition to perforation, missiles can also cause scabbing of walls and slabs, resulting in secondary effects; therefore, the potential for secondary missiles will also be reviewed). Additionally, frames around external or internal openings (i.e., jambs, lintels, sills, and similar items) shall be checked for the direct impact of a missile, jet load or pipe whip effects in the worst location and direction.

The hazards assessment methodology is largely driven by probabilistic arguments in the first instance and is done in the following manner to determine postulated significant missiles:

- If the probability of occurrence of the missile, P_1, is determined to be less than 10^{-7} per year, the missile may be dismissed from further consideration because at that likelihood it is considered not to be a statistically significant risk
- If P_1 is found to be greater than 10^{-7} per year, the missile shall be examined for its probability of impacting a design target P_2
- If the product of P_1 and P_2 is less than 10^{-7} per year, the missile may be dismissed from further consideration
- If the product of P_1 and P_2 is greater than 10^{-7} per year, the missile is examined for its damage probability P_3. If the combined probability (i.e., $P_1 \times P_2 \times P_3 = P_4$) is less than 10^{-7} per year, the missile may be dismissed
- Finally, measures shall be taken to design acceptable protection against missiles with P_4 greater than 10^{-7} per year to reduce P_1, P_2, and/or P_3 so that P_4 is less than 10^{-7} per year

The following plant shall be examined in order to identify potential sources of internal missiles:

- **Rotating Plant** (excluding turbine-generated missiles) – Equipment within the general categories of pumps, fans, blowers, diesel generators, compressors, and components in systems normally functioning during power reactor operation, will be examined for any possible source of credible and significant missiles. High-speed rotating machinery may generate missiles from component overspeed or such failures as the pump itself (from seizure), pump or component parts, and rotating segments (e.g. impellers and fan blades).
- **Turbine-Generators** – The following is stated in Reference 15.7-17: *In accordance with US NRC RG 1.115, meeting the intent of REGDOC-2.5.2, Section 7.4.1, it shall be shown that the risk from potential turbine missiles is acceptably small, either because design features are provided to prevent damage or because the probability*

of a strike by a turbine missile is sufficiently low. The hazard rate due to turbine missiles shall be less than 10^{-7} per year for the loss of a safety-related system from a single event. Favorable turbine generator placement and orientation, combined with quality assurance in design and fabrication, maintenance, and inspection programs, and overspeed protection systems, shall provide an acceptably small risk from turbine missiles. If the risk is acceptably low, barriers are not required to protect nuclear safety-related items.

This current position does not suitably cover turbine-generated missiles deterministically and therefore, there is a need to establish an appropriate methodology to deterministically assess turbine-generated missiles. This will form part of a FAP item, please refer to Action PSR15.7-66 in Appendix B. To support this, the SCM Specification, (Reference 15.7-24), produced during GDA Step 2 (in response to FAP item PSR15-3, see Appendix B), includes an outline of the approach to developing the methodology for the deterministic assessment of turbine-generated missiles.

- **Non-Rotating Plant –** Potential missiles that could result from the failure of pressurised components are categorised as contained fluid energy missiles or stored-energy (elastic) missiles. These potential missiles shall be conservatively evaluated against the design criteria. Examples of potential contained fluid-energy missiles are valve bonnets, valve stems, and retaining bolts. Valve bonnets are considered jet-propelled missiles and shall be analysed as such. Valve stems shall be analysed as piston-type missiles, while retaining bolts are examples of stored strain-energy missiles. Pipe rupture loads will also be considered, and these include loads generated by the rupture of a high energy pipe during a postulated accident and include the effects of impact of a ruptured pipe.

Structures or barriers (targets), providing missile protection, act as energy absorbers. The target absorbs the energy by local damage at the location of impact and by overall structural response of the target. The ability of the target to absorb energy depends on the dynamic properties of the target, support condition, and other imposed loads at the time of impact.

Missile impact can be divided into two categories, hard or soft, depending on the missile deformability relative to the target deformability. Hard missile impact results in both local and overall damage to the target component. Soft missile impact is an inelastic impact without rebound, with large displacement and deformation of the projectile (i.e., deformable missile) compared to the target which mainly affects the overall structure damage (e.g., automobile missile). Barrier design shall minimise both local damages, by preventing scabbing and perforation, and the overall structural damage by preventing the collapse of the barrier resulting from inability to resist the absorbed energy.

The formulas and procedures by which structures and barriers will be designed to resist missiles for both local and overall structure/barrier design are presented in Section 7 of Reference 15.7-17 (Note: if produced in the future, a summary is to be provided in an Internal Missiles Hazard Topic Report).

Assumptions & Conservatisms

The formulas and procedures by which structures and barriers shall be designed to resist missiles (for both local and overall structure/barrier design) contain the following assumptions and conservatisms:

- The local damage prediction methodology assumes that the missile strikes the target normal to the surface, and the axis of the missile is assumed parallel to the line of flight. These assumptions result in a conservative estimation of local damage.
- The local damage prediction methodology for Steel-Plate Composite (SC) barriers conservatively ignores the front (impact side) steel faceplate in the calculation as it has

little influence on the behaviour, with the exception that it constrains concrete spalling on its side.

- One of the overall damage prediction energy balance methods (Williamson and Alvy) assumes that at the instant of missile impact the local deformation is plastic with the missile and the effective mass of the target moving together.
- Within one of the overall damage prediction energy balance methods (Bechtel Topical Report 9A), in order to calculate the required missile barrier strain energy, if the impact is of short duration, the target displacement and the corresponding spring force (resisting the impact force) are small and can be conservatively neglected.

In addition to the above, PSR Subchapter 15.6 (Probabilistic Safety Assessment) (Reference 15.7-13) identifies the following internal missiles related assumptions:

- Administrative controls are implemented to preclude compressed gas cylinders from becoming missiles in areas containing risk-significant mitigating equipment.
- Valves are designed to prevent removable parts from becoming missiles in the event of failure in accordance with guidance in the IAEA SSG-64 (Reference 15.7-7).
- Rotating equipment (excluding the main turbine) is designed such that potential failure-generated missiles are prevented from impacting risk-significant equipment through spatial or engineered means.

Consideration of Cliff-Edge Effects

No cliff-edge effects have currently been identified.

Cliff-edge effects will be considered in the future when the deterministic assessment for the Internal Missiles Hazard matures, and this is covered by Action PSR15.7-70 on the FAP (Appendix B refers).

Illustrative Analyses

Deterministic assessment of the Internal Missiles Hazard for the BWRX-300 design is not currently mature enough to present illustrative analyses.

Illustrative analyses will be presented in the future when the deterministic assessment for the Internal Missiles Hazard matures, and this is covered by Action PSR15.7-62 on the FAP (Appendix B refers).

Consideration of Cross-Cutting Issues in the Safety Case

No cross-cutting issues have currently been identified; however, should any be identified in the future once the deterministic assessment for the Internal Missiles Hazard matures (Action PSR15.7-62 in Appendix B refers), these will be considered.

15.7.2.5 Dropped & Impacting Loads

The following subsections address the Dropped and Impacting Loads Hazard and summarises the general approach and methodology used to assess and demonstrate the tolerance of the BWRX-300 design to the defined hazards. These subsections shall include the following aspects of the Dropped and Impacting Loads Hazard:

- Dropped Loads
- Collapsed Structure:
  - Collapsed Structures
  - Falling Objects (toppling loads)

There is currently limited information available for the deterministic assessment of the BWRX-300 Dropped and Impacting Loads Hazard, such that this section has been separated out to summarise the generic information currently available across the whole hazard area. Once the information available for the deterministic assessment of the Dropped and Impacting Loads Hazard is more mature, this section of the subchapter shall be revisited and separated into the following aspects of the hazard: dropped loads and collapsed structures. This will form part of a FAP item, please refer to Action PSR15.7-69 in Appendix B.

Definition of the Hazard

Dropped and impacting loads encompass any item that is dropped, swung, or otherwise falls or is lowered out of control and have the potential to cause initiating faults as well as to damage safety SSCs otherwise claimed in the safety case. In the case of a dropped fuel load this can cause a direct release. They can be caused by failure of cranes or lifting rigs, structural failures caused by external hazards, local hazards (e.g., impact from a heavy load following an uncontrolled swing), and slinging faults. In addition, lifting structures (particularly temporary structures) can fail during a lift, and collapse of such structures is covered under dropped loads.

006N5064 (Reference 15.7-8) describes the FSPs and design provisions related to the Dropped Loads Hazard. Heavy loads within the plant are lifted with lifting equipment designed to appropriate standards and safety factors. The use of preplanned safe-load pathways and equipment design reduce the likelihood of load drop accidents. Further protection is provided by mitigating the effects of load drops on critical SSCs. The FSPs for the Dropped Loads Hazard are centred around these measures, and these FSPs include:

- Selection and design of lifting equipment reduces the risk of a dropped load. Examples of design measures traceable to this FSP are:
    - Cranes and other equipment lifting nuclear loads are designed to the most rigorous codes and standards.
    - All other lifting equipment is designed such that a single failure does not result in a dropped load.
    - Use of a redundant load path on the Fuel Handling Machine mast grapple so that a single component failure does not result in a fuel assembly drop.
    - Lifting equipment is selected that is designed to allow easy access for testing, inspection, and maintenance to ensure structural design safety factors are retained.
- Effects of load drops are minimised. Examples of design measures traceable to this FSP include identification of Safe Heavy Load Travel Paths for components designated as heavy loads that are being moved over or near other SSCs.

Assessment Methodology for the Hazard

The aim of the assessment of dropped and impacting loads hazards shall be in part to demonstrate that the FSFs are not impacted and in addition, that the relevant FSPs are met or are not challenged.

Requirements supporting missile protection for SSCs inside and outside the Power Block are developed and located in the BWRX-300 Missile Protection Design Specification (Reference 15.7-17). The report documents the requirements related to missile protection for the design and evaluates the BWRX-300 Nuclear Power Plant SSCs. The scope of the document includes missiles that are caused by, or as a consequence of, gravitational effects (i.e., dropped and impacting loads). The missile protection design specification also defines hard object impact loads as impact loads including loads resulting from the drop of large loads lifted and handled in areas where there are nuclear safety classified systems and components.

An overview of the methodology is provided in the Internal Missiles Hazard section above.

There is therefore a need to consider dropped and impacting loads separate to internal missiles as a hazard topic. This will form part of a FAP, please refer to Action PSR15.7-69 in Appendix B.

It should be noted that a discrepancy has been identified with respect to the application of Categorisation and Classification for the Reactor Building Crane. This crane is a high integrity design with redundant load paths. Given the nature of the lifts performed by the crane (heavy lifts and fuel movements) it would be expected to be a Class 1 SSC (based on UK experience); however, the current information identified for the BWRX-300 design states that the crane is Class SCN. This issue shall be covered in NEDO-34171, "BWRX-300 UK GDA Chapter 9A: Auxiliary Systems", (Reference 15.7-18) and NEDO-34165, "BWRX-300 UK GDA Chapter 3: Safety Objectives and Design Rules for SSCs", (Reference 15.7-19).

As part of the FAP item (Action PSR15.7-62 in Appendix B) for developing the methodology for deterministic assessment of the Dropped and Impacting Loads Hazard, the factors that should be considered include the following:

- Assessment Methodology for the Hazard
- Assumptions & Conservatisms
- Consideration of Cliff-Edge Effects
- Illustrative Analyses
- Consideration of Cross-Cutting Issues in the Safety Case

15.7.2.6 Combined Internal Hazards

The following subsections address the Combined Internal Hazards and summarises the general approach and methodology used to assess and demonstrate the tolerance of the BWRX-300 design to the defined hazards. These subsections shall include the following aspects:

- Combination of two or more internal hazards
- External hazards combined with internal hazards

Definition of the Hazard

Hazard combinations associated with Internal Hazards can be divided into the following categories:

- Consequential Hazards – One or more hazards that affect the plant and occur as the result of a separate event that also affects the plant, for example, an internal fire could result in an internal explosion.
- Correlated Hazards – One or more hazards that affect the plant in the same timeframe due to persistence or similar causal factors, for example, a high-energy pipe break could lead to pipe-whip, jets and flooding occurring simultaneously.
- Independent (Coincidental) Hazards – Combinations of randomly occurring independent events affecting the plant simultaneously, for example, an internal fire and a dropped load that are not causally related.

For many external or internal hazards, the combinations are rarely limited to a combination of only two hazards. An initiating external or internal hazard can result in multiple events. These combined events are reviewed during the internal and external hazards assessment. Event chains of three or more hazards subsequent to each other are possible.

Assessment Methodology for the Hazard

The methodology for the assessment of hazard combinations is discussed in NEDO-34271, “Combined Hazard Topic Report”, (Reference 15.7-23). This states that event combinations used to develop a list of potential combined hazards is initially based on the identified individual hazards and can be Consequential, Correlated or Independent. The number of individual hazards identified to occur at a given plant location is already high, as such, building combinations of all possible individual hazards results in a number of combined hazards that is not manageable without applying a systematic approach.

Identification of consequential hazards begins with the unscreened single hazards and determining those hazards that may result from the initial hazard. This can be performed using a matrix approach, listing the hazards graphically and showing the combinations of two hazards (so-called first order combinations) where the possible combinations are identified. The combined hazards can be further reviewed based on this initial identification to determine additional possible hazard combinations (second-order combinations) or additional identified combinations.

For combinations of correlated hazards, it is not directly possible to build a matrix for these combinations. The analyst starts the combined hazard screening by identifying potential common causes for those individual (single) hazards not screened out for the plant/site and builds a tree-type structure (or similar) for all hazards correlated by such common causes representing the roots of the branches. With such a tree-type structure, higher order combinations of correlated hazards can be built and undergo a screening process.

For the third category of combinations of independent hazards, the same two-dimensional matrix structure is used. The possibility of an event combination is demonstrated by a colour change or other designation in the corresponding matrix field. The matrix involves the identification of hazards that may impact the plant/site for a time period longer than 3 days. The likelihood is included in the matrix based on the duration of the first hazard and the likelihood of the second hazard occurring during that time period.

Combined events are identified by analysing the correlations and the effects on the plant. The analysis of possible correlations (dependency) between events is made by assessing the physical bases of the phenomena, observed data, actual operating events, and general knowledge of local conditions.

Expert judgment and rough quantitative analysis are used for estimating correlations. The observed data for intensities relevant to the PSA is sufficient for order of magnitude correlation estimates.

The overall process for selecting, screening, and analysing combinations of hazards is provided in Figure 15.7-4. The quantification of the hazards is performed similar to the quantification of the individual hazards with consideration of the effects of the combined hazards on the SSC fragilities, the likelihood of the combined hazards, and the inclusion of these factors in the PSA model.

It is stated in the Combined Hazards Topic Report that the process for the specific modelling depends on the hazard, and the supporting single hazard PSA treatment. The current approach to hazard combinations largely reflects the limited consideration of combined hazards within the PSA. It does not fully consider deterministic aspects in the approach; this is particularly relevant within the identification and screening of credible combinations. Much of the discussion on hazard combinations is taken from 008N9751, “BWRX-300 Probabilistic Safety Assessment Summary Report”, (Reference 15.7-20). It is noted that as part of PSA individual hazard assessment, some consequential and correlated hazards have been considered based on RGP of typically expected combinations, as follows:

- Consequential (External-Internal Hazard Combinations):
    - The primary external hazards with the potential to casually generate an internal hazard are seismic events. The potential internal hazard effects of seismic events are seismic-induced fires and flooding. Many other internal hazard effects are subsumed by fire and flooding hazards (e.g., fires, explosions, pipe whip, jet effects). The Seismic PSA documents qualitative assessments of seismic-induced fire and flooding, and building-to-building interactions.
- Consequential (Internal-Internal Hazard Combinations):
    - Heavy load drop-induced floods and structure damage are considered as part of the fuel and heavy loads movements PSA evaluation.
- Correlated (External Hazards Combinations):
    - The High Wind PSA includes consideration of high wind events with other concurrent hazards such as Wind-Driven Rain, Wind-Driven Ice, Tornado and Hurricane induced missiles and Atmospheric Pressure Change.
- Combined hazards assumptions included from a PSA risk perspective, not consequence perspective include:
    - Turbine-Generator missile-induced fires/explosions are not explicitly addressed in the fire PSA at this stage. However, they are assumed to be bounded by existing fire ignition frequency bins and the conservative treatment (all fires are full room burns) in the GDA BWRX-300 Fire PSA.
    - Jet impingement and pipe whip effects are not explicitly addressed in the PSA at this stage. All flood susceptible SSCs in the flood propagation path are conservatively assumed to fail at the start of the flood scenario. Hence, jet impingement and pipe whip effects induced by flooding events are assumed to be bounded by the current flooding PSA methodology.

The above cases and assumptions will be reviewed and further developed as part of future PSA hazard combinations work (captured by PSR Subchapter 15.6 [Reference 15.7-13] FAP items).

The approach outlined in Figure 15.7-4 does indicate the potential for Deterministic Safety Assessment (DSA) of combinations, but the shape of future DSA for hazard combinations is currently unknown. Therefore, this is considered a gap and will form the basis of a FAP item, please refer to Action PSR15.7-72 in Appendix B. To support this, the SCM Specification, (Reference 15.7-24), produced during GDA Step 2 (in response to FAP item PSR15-3, see Appendix B), includes an outline of the approach to developing both the deterministic identification and screening of hazard combinations and a detailed methodology for the deterministic assessment of credible hazard combinations.

Assumptions & Conservatisms

As discussed above, the current approach to hazard combinations largely reflects the limited consideration of combined hazards within the PSA and does not fully consider deterministic aspects; therefore, no relevant DSA-related assumptions or conservatisms have been identified for hazard combinations. In addition to the individual assumptions and conservatisms for individual hazards, any assumptions, and conservatisms for hazard combinations over and above those for individual hazards will be identified and considered in the future when the deterministic assessment for hazard combinations matures and this is covered by Action PSR15.7-72 on the FAP (Appendix B refers). Similarly, this action will also enable the following to be considered for hazards combinations:

- Consideration of Cliff-Edge Effects
- Illustrative Analyses
- Consideration of Cross-Cutting Issues in the Safety Case.

15.7.3 Consideration of Internal Hazards in the Safety Assessment

Implementation of 006N5064 (Reference 15.7-8) includes hazard evaluations as a means to ensure that all potential hazards the plant might experience are identified and considered in the hazard analyses. A primary objective of each hazard evaluation is to identify hazards with potential to initiate a PIE and pass that list of hazards to the relevant downstream analysis. Unlike the Failure Analyses, in the case of external and internal hazards, any number of possible PIEs might result from the hazard. Therefore, the hazard evaluation does not attempt to postulate specific PIEs caused by the identified hazards.

The focus of the hazard evaluation is to identify the list of credible hazards and define the expected frequencies versus the intensity. These are then fed into the appropriate deterministic and probabilistic analyses to demonstrate that the plant design can withstand the hazards while maintaining performance of the FSFs.

As previously noted, the outputs from the hazard evaluation are fed directly into appropriate deterministic hazard analyses. The objective of these analyses is to demonstrate that all selected credible hazards and hazard sources/sub-sources are protected against through DL1 provisions within the design of the plant SSCs.

These hazards analyses are closely related to the FSPs. During design phases, they establish bases for the more detailed DL1 requirements which implement the FSPs. In the final state, they demonstrate that the completed design is adequate with respect to protection against the hazards.

The objectives of these DL1 approaches are:

- Eliminate, where practicable, or minimise sources of internal hazards.
- Contain or mitigate the consequences of internal hazards to minimise likelihood of causing a PIE or to limit the extent of the consequences of a PIE.
- Ensure continued availability of DL3 functions to provide mitigation of PIEs that result from an internal hazard, including qualification of equipment to function under associated environmental conditions.
- Ensure certain fail-safe features are included in DL3 function implementation such that protective actions are likely to be initiated for a variety of relevant equipment failure causes.
- Ensure adequate provisions within the design to allow plant personnel to monitor FSF performance and physical barrier integrity, to support management of unforeseen conditions or complicating factors associated with impacts of an internal hazard event.
- Ensure that other equipment that does not support DL3 functions is appropriately protected and/or qualified as required to satisfy plant safety goals, with due consideration of its risk-significance for a given hazard.

This approach does not distinguish between DL3 functions that are specific to the hazard or any potential PIEs. Instead, the approach ensures availability of all DL3 functions irrespective of the PIEs they provide protection against. Therefore, the main success criteria for the IHE, based on the information presented above, is to ensure that FSPs are met/not challenged, and that DL3 (as a whole) is not challenged. Taking the approach outlined in the safety strategy, it is not possible to identify individual hazard initiators/sources, the associated unmitigated consequences (including indirect PIEs), or the specific safety measures/functions for an individual initiator/source.

There is a general FAP item (Action PSR15.7-62 in Appendix B) discussed in Section 15.7.2 above, around the development of suitable deterministic methodologies, these could be used to identify inputs for the treatment of hazards within a hazard schedule. This aspect will form the basis of a separate FAP item, refer to Action PSR15.7-71 in Appendix B.

CONCLUSION

This subchapter provides a description of the internal hazards assessment processes for the BWRX-300. The document has identified the approach to internal hazards, as defined in 006N5064 (Reference 15.7-8), for ensuring that the FSFs are not impacted. This is primarily through ensuring FSPs, which are integrated into the design to prevent the internal hazards occurring or to mitigate the consequences. The FSPs ensure that all safety functions and measures within DL3 are not challenged following an event. The FSPs are identified across a range of individual hazards, including hazards screened out from further deterministic assessment based on probabilistic arguments. The assessment of internal hazards includes methodologies that consider combinations of hazards and cliff-edges.

For those hazards that require further deterministic assessment, the subchapter has identified hazard-specific methodologies for the identification of sources, characterisation, and assessment of consequences. These assessments are currently at differing levels of maturity and an illustrative example for internal fire only is included. Further deterministic assessment for other hazards (e.g. flooding and pressure part failure) are also in development with outputs from the analysis being incorporated as the internal hazard's safety case matures.

However, the development of the subchapter has identified a number of areas where the BWRX-300 safety strategy for internal hazards currently represents a gap when compared to the requirements for GDA. These differences originate from the screening of individual hazards or hazard sources from further deterministic assessment based on probabilistic arguments. This includes hazards such as turbine-generated missiles and dropped loads. In addition, the BWRX-300 credits design concepts (such a BEZ or 2% operating life) to further screen out specific hazards or hazard sources from deterministic assessment. The use of probabilistic arguments and the design concepts to screen out specific hazards or hazard sources from deterministic assessment does not meet UK GDA expectations and this forms the basis of a number of items recorded in the FAP.

For cases where hazard sources have been excluded, due to design concepts, there are methodologies to analyse the consequences and the FAP items focus on the scope of the deterministic assessment. Where a number of individual hazards or hazard sources have been screened out on the grounds of probabilistic arguments, methodologies to deterministically assess them have not been identified. As a consequence, the associated FAP items focus on the development of the deterministic assessment methodologies. The development of the deterministic assessment for internal hazards should consider hazard combinations, consider cliff-edge effects on a hazard-by-hazard basis and ensure the outputs of the assessments align with the wider Safety Case to enable demonstration of the golden thread. In addition, the deterministic assessment methodologies should ensure that identified risks are subject to existing processes for risk reduction and enable an ALARP demonstration to be made that meets UK expectations. To support this, claims and arguments have been developed, and presented in Appendix A, which shall enable the appropriate evidence to be presented.

Given the nature of the items included in Appendix B, it is proposed that addressing many of them is undertaken in steps, which align to the maturity of the design and supporting inputs. Many of the detailed commitments require Action PSR15-3 to be completed to define the general approach across the project. For example, the development of the deterministic assessment methodologies should align with GDA Step 2. The identified scope of work shall then be undertaken during the development of the PCSR, or at the site-specific stage (especially when there are interactions with external hazards). FAP item PSR15-3 has been addressed during GDA Step 2 via the production of the SCM Specification, (Reference 15.7-24), which outlines the requirements for a SCM for the deployment of the BWRX-300 baseline design in the UK, which the future phases of the project need to consider. Within this specification it highlights an approach to the development of information or methodologies to meet UK regulatory expectations and requirements within the PCSR and provides a level of confidence that identified differences shall be addressed. The SCM shall be complementary to the BWRX-300 Safety Strategy (Reference 15.7-8) to align with UK RGP.

While items have been identified that mean certain hazards or hazard consequences have not yet been assessed, the philosophy outlined in the BWRX-300 safety strategy, associated with FSPs and ensuring DL3 safety functions, provides confidence that the design can deliver FSFs in the event of a design basis internal hazard. In addition, this document supports the overall demonstration that risks associated with the BWRX-300 design shall be identified and appropriately managed to meet the overall national safety objective. Therefore, this subchapter supports the high-level safety objective that the design and intended construction and operation of the UK BWRX-300 shall protect the workers and the public by providing multiple levels of defence to fulfil the FSFs.

Table 15.7-1: Internal Hazards in Scope for GDA

Hazard Group	Hazard
Internal Fires [Note 1]	Internal fire (flammable sources)
Internal Explosion [Note 1]	Boiling Liquid Expanding Vapour Explosion (BLEVE)
	Explosion within plant
	Explosive electrical faults
	Shockwave from transformer explosion
Internal Flooding	Internal flooding
	Water currents during a flood
	Ground washout
	Spray
Pressure Part Failure	Pipe failure effects
	Pipe/pump mechanical failures
	Pipe whip
	Jet effects
	Steam release
	Release of stored energy
Internal Missiles	Internally generated missiles
	Turbine-generated missiles
	Disruptive failure of rotating machinery or other equipment
Dropped & Impacting Loads	Collapsed structures/falling objects
	Dropped or impacted loads (Heavy load drop)

Note 1: As noted in the “Generic Design Assessment” subsection above, although screened in for GDA in Reference 15.7-1, the “Fire from Cask Transporter, “On-site Hazardous Materials”, “Explosion after pipeline accident”, “Ground Washout from Internal Flooding” and “Explosion after transportation accident” hazards are deemed to be outside of GDA scope and so have not been included in this subchapter or in this table.

Figure 15.7-1: Subchapter 15.7 (Deterministic Safety Analyses – Analysis of Internal Hazards) Route Map

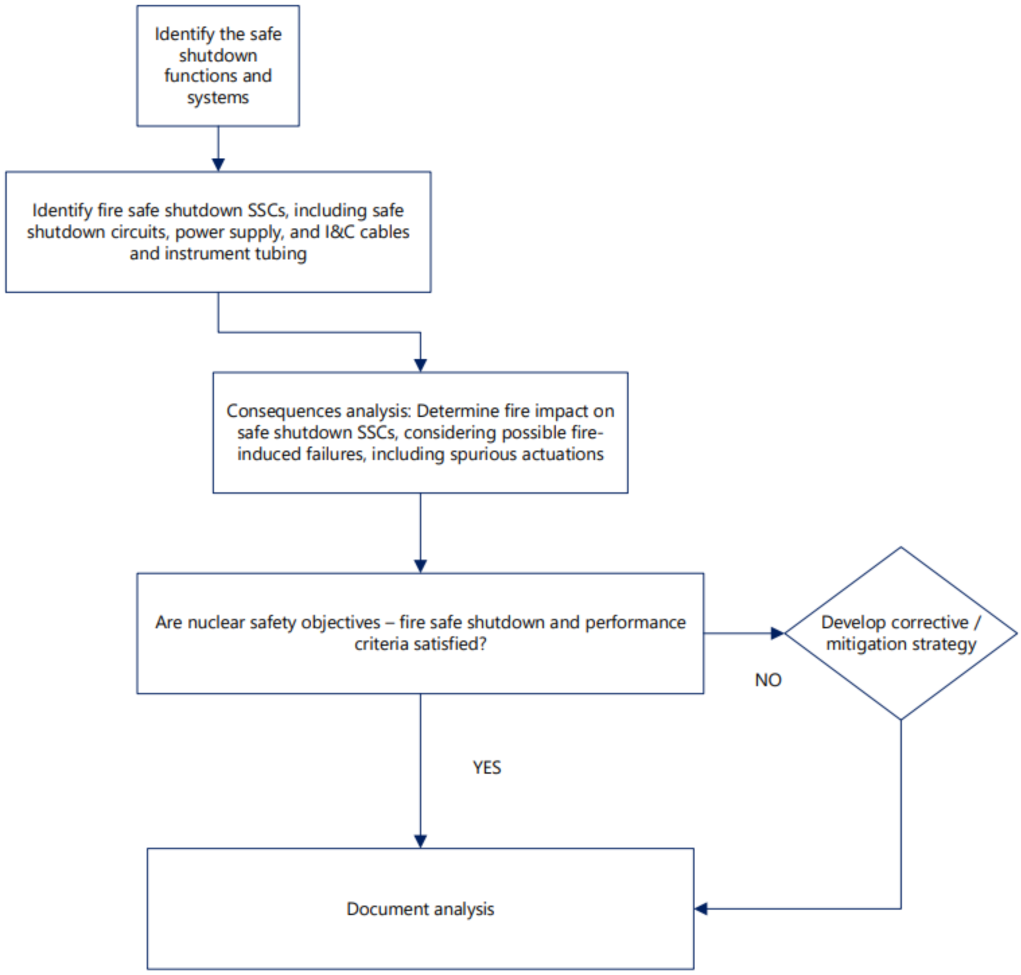


Figure 15.7-2: BWRX-300 Fire Safe Shutdown Analysis Methodology

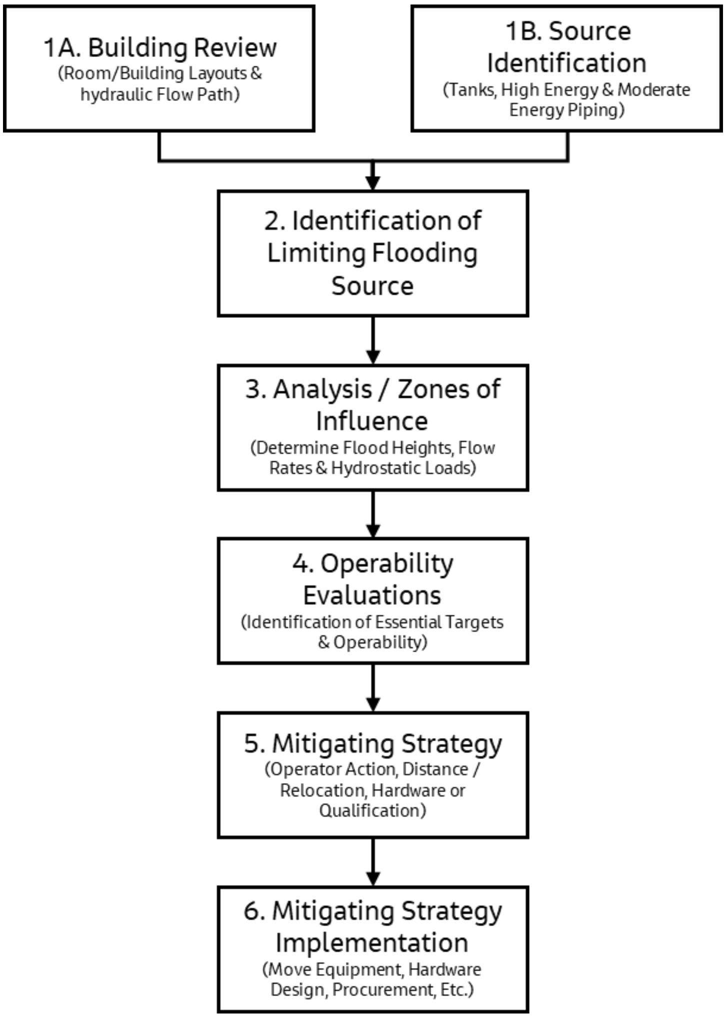


Figure 15.7-3: Internal Flooding Methodology Overview

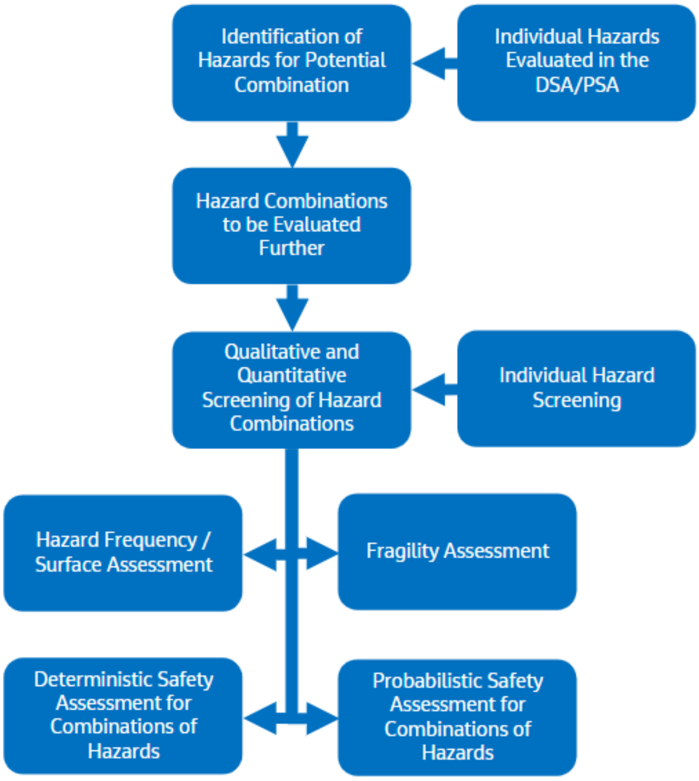


Figure 15.7-4: Overall Process for Selection, Screening and Analysis of Hazard Combinations

15.7.4 References

15.7-1. NEDC-34144P, “Internal Hazards Identification”, Revision 0, GE-Hitachi Nuclear Energy, May 2024

15.7-2. ONR NS-TAST-GD-014, “Technical Assessment Guide: Internal Hazards”, Issue 7.1, ONR, December 2022

15.7-3. NEDC-34148P, “BWRX-300 UK GDA Scope of Generic Design Assessment”, Revision 2, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-4. NEDO-34163, “BWRX-300 UK GDA Chapter 1: Introduction”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC

15.7-5. IAEA SSR-2/1, “Safety of Nuclear Power Plants: Design”, International Atomic Energy Agency, 2016.

15.7-6. IAEA GSR Part 4, “Safety Assessment for Facilities and Activities – General Safety Requirements”, International Atomic Energy Agency, 2016.

15.7-7. IAEA SSG-64, “Protection against Internal Hazards in the Design of Nuclear Power Plants”, International Atomic Energy Agency, 2021

15.7-8. 006N5064, “BWRX-300 Safety Strategy”, Revision 6, GE-Hitachi Nuclear Energy, January 2024.

15.7-9. NEDC-34143P, “Approach to Internal and External Hazards”, Revision 1, GE-Hitachi Nuclear Energy, May 2024.

15.7-10. 006N6567, “BWRX-300 Fire Hazard Assessment Requirements Document”, Revision 2, GE-Hitachi Nuclear Energy, November 2023.

15.7-11. 006N7487, “BWRX-300 Fire Safety Shutdown Requirement and Analysis Document”, Revision 1, GE-Hitachi Nuclear Energy.

15.7-12. NEDC-34139P, “BWRX-300 UK Codes and Standards Assessment”, Revision 3, GE-Hitachi Nuclear Energy, August 2024.

15.7-13. NEDO-34184, “BWRX-300 UK GDA Chapter 15.6: Safety Analysis – Probabilistic Safety Assessment”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-14. 008N1679, “BWRX-300 Internal Flooding Design Specification”, Revision 1, GE-Hitachi Nuclear Energy, July 2024.

15.7-15. 006N6938, “BWRX-300 Pipe Rupture Hazards Analysis Criteria”, Revision 1, GE-Hitachi Nuclear Energy, November 2023.

15.7-16. NEDO-34186, “BWRX-300 UK GDA Chapter 15.8: Safety Analysis – Analysis of External Hazards”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-17. 007N2154, “BWRX-300 Missile Protection Design Specification”, Revision 0, GE-Hitachi Nuclear Energy.

15.7-18. NEDO-34171, “BWRX-300 UK GDA Chapter 9A: Auxiliary Systems”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-19. NEDO-34165, “BWRX-300 UK GDA Chapter 3: Safety Objectives and Design Rules for SSCs”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-20. 008N9751, “BWRX-300 UK Probabilistic Safety Assessment Summary Report”, Revision B, GE-Hitachi Nuclear Energy, July 2025.

15.7-21. NEDO-34199, “BWRX-300 UK GDA Chapter 27: ALARP Evaluation”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-22. NEDO-34182, “BWRX-300 UK GDA Chapter 15.4: Safety Analysis – Human Actions”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-23. NEDO-34271, “BWRX-300 UK GDA Combined Hazards Topic Report”, Rev B, GE-Hitachi Energy, Americas, LLC.

15.7-24. NEDC 34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, April 2025

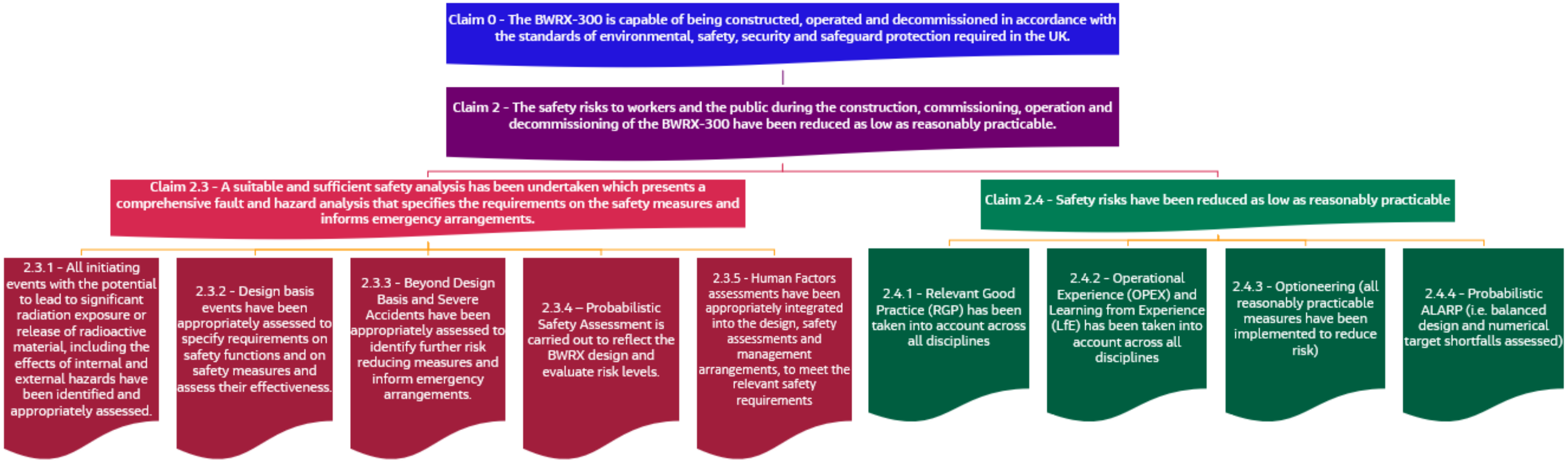
15.7-25. NEDO-34183, “BWRX-300 UK GDA Chapter 15.5: Deterministic Safety Analysis”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

15.7-26. NEDO-34194, “BWRX-300 UK GDA Chapter 22: Structural Integrity of Metallic Systems, Structures and Components”, Rev B, GE-Hitachi Nuclear Energy, Americas, LLC.

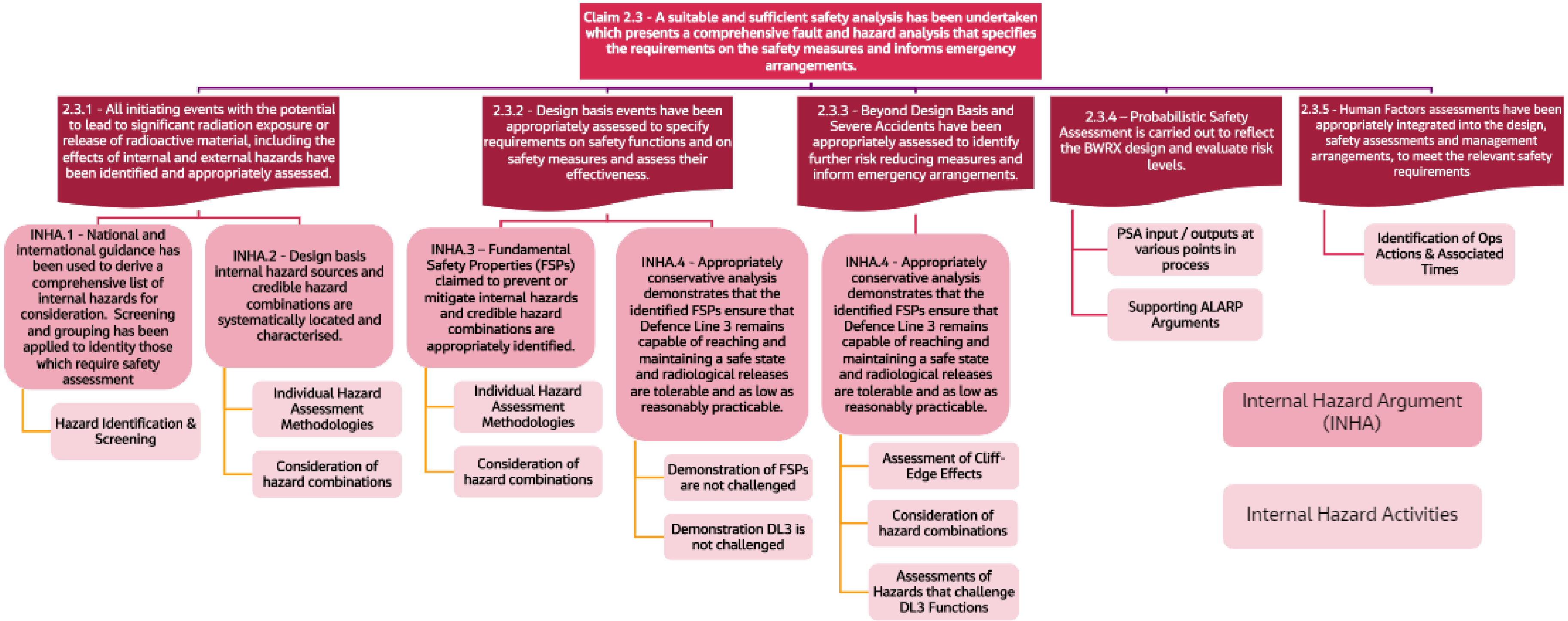
APPENDIX A CLAIMS & ARGUMENTS STRUCTURE AND ALARP DISCUSSION

Claims & Arguments Structure

The structure of the claims and sub-claims relevant to this Internal Hazards subchapter, which reside under the overarching Claim 0 for the BWRX300 GDA PSR are presented below. It should be noted that although some ALARP considerations shall be covered within this subchapter, relevant to the sub-claims under Claim 2.4 shown below, these sub-claims are covered in more detail in NEDO-34199, "BWRX-300 UK GDA Chapter 27: ALARP Evaluation", (Reference 15.7-21). In addition, although sub-claims 2.3.4 and 2.3.5 shown below interface with this subchapter, they are covered in more detail in PSR Subchapter 15.6 (Reference 15.7-13) and NEDO-34182, "BWRX-300 UK GDA Chapter 15.4: Human Actions", (Reference 15.7-22) respectively.



Therefore, the main safety claim that is addressed by this subchapter is Claim 2.3, which is met by the achievement of the identified sub-claims shown above. Demonstration of these sub-claims is via a number of primary arguments for Internal Hazards, which include the following:



The primary arguments for Internal Hazards and associated secondary arguments / activities that are covered by this subchapter are presented in the below table. These arguments and supporting activities are underpinned within this subchapter by use of appropriate RGP and OPEX, including the appropriate identification of sources and references.

Internal Hazards Primary Arguments	Secondary Arguments / Activities
INHA.1 - National and international guidance has been used to derive a comprehensive list of internal hazards for consideration. Screening and grouping have been applied to identity those which require safety assessment	Performed in NEDC-34144P (Reference 15.7-1), summarised in Section 15.7.1.6.
INHA.2 - Design basis internal hazard sources and credible hazard combinations are systematically located and characterised.	Hazard Assessment Methodology that enables: • Identification, location & characterisation of applicable hazards or credible hazard combinations • Identification of bounding cases of hazards or credible hazard combinations for assessment Note: this shall be addressed in Section 15.7.2.
INHA.3 - FSPs claimed to prevent or mitigate internal hazards and credible hazard combinations are appropriately identified.	Hazard Assessment Methodology that enables: • Identification of applicable FSPs for the Internal Hazards Note: this shall be addressed in Section 15.7.2.
INHA.4 - Appropriately conservative analysis demonstrates that the identified FSPs ensure that Defence Line 3 remains capable of reaching and maintaining a safe state and radiological releases are tolerable and as low as reasonably practicable.	Hazard Assessment Methodology that enables: • Demonstration that FSPs are met / not challenged • Demonstration that DL3 is not challenged • And incorporates the following elements: – Assessment of Cliff-Edge effects – Identification of Actions that may impact PSA – Identification of Human Factors Actions for further assessment – Appropriate optioneering and development of ALARP arguments Note: the deterministic assessment methodologies for each of the hazards presented in Section 15.7.2 are not yet mature and do not currently do not provide demonstration that the FSPs are met / not challenged or that DL3 is not challenged. Additionally, they do not currently incorporate the above listed elements. Therefore, a FAP item has been raised to further develop the methodologies for each of the internal hazards in order for this Argument to be demonstrated (Action PSR15.7-62 in Appendix B refers).

ALARP Discussion

Overall, the demonstration that internal hazards are ALARP requires deterministic methodologies that enable:

- Systematic identification of individual hazards and hazard sources, including credible combinations of hazards
- Characterisation of the hazard, or hazard combinations, that aligns with RGP
- Demonstration of the tolerability of consequences
- Demonstration that the analysis is appropriately conservative and considers RGP
- Informed decision making on potential changes needed (refinements to the assessments or design changes)

The current methodologies provide the basis for some of these aspects to be determined, but not all. This is notably in areas where hazards have been screened out on frequency alone and in determining the tolerability of consequences across most internal hazards.

The deterministic assessment is not mature enough to determine whether the consequences of the identified internal hazards are considered tolerable. 006N5064 (Reference 15.7-8) outlines the overall approach to hazards, which identifies that the treatment of hazards is largely performed outside of the DSA for the main fault list. Therefore, the DSA success criteria defined in Section 3.1.5 of 006N5064 (Reference 15.7-8), are not directly applicable to hazards. As indicated previously in Subsection 15.7.1.1, only hazards that directly impact the FSF (e.g. a LOCA event) are classed as a PIE and would be added to the fault list.

To determine whether the consequences of internal hazards are tolerable the current assessments are largely developed in the PSA, but there is a need to develop the deterministic assessment for hazards and therefore a need to develop success criteria that apply. 006N5064 (Reference 15.7-8) identifies the need for hazards to ensure that applicable FSPs are met or not challenged. In addition, the FSPs are required to ensure continued availability of all safety functions and measures associated with DL3. These requirements, (i.e. that the hazard related FSPs are met / not challenged or that DL3 is not challenged), have the potential to form the basis of success criteria for internal hazards to determine the tolerability of specific hazards or hazard sources.

These aspects are highlighted by several of the FAP items listed in Appendix B, which focus on the development of assessment methodologies. The development of the methodologies should consider what the outcome of the assessment is, to ensure the outputs provide sufficient information to articulate for internal hazards the ‘golden thread’ that runs through the analysis and the demonstration of ALARP.

In addition, it is envisaged that the following points shall support the demonstration of ALARP for risks arising from internal hazards:

- Internal hazards are identified and characterised based on RGP
- All credible combinations involving internal hazards are identified and will be assessed
- Optioneering exercises are conducted for UK-specific design changes to ensure that alternate design solutions are considered, reviewed and ranked prior to the selection of the chosen solution. This process is not limited to those aspects of the design that are modified for UK deployment.
- SSCs are designed and qualified with appropriate levels of conservatism and safety margins

- Internal hazard considerations are included in the development of general plant layout. For example, considering the collapse of non-safety classified structures on safety classified SSCs following a seismic event or the orientation of rotating plant compared to safety classified SSCs.

APPENDIX B INTERNAL HAZARDS FORWARD ACTIONS

Action ID	Finding	Forward Actions	Delivery Phase
PSR3-1	Safety goals are currently set for the BWRX-300 target Core Damage Frequency and Large Release Frequency. Whilst these are useful metrics to assess, they do not allow comparison with the UK ONR SAP Numerical Targets 4-9 within the PSR.	Determine and justify the numerical targets to be adopted for the UK implementation of the BWRX-300 and document them in the specification for the SCM for implementation of the BWRX-300 in the UK. This action has been addressed during GDA Step 2 via the production of NEDC 34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, which includes an outline of the approach to developing a radiological criterion suitable for defining the set of faults subject to design basis analysis and judging the effectiveness of the safety measures designated in the design basis analysis (as identified in FAP item PSR15.5-32 in PSR Subchapter 15.5). Note: detailed methods development and performance of analysis will be in a later licensing phase.	Within Step 2
PSR15-3	Whilst sufficient for the PSR, the underpinning Fault and Hazards Analysis methodologies are not consistent with RGP for use in support of a UK PCSR. The following methodologies will require revision / refinement for use in the PCSR: • Level 3 PSA • External hazards analysis of Radioactive Waste Structures • Deterministic analysis of hazards and combined hazards • Turbine generated missiles • Aircraft impact	Agree the approaches to be adopted for the UK implementation of the BWRX-300 and document them in the specification for the SCM for implementation of the BWRX-300 in the UK. This action has been addressed during GDA Step 2 via the production of NEDC 34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, which outlines the requirements for a SCM for the deployment of the BWRX-300 baseline design in the UK, which the future phases of the project will need to consider. Within this specification it highlights an approach to the development of information or methodologies (associated with the items listed in the Finding) to meet	Within Step 2

Action ID	Finding	Forward Actions	Delivery Phase
	• Application of BEZs • Consideration of moderate energy pipework	UK regulatory expectations and requirements within the PCSR and provides a level of confidence that identified differences will be addressed. Note: detailed methods development and performance of analysis will be in a later licensing phase.	
PSR15.7-21	In the assessment of HELBs from infrequently energised lines, the '2% rule' has been applied in the BWRX-300 design to exclude the following from assessment: G11 – Boron Injection System (meets High Energy criteria under accident conditions, a proportion of the system meets High Energy criteria during pump testing) G22 – Shutdown Cooling System G41 – Fuel Pool Cooling and Cleanup System (meets High Energy criteria under off-normal conditions) K10 – Liquid Waste Management System (meets High Energy criteria under off-normal conditions) N37 – Turbine Bypass System T10 – Passive Containment Cooling System (meets High Energy criteria under accident conditions) T31 – Containment Inerting System (meets High Energy criteria under severe accident conditions) This is not a rule that can be applied, as UK expectation is that short duration of operation should not be used to exclude the most onerous failures from the safety case.	The 2% rule will not be applied to the UK project and the PRHA will be updated in support of the next licensing phase. Priority will be given to the G11, G22 and N37 systems followed by the G41 and K10 systems and then the T10 and T31 systems.	For PCSR/PCER
PSR15.7-62	<u>Use of DSA in the Assessment of Internal Hazards</u>		For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	The regulatory requirements are that the assessment of internal hazards should expect to include deterministic and probabilistic data in the analysis of hazards, with a greater emphasis on deterministic means of demonstrating safety. The methodologies for the assessment of internal hazards should demonstrate deterministically that the FSPs are met or not challenged and that the SSCs performing DL3 functions are not impacted by the hazards. In addition, the methodologies should consider the following: • Assumptions and conservatisms • Consideration of cliff-edge effects • Illustrative analyses • Consideration of cross-cutting issues in the safety case. However, this is not the current position for the internal hazards (Note: the level of maturity of the information currently available varies between the different hazards).	The action should look to develop an approach on the use of DSA to assess internal hazards, this has been addressed for GDA Step 2 via the gap recorded in PSR15-3, for which NEDC 34357P, "BWRX-300 UK GDA Safety Case Manual Specification", Rev 0, has been produced. Develop detailed methodologies for PCSR/PCER for the deterministic assessment of internal hazards, such that it demonstrates that the FSPs for a particular hazard have been met and that DL3 is not challenged. As part of that development, the methodologies for all internal hazards should also consider the following: assumptions and conservatisms; consideration of cliff-edge effects; illustrative analyses; and consideration of cross-cutting issues in the safety case. Any software tools or codes used in the analyses should be identified along with what (if any) uncertainties might exist). The methodologies should ensure that identified risks will be subject to extant GE Hitachi Nuclear Energy (GEH) processes for risk reduction and enable an ALARP demonstration to be made that meets UK expectations.	
PSR15.7-63	<u>Application of BEZs</u> The application of a BEZ as described in PSR Chapter 3 Attachment A Section 3.2.4.1 does not align to UK RGP. To align with UK RGP, the presentation of justification / substantiation should consider: • Looking at the developments in the standard plant, and the supporting justification / substantiation.	The action should look to develop an approach for the highest integrity components in the assessment of internal hazards, this has been addressed for GDA Step 2 via the gap recorded in PSR15-3, for which NEDC 34357P, "BWRX-300 UK GDA Safety Case Manual Specification", Rev 0, has been produced.	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	• Look to represent the information in a Claims, Arguments, Evidence structure, developing muti-legged arguments for the items where the highest integrity claims are made. • Look to incorporate the information presented in NEDO-34194, "BWRX-300 UK GDA Chapter 22: Structural Integrity of Metallic Systems, Structures and Components", (Reference 15.7-26) into the multi-legged arguments and identification of potential sources of future evidence. • Review the proposed approach to consider the challenges from other disciplines (e.g. radiological protection) to inform what is reasonably practicable. • Review UK RGP to determine if any further potential gaps arise and understand how or when these can be addressed. • Ensure the information can demonstrate the approach is ALARP.	Following that the action should look to develop detailed methodologies for PCSR/PCER that incorporates the considerations listed in the Finding in order to establish what further work might be needed to address any gaps or shortfalls. This would benefit from input from the appropriate GEH piping and structural integrity teams.	
PSR15.7-64	<u>Consideration of DEGB for Seismically Supported, Moderate-Energy Piping</u> Postulating DEGB for moderate-energy pipework to determine if the unmitigated consequences are tolerable, irrespective of the seismic classification, is considered good practice. However, this represents a gap in the BWRX-300 analysis due to the failures of seismically classified pipes only postulating through wall cracks. As a result, the flooding consequences assessed only assume leak rather than DEGB flow rates. Therefore, more onerous consequences (larger	The action should look to develop an approach regarding when and where DEGB is considered in the assessment of internal hazards, this has been addressed for GDA Step 2 via the gap recorded in PSR15-3, for which NEDC 34357P, "BWRX-300 UK GDA Safety Case Manual Specification", Rev 0, has been produced. Beyond the development of the initial approach, an action should look to develop detailed methodologies	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	flooding rates and flooding volumes) are potentially excluded from the current flooding analysis.	for PCSR/PCER in order to understand the scale / scope of pipework where DEGB has not been assessed. The additional scope would then be assessed accordingly via the existing flooding methodology.	
PSR15.7-65	<u>Pipe-whip and Jet Effects for Moderate-Energy Piping</u> The UK regulatory expectation highlights that the assumption for no pipe whip below 2.0Mpa is not rigorous. It is acknowledged that, while the impacts may not damage walls or structures, the potential effects on fragile plant components such as delicate instruments should be considered. Therefore, it is expected that pipe-whip and jet effects are also considered for moderate-energy piping, especially for those systems that operate close to the high-energy threshold criteria.	As with other actions for internal hazards, the future action should look to develop an approach regarding when and where pipe-whip and jet effects are considered in the assessment of internal hazards, this has been addressed for GDA Step 2 via the gap recorded in PSR15-3, for which NEDC 34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, has been produced. Beyond this, the action should develop methodologies for PCSR/PCER in order to define a scope of work that meets with the approach adopted to assess the consequences of pipe-whip and jet for moderate energy lines.	For PCSR/PCER
PSR15.7-66	<u>Turbine-Generated Missiles</u> The current analysis supports the design of barriers that resist internally generated missiles (outside and inside containment), turbine missiles, missiles generated by natural phenomena, and site proximity missiles (except aircraft). It was noted that the expectation of further work would show the risk from potential turbine missiles is acceptably small, either because design features are	This action should look to develop an approach regarding turbine-generated missiles in the assessment of internal hazards, this has been addressed for GDA Step 2 via the gap recorded in PSR15-3, for which NEDC 34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, has been produced. Beyond this, the action should develop detailed methodologies for PCSR/PCER in order to define a scope of work that meets with the approach adopted to	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	provided to prevent damage or because the probability of a strike by a turbine missile is sufficiently low. The ONR Technical Assessment Guide for Internal Hazards (NS-TAST-GD-014) identifies that (in paragraph 5.138) that "The significance of turbine disintegration events as an internal hazard is recognised in relevant good practice including IAEA and US NRC guidance". Paragraph 5.139 goes onto note that "Inspectors should therefore expect safety cases to include turbine disintegration events within the design basis and demonstrate that the events will not disable safety related plant and equipment or that there is an adequate combination of engineered safeguards and management controls to reduce the risk so far as is reasonably practicable (SAPs EHA.1, EHA.3, EHA.6, EHA.5, and EHA.14)". However, there is currently limited information on the deterministic assessment of turbine generated missiles or what the further work might entail. Given the focus on turbine generated missiles in the GDA process, this will be considered separately to other internal missile sources.	assess the consequences of turbine generated missiles. This should take on board previous lessons learned and engage the right groups within GEH to enable a suitable and sufficient safety case to be developed.	
PSR15.7-67	Other Internal Missiles The current analysis supports the design of barriers that resist internally generated missiles (outside and inside containment), turbine missiles, missiles generated by natural phenomena, and site proximity missiles (except aircraft).	The action should look to develop an approach regarding internal missiles in the assessment of internal hazard, this has been partially addressed for GDA Step 2 via the NEDC 34357P, "BWRX-300 UK GDA Safety Case Manual Specification", Rev 0, which outlines the	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	However, there is currently limited information on the deterministic assessment of missiles, and this is considered a gap.	deterministic approach to the assessment of internal hazards. Beyond this, the action should develop detailed methodologies for PCSR/PCER in order to define a scope of work that meets with the approach adopted to assess the consequences of internal missiles. This should take on board previous lessons learned and engage the right groups within GEH to enable a suitable and sufficient safety case to be developed. It should be noted that the identified methodology currently considers all missiles, excluding aircraft, and as such is applicable to external hazards also (as presented in PSR Subchapter 15.8). Therefore, the approach developed should also include external missiles, such as missiles generated by natural phenomena and site proximity missiles (except aircraft).	
PSR15.7-68	<u>Internal Explosions</u> There is currently limited information available for the deterministic assessment of the BWRX 300 Internal Explosion Hazard. Although explosion hazards and mitigations are identified in some of the Room Data Sheets in 006N6567, "BWRX-300 Fire Hazard Assessment Requirements Document", Rev 2, this will need to be updated as the design matures. In addition, it is unclear whether the systems identified are claimed as SSCs for nuclear safety or if SSCs are located elsewhere in the room / location. It should be noted that where arguments are presented for the exclusion of certain sources, the arguments	This action should develop detailed methodologies for PCSR/PCER in order to define a scope of work that meets with the approach adopted to assess the consequences of internal explosions. This should take on board previous lessons learned and engage the right groups within GEH to enable a suitable and sufficient safety case to be developed that is aligned to regulatory expectations.	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	should be suitably robust. For instance, the exclusion may be based on equipment design (e.g. design of HVAC and hydrogen detection in battery rooms). Sufficient information will need to be provided for the design strategy and sizing of this equipment to support the arguments. The information presented should make it clear whether any such equipment is claimed in any of the nuclear safety DLs. Due to the limited information on the deterministic assessment of internal explosions this is considered a gap.		
PSR15.7-69	<u>Dropped Loads</u> Dropped and impacting loads are partially addressed as part of Internal and External Missiles, as missiles due to gravitational effects. These are missiles that are caused by, or are a consequence of, gravitational effects. However, there is currently limited information on the deterministic assessment of dropped loads or what further work might entail. Given the focus on dropped loads in the GDA process the current information is considered a gap.	The action should look to develop an approach regarding dropped and impacting loads in the assessment of internal hazards, this has been partially addressed for GDA Step 2 via NEDC 34357P, "BWRX-300 UK GDA Safety Case Manual Specification", Rev 0, which outlines the deterministic approach to the assessment of internal hazard. Consideration within the scope of the approach should also be given to including the collapse of significant internal structures (e.g. crane or steelwork structures) and toppling of stacked loads (e.g. dry-store fuel casks). Beyond this, the action should develop detailed methodologies for PCSR/PCER in order to define a scope of work that meets with the approach adopted to assess the consequences of dropped and impacting loads. This should take on board previous lessons learned and engage the right groups within GEH to	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
		enable a suitable and sufficient safety case to be developed.	
PSR15.7-70	<u>Consideration of 'Cliff-Edge' Effects</u> Current cliff-edge assessments are limited to PSA only, at the boundaries of DB/DEC and DEC/SAA. No deterministic considerations are assessed for internal hazards or around specific hazard effects; therefore, this is considered a gap. There is the potential for this action to incorporate external hazard cliff-edge effects, if they are currently assessed in the same manner. It is possible that the deterministic assessments of single hazards already take account of changes in the hazard effects that could result in cliff-edges. For instance, HELB assessments do consider whip and jet simultaneously. Therefore, some potential cliff-edges for this hazard will be addressed as part of the committed future work on HELB. However, it is not clear if these types of changes to effects, or other factors that change the hazard consequences, are considered across all hazards. These may be identified in the approaches to deterministic assessments that have yet to be developed or shared.	The action should look to develop an approach regarding the deterministic assessments of cliff-edges in the assessment of internal hazards, this has been partially addressed for GDA Step 2 via NEDC 34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, which outlines the deterministic approach to the assessment of internal hazard. Beyond this, the action should develop detailed methodologies for PCSR/PCER in order to define a scope of work that meets with the approach adopted to assess the consequences of cliff-edge effects on a hazard-by-hazard basis. This should take on board previous lessons learned and engage the right groups within GEH to enable a suitable and sufficient safety case to be developed.	For PCSR/PCER
PSR15.7-71	<u>Hazard Inputs to the Hazard Schedule</u> Due to the approach to Hazards in 006N5064, “BWRX-300 Safety Strategy”, Rev 6, internal hazards and combined hazards do not get covered in the fault list, only direct PIEs are covered (e.g. LOCA). However,	The action should look to develop an approach regarding the deterministic assessments of internal hazards and the outputs of the assessment, this has been partially addressed for GDA Step 2 via	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	pipe rupture or flooding or fire (and any indirect PIEs) are not assessed. The deterministic approach is (in part) to demonstrate that the individual or combined hazard effects do not impact DL3 functions or measures as a whole. However, the current approach does not demonstrate that specific safety features to minimise or mitigate the consequences of the hazard are impacted. Taking the current approach, it is not possible to identify individual hazard initiators / sources, the unmitigated consequences, or the associated safety measures / functions. This may need a different approach to enable the development of a hazard schedule, but it currently represents a gap.	NEDC-34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, which outlines the deterministic approach to the assessment of internal hazard. Beyond this, the action should develop detailed methodologies for PCSR/PCER in order to present the outputs of the deterministic assessment of internal hazards in a manner that supports hazard schedule development. This should take on board previous lessons learned and engage the right groups within GEH to enable a suitable and sufficient safety case to be developed. The DSA should demonstrate that the FSPs for a particular hazard have been met and that DL3 is not challenged. The development of the DSA methodologies should consider what inputs and outputs would be needed to present information in a format analogous to a hazard schedule.	
PSR15.7-72	<u>Identification of Combined Hazards</u> The current approach to the assessment of hazard combinations largely reflects the limited consideration of combined hazards within the PSA. It does not fully consider deterministic aspects in the approach; this is particularly relevant within the identification and screening of credible combinations. Much of the discussion on hazard combinations is taken from 008N9751, “BWRX-300 PSA Summary Report”. The approach that is outlined in the document does indicate the potential for DSA of combinations, but the shape of	The action should look to develop an approach regarding the deterministic assessment of credible hazard combinations, this has been addressed for GDA Step 2 via the gap recorded in PSR15-3, for which NEDC 34357P, “BWRX-300 UK GDA Safety Case Manual Specification”, Rev 0, has been produced. Beyond this, the action should develop detailed methodologies for PCSR/PCER in order to deterministically assess hazard combinations (external combinations, internal combinations, and external to internal combinations). This should take on board	For PCSR/PCER

Action ID	Finding	Forward Actions	Delivery Phase
	future DSA for hazard combinations is not known. Therefore, this is considered a gap. This action should focus on the deterministic assessment of hazards, including identification, screening, characterisation and assessment of consequences. In addition, it should include external combinations, external to internal combinations and internal combinations. The probabilistic assessment of hazard combinations will be addressed separately within the UK PSR Subchapter 15.6 (PSA).	previous lessons learned and engage the right groups within GEH to enable a suitable and sufficient safety case to be developed that appropriately interacts with the PSA. It is acknowledged that some external hazards may only be determined at the site-specific stage and as such, combinations involving these hazards may only be assessed at this point.	
PSR15.7-73	Update of Input Information for Internal Fire Key documents that provide an input to the development of the Internal Fire Safety Case are 006N6567, "BWRX-300 Fire Hazard Assessment Requirements Document", Rev 2, and 006N7487, "BWRX-300 Fire Safety Shutdown Requirement and Analysis Document", Rev 1. Both documents are currently being updated or have identified the need for future updates as the design matures. Future changes will need to be reflected in future updates of the documents to be submitted.	The scope of future work needs to be reviewed to ensure deterministic assessments are suitable and sufficient to meet regulatory expectations. In addition, the approach should align to wider deterministic assessment of internal hazards.	For PCSR/PCER

APPENDIX C INTERNAL FIRE ASSESSMENT ILLUSTRATIVE EXAMPLES

Introduction

Purpose

This appendix presents an overview and examples of the FSSA produced for the conceptual design of the BWRX-300. The level of detail is commensurate with the Step 2 GDA and the examples presented are intended to illustrate the robustness of the methodology and do not necessarily represent the final conclusions of the assessment as the design is still under development. The assessment is at an early stage and based on draft information, as such the extracts are shown for illustration purposes only.

Scope

The methodology for the FSSA is summarised is shown in Figure 15.7-2.

This appendix summarises the assessments produced in 006N7487 (Reference 15.7-11) using data from 006N6567 (Reference 15.7-10). It should be noted that the FSSA is not yet fully developed, and the examples provided within this appendix have been presented for the purposes of illustrating the general approach and robustness of the method for the deterministic assessment of the Internal Fire Hazard, rather than to present a complete assessment. Further illustrative analyses will be presented in the future when the deterministic assessment for the Internal Fire Hazard matures, and this is covered by Action PSR15.7-62 on the FAP (Appendix B refers).

Appendix Structure

The structure of this appendix follows the steps shown in Figure 15.7-2. The safe shutdown functions and systems are identified in this appendix, following which, safe shutdown SSCs are identified. The assessment of illustrative examples of individual fire hazard areas which contain equipment claimed for nuclear safety that might be affected by a fire in the area is then presented via consequence assessment and assessment against fire safe shutdown criteria.

Step 1 – Identify the Safe Shutdown Functions and Systems

The safe shutdown functions and systems are summarised in Figure C-5 below. The analysis only considers the Reactor Building at this stage in the project lifecycle.

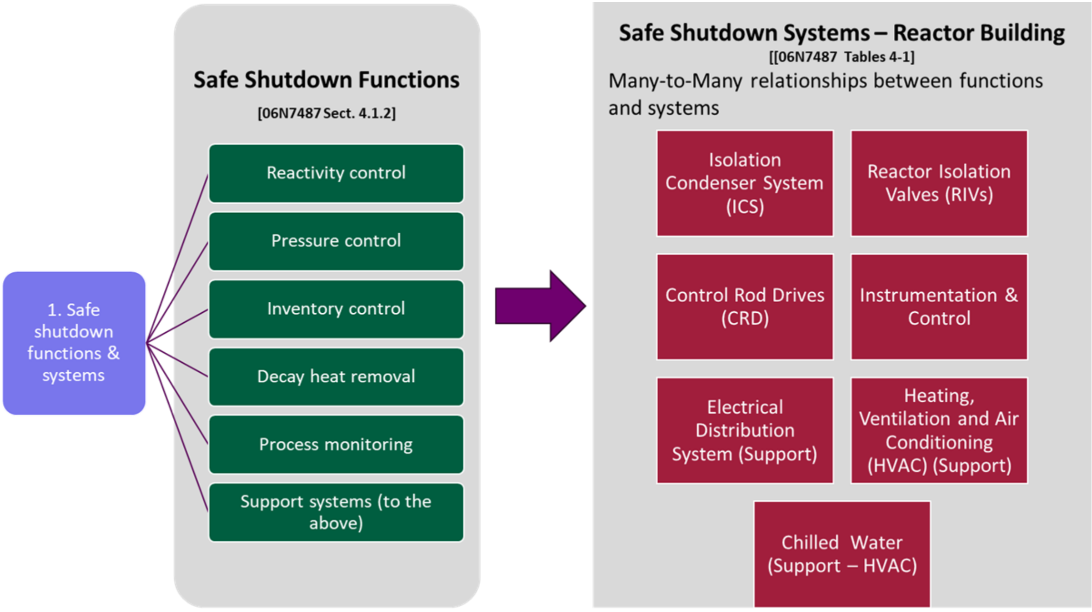


Figure C-5: Safe Shutdown Functions and Systems

Step 2 – Identify the Safe Shutdown SSCs

Safe Shutdown Components identified for these systems are shown in Figure C-6 below.

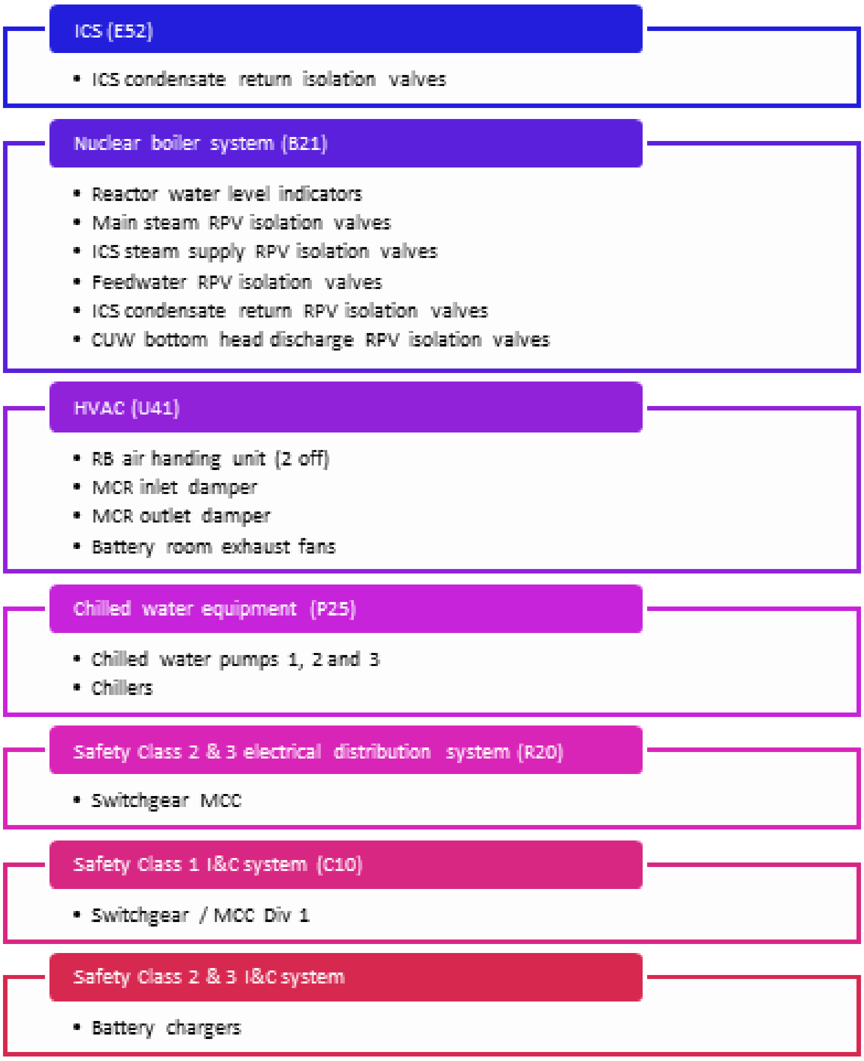


Figure C-6: Safe Shutdown Equipment

The FSSA includes a preliminary analysis of cable routes associated with this equipment, although it is noted that the cable routing data is not yet mature, so the assessment is based on very early data only.

Step 3 – Consequence Analysis

The previous steps in the analysis were carried out at high level, but Step 3 onwards considers the effects of fire in individual fire areas. Over 100 fire areas have been analysed, so this appendix only presents a small selection of representative examples to illustrate the process. The examples chosen are fire areas that have potential ignition sources and combustible materials, and which are expected to contain systems claimed for shutdown.

The deterministic assessment methodology conservatively assumes that systems within a fire area are damaged regardless of the actual combustible inventory or ignition sources in the room, or the presence of fire detection and suppression systems.

Example 1: Fine Motor Control Rod Drive (CRD) Group 1 Control Fire Area

The Room Data Sheet from 006N6567 (Reference 15.7-10) shows that this area contains Group 1 control equipment and cables. The equipment identified in this area is from a single safety classified division.

Major combustibles identified in this area include cables in trays, switchgear, motor controls, Uninterruptible Power Supplies (UPS), batteries, sump pumps and controllers. Ignition sources are identified as switchgear, motor control, UPS, and batteries.

A fire is postulated to start within the controllers and could spread to all cable and adjacent equipment in the room. The data sheet states that fire will not spread to other areas as the area is intended to be enclosed by 3-hour fire rated barriers, and other barriers which although not rated, are of substantial construction.

Example 2: Primary Containment Fire Area

This fire area includes the reactor vessel. Cables from all three divisions have been routed through this area, but the Room Data Sheet in 006N6567 (Reference 15.7-10) notes that the primary containment is inerted with nitrogen during normal operation so that a fire could not occur.

The primary containment fire area contains cables in trays as major combustibles, and electrical panels as ignition sources. No fire scenarios are postulated during normal operations because the primary containment is inerted with nitrogen. The room data sheet does not include any discussion about the possibility of a fire during other plant states after the inert atmosphere has been removed to allow personnel access for maintenance, but this has been considered in the subsequent analysis of Steps 4 - 6 in the FSSA.

Steps 4 - 6: Assessment Against Fire Safe Shutdown and Performance Criteria

The examples described in the previous section are then assessed further in the FSSA document to determine whether one train of safe shutdown equipment would remain free from fire damage. The examples presented in this GDA subchapter have been chosen to illustrate one fire area which successfully meets the criteria, and one which fails to meet the criteria.

Example 1: Fine Motor CRD Group 1 Control Fire Area

No safe shutdown functions are identified as being failed in Table 4-5 of 006N7487 (Reference 15.7-11), so this fire area is concluded to pass the assessment.

Although not explicitly stated in the FSSA table, this result is consistent with the previous step which only identifies equipment from a single division as being present in the room, and the fire resistance of the fire area boundaries which prevent a fire from spreading beyond the area.

Example 2: Primary Containment Fire Area

Several safe shutdown systems are identified in Table 4-5 of 006N7487 (Reference 15.7-11) as being failed in this fire area, including all three trains of the Isolation Condenser System (ICS). Resolutions have therefore been identified in the FSSA to allow for the failed safe shutdown systems in different operating modes, and these are summarised below.

During operation at power: The inert containment atmosphere precludes initiation or propagation of a fire.

During shutdown modes when the inert atmosphere has been removed: Spatial separation of redundant components within the plant area is claimed, and the combustible inventory is stated to be low. Although both the CRD and HCU systems might sustain damage, the assessment concludes that there would be no effect on plant safe shutdown because all control rods would have been inserted into the reactor before removing the inert atmosphere. Further backup of reactor scram capability and maintenance of safe shutdown can be provided by other systems such as the Boron Injection System which are located in other fire areas of the plant. The assessment also identifies the fire resistance of the boundaries of the reactor containment fire area which would prevent a fire from spreading beyond this area. It is noted that currently the assessment of this room in the FSSA only addresses reactivity control and does not cover decay heat removal; however, as noted earlier in this appendix, the FSSA is not yet fully developed and further illustrative analyses details will be presented in the future when the deterministic assessment for the Internal Fire Hazard matures, and this is covered by Action PSR15.7-62 on the FAP (Appendix B refers).

The above resolutions are based on preliminary unverified information and would be expected to be developed further for subsequent stages of the design.