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| ONR Report  ONR’s Regulatory influence on the EPR Design in the UK |



ONR Report

ONR’s Regulatory influence on the EPR Design in the UK

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# Executive Summary

Hinkley Point C (HPC) is a high-profile project and attracts widespread stakeholder attention. In early 2024 NNB GenCo (EDF) released public communications that referenced some 7,000 design changes in order to meet ‘British regulations’, including 35% more steel and 25% more concrete (when compared to the reference plant at Flamanville in France). Although NNB Genco has not attributed these figures to ONR’s regulation, recent media reports have increasingly cited ONR as the sole driver for the changes.

To ensure that we continue to consider the impact of our regulation, and to incorporate learning for the future, we conducted a review of the design evolution of the European Pressurised Water Reactor (EPR) at Hinkley Point C (HPC). The aim of this review was to understand the role we may have played in the large number of changes cited, and to further learn from experience. This report details the review undertaken and the conclusions reached.

ONR engaged positively with NNB GenCo who co-operated with this review. The aim of this engagement was to understand details of the design changes it considers has had the greatest impact on cost and schedule. This identified seven groups of changes:

* High integrity components.
* Categorisation and classification.
* Control and instrumentation architecture.
* Additional heating, ventilation, and air conditioning.
* Use of fibre free Insulation.
* Greater use of concrete and steel.
* Miscellaneous smaller changes.

This report discusses the overall number of design changes and provides additional detail on the seven groups of significant change identified by NNB GenCo.

Across the sample of modifications reviewed, the conclusions were broadly similar.

All the identified changes were proposed by or discussed with the UK European Pressurised Water Reactor (UK EPR) requesting parties (EDF and AREVA) during the Generic Design Assessment (GDA) in the period 2008 to 2012.

On balance, ONR believes that the modifications reviewed were proportionate, and that its approach was broadly consistent with that of other international regulators.

An intent of the GDA is to help reduce the developer’s risks on costs and timescales by providing clarity on design changes as early as possible. This was achieved for the UK EPR; the modifications reviewed were identified early and have remained largely unchanged since 2012.

Contents

[Executive Summary 1](#_Toc178776906)

[1. NNB GenCo Statement 4](#_Toc178776907)

[2. Review Findings 4](#_Toc178776908)

[3. High Integrity Components (HIC) 6](#_Toc178776909)

[3.1. Overview 6](#_Toc178776910)

[3.2. Differences in regulatory approaches 7](#_Toc178776911)

[3.3. Safety benefit 7](#_Toc178776912)

[3.4. Impact 8](#_Toc178776913)

[4. Categorisation and Classification 8](#_Toc178776914)

[4.1. Overview 8](#_Toc178776915)

[4.2. Differences in regulatory approaches 10](#_Toc178776916)

[4.3. Safety benefit 10](#_Toc178776917)

[4.4. Impact 10](#_Toc178776918)

[5. Control and Instrumentation Architecture 10](#_Toc178776919)

[5.1. Overview 10](#_Toc178776920)

[5.2. Differences in regulatory approaches 12](#_Toc178776921)

[5.3. Safety benefit 13](#_Toc178776922)

[5.4. Impact 13](#_Toc178776923)

[6. Additional Heating, Ventilation, and Air Conditioning 14](#_Toc178776924)

[6.1. Overview 14](#_Toc178776925)

[6.2. Differences in regulatory approach 15](#_Toc178776926)

[6.3. Safety benefit 15](#_Toc178776927)

[6.4. Impact 16](#_Toc178776928)

[7. Use of fibre-free insulation 17](#_Toc178776929)

[7.1. Overview 17](#_Toc178776930)

[7.2. Differences in regulatory approaches 17](#_Toc178776931)

[7.3. Safety benefit 18](#_Toc178776932)

[7.4. Impact 18](#_Toc178776933)

[8. Greater use of concrete and steel 19](#_Toc178776934)

[8.1. Overview 19](#_Toc178776935)

[8.2. Differences in regulatory approach 19](#_Toc178776936)

[8.3. Safety benefit 20](#_Toc178776937)

[8.4. Impact 20](#_Toc178776938)

[9. Other Design Changes 21](#_Toc178776939)

[9.1. Fuel route - overview 21](#_Toc178776940)

[9.2. Fuel route - differences in regulatory approaches 22](#_Toc178776941)

[9.3. Fuel route - safety benefit 22](#_Toc178776942)

[9.4. Fuel route - impact 22](#_Toc178776943)

[9.5. UK standards on fire safety - overview 23](#_Toc178776944)

[9.6. UK standards on fire safety - differences in regulatory approaches 23](#_Toc178776945)

[9.7. UK standards on fire safety - safety benefit 23](#_Toc178776946)

[9.8. UK standards on fire safety - impact 23](#_Toc178776947)

[10. Conclusions 24](#_Toc178776948)

[11. References 25](#_Toc178776949)

# NNB GenCo Statement

In January 2024, NNB GenCo announced cost and schedule increases to the Hinkley Point C (HPC) project. To accompany this announcement, a stakeholder newsletter was published titled “January 2024 – Hinkley Point C”, which stated:

“*The design has been substantially adapted to meet British regulations with 7,000 design changes, adding 35% more steel and 25% more concrete – all designs must go through this process*.”

This statement was included within the public project update video published on the HPC website [1]. The figures were subsequently quoted in the media and continue to be repeated by journalists and others.

# Review Findings

The broad findings are:

* Many changes resulted from learning from other EPR projects, and site-specific factors unique to HPC.
* A number of design changes were driven by factors outside of ONR’s influence, relating to aspects where the Environment Agency and the Health and Safety Executive are/were the regulatory authorities.
* ONR has been unable to identify the detail of the 7,000 changes identified by NNB GenCo. From the review, we believe the number includes approximately 5,000 that occurred during the basic design phase (reference configuration [RC]) RC1 in the period 2014-2018, and a further 2,000 that were initially specified within the RC2 detailed design stage in 2019.
* A breakdown of the approximately 5,000 design changes that occurred during the basic design phase RC1 is not available. Based on more detailed information provided by NNB GenCo in relation to the detailed design phase RC2, it is expected that those changes that are nuclear safety significant, and related to ONR’s regulation, represent a small percentage of this total.
* NNB GenCo categorises design changes into one of three types. Type 1 changes are significant impact, Type 2 changes are medium impact, with no safety purpose but medium cost impact and Type 3 changes are small impact (typically documentation changes). Type 1 changes have a potential important safety purpose or significant cost or schedule impact.
* Based on information provided by NNB GenCo, only 7% of the modifications during the detailed design phase RC2 were Type 1 – significant impact, and only a proportion of these will have been related to nuclear safety, as this category also covers high cost and schedule impact, which are not necessarily linked to nuclear safety.
* During the GDA, and prior to site licensing, a total of 82 design changes were proposed by EDF and AREVA, and further details are given below. A full list of GDA design changes is given in Table 2 of the assessment report for close out of cross-cutting GDA Issue GI-UKEPR-CC-02 [2].
* At the end of Step 4 of GDA, 28 design changes were agreed by ONR for inclusion in the GDA reference design. These design changes arose from proposals from EDF and AREVA to improve the UK EPR reactor design, either from experience gained on other EPR projects or from regulatory challenges.
* During the GDA close-out phase, a further 54 design changes were proposed by EDF and AREVA within their responses to the GDA Issues and accepted by the Regulators (ONR and Environment Agency). In ONR’s opinion, these related mainly to the following areas:
  + Instrumentation and control improvements.
  + Fault studies.
  + Categorisation and classification.
  + Structural integrity.
  + Fukushima learning.

ONR believes that the modifications reviewed were proportionate and aligned with international standards. Furthermore, ONR’s approach was broadly consistent with that of other international regulators, who in some instances required similar design improvements. However, we accept the level of effort required to implement these changes has proven to be higher than EDF and AREVA estimated at the time of GDA.

In 2024, ONR asked NNB GenCo to identify the key groups of changes they consider are a result of ONR’s regulation. In response, NNB GenCo identified:

* Claimable software reliability.
* Categorisation and classification of safety systems.
* Heating, ventilation and air conditioning (HVAC) system modifications.
* High integrity components (HIC) requirements.
* Insulation material inside the containment building; and,
* Concrete volumes.

The changes identified are familiar to ONR and relate to GDA (2008-2012), except for those specifically concerned with concrete volumes.

The changes are considered in more detail in the subsequent sections of this report. ‘Claimable software reliability’ has been referred to in this report as ‘control and instrumentation architecture.’

ONR has also been unable to establish whether the changes to HPC, compared to those of the reference plant (Flamanville 3, design freeze 2008) have been compared on a truly like-for like basis. To carry out such a comparison would involve screening out of site-specific issues, resolving differences in sample cohort and identifying elective change.

# High Integrity Components (HIC)

## Overview

The consequences of failure of certain components, for example the Reactor Pressure Vessel (RPV), cannot be mitigated and will lead to a large release of radiation to the environment. NNB GenCo designates these as ‘high integrity components (HICs)’ and they are referred to in ONR’s Safety Assessment Principles (SAPs) as ‘highest reliability components’. Aligned with its principle of being risk-informed, ONR gives increased attention to these components.

The concept of highest reliability stems from the UK study group on the integrity of pressure vessels [3] and the concept is translated into the ONR SAPs at paragraph 286. It has been reviewed and discussed at length across UK industry and academia (for example, the Technical Advisory Group on Structural Integrity (TAGSI) [4]), and the principles have gained wide recognition. The core principles of highest reliability are:

* The need for highest reliability claims should be engineered out, where possible.
* Where highest reliability claims are made, the component should be demonstrably:
  + Well made, with known physical characteristics.
  + Defect tolerant.
  + Monitored by qualified inspections.

Highest reliability expectations have been made consistently and clearly since before the GDA of the EPR, and ONR’s approach is consistent with IAEA guidance in this area [5].

The structural design of nuclear plant items is undertaken using a ‘design code’. These provide the baseline of structural integrity. Each regulator then requires additional analysis to convert the code into national legislation, and this is different between regulators, despite significant efforts to harmonise. For example, the French nuclear safety regulator, ASN, applies additional expectations in terms of materials homogeneity in the RPV domes, which are covered by the fracture toughness testing performed in the UK.

The additional requirements above code, to meet the requirement for HIC in the UK, resulted in EDF and AREVA undertaking additional testing and analysis. Specifically:

* Fracture toughness testing.
* Defect tolerance analysis.
* Qualification of inspections techniques.

## Differences in regulatory approaches

Primarily, the difference arises in converting design code into national requirements to satisfy the legislation of that country. The concept of highest reliability is UK-specific, although aligned with IAEA requirements, and work undertaken through forums such as the NEA’s Multinational Design Evaluation Programme (MDEP) aims to bring regulatory requirements closer together. Although additional testing was required for the UK, there are other aspects of the French and USA (and other regulators) approach that are not required for the UK, and vice versa. There is no universally-agreed/accepted approach, although work is ongoing in this area.

## Safety benefit

The application of the UK’s highest reliability expectations means that the most safety significant components are identified explicitly and that the attention of both the dutyholder and the regulator are targeted on them. The approach provides direct evidence that where the hazards posed by the nuclear plant are highest, then the risks are understood, managed and reduced so far as is reasonably practicable. This has driven demonstrable improvements in safety compared with code compliance. These include:

1. Ensuring that components enter service as defect-free as possible through appropriate in-manufacture examination, and that materials are as resistant to degradation as they can be.
2. Ensuring that in-service inspections use more capable techniques that can be demonstrated to detect any defects of concern.
3. Properly characterising the materials’ properties for forgings and welds in terms of resistance to fracture.
4. Demonstrating that highest reliability components are tolerant of defects.
5. Use of standards for objective based qualification, specifically the European Network for Inspection Qualification (ENIQ) methodology, which in turn increases confidence in the ability to reliably detect defects of a certain size.
6. Properly consider the design for inspectability.

## Impact

ONR’s regulatory expectations during GDA led directly to design changes. As an example, a short length of straight pipe was added to the primary coolant circuit meaning that the UK EPR has fewer welds that are not fully inspectable. It is ONR’s understanding that this modification will be taken forward in future deployments of the EPR. Furthermore, the additional testing and analysis will have resulted in increased cost.

For highest reliability components, almost all countries expect some additional requirements beyond code compliance that are aligned to nuclear safety risk. ONR’s expectations are in accordance with the UK’s legal requirement to reduce risks so far as is reasonably practicable. Highest reliability is how these expectations are embodied for structural integrity in the UK, and ONR engages nationally and internationally to explain, review, learn and modernise the UK approach.

ONR’s expectations for HIC components are appropriately demanding but fully-aligned with its principles of proportionality and targeting of risk. These have driven improvements in nuclear safety that have been adopted globally.

Expectations for highest reliability have been clear, proportionate and consistent before, during and after the GDA of the EPR, and align with international requirements.

# Categorisation and Classification

## Overview

There is a fundamental expectation, embodied in both UK and international regulatory guidance, that power reactors should be designed to assure the delivery of three fundamental safety functions:

* Control of reactivity.
* Removal of heat from the core.
* Confinement of radioactive material.

These fundamental safety functions can be broken down into more specific sub-functions through a top-down analysis of functional requirements. The process is usually continued to a point where safety functions can be associated with structures, systems and components (SSCs) delivering those functions within a reactor design. The identification and categorisation of these safety functions, and the classification of SSCs delivering the functions, plays an important role in assuring that adequate levels of fault tolerance are provided.

ONR SAPs state that safety functions should be identified and categorised based on their safety significance, (ECS.1) and that SSCs delivering those functions should be identified and classified based on the safety significance of the functions they deliver (ECS.2). The classification assigned to a particular SSC should then determine the codes and standards by which it is designed, manufactured, constructed, installed, commissioned, quality-assured, maintained, tested and inspected (ECS.3). Overall, the UK approach is graded such that the most demanding standards are applied to those SSCs delivering safety functions having the highest safety significance, whilst other appropriate standards are applied to those SSCs having a lesser safety significance.

During Step 3 of the EPR GDA, ONR confirmed that aspects of the methodology for categorisation and classification proposed by EDF and AREVA were not fully-aligned with UK expectations, which are consistent with IAEA standards SSG-30 (see RO-UKEPR-43 [6]). The shortfalls included that functional categorisation should be distinct from but strongly linked to the SSC classification, and that methodologies should be applied consistently to all SSCs. Furthermore, some systems were under-classified, potentially affecting their reliability.

EDF and AREVA revised their methodology which led to some design changes, although most SSCs remained the same. The design changes were in the following areas:

* Requirements for pressurised mechanical components.
* Classification of diverse lines of protection.
* Classification of C&I.
* Classification of spent fuel pool cooling system.
* Classification of electrical SSCs.

The revised methodology was applied beyond these areas, for example to duty systems, civil structures and hazards, but with the result that no design changes were identified.

## Differences in regulatory approaches

Most regulators expect a three-tier approach to categorisation and classification, and the UK and France are consistent in this respect. However, in some countries the approach is driven by consideration of front-line safety systems associated the operation of the reactor core at power.

In the UK, with our non-prescriptive, goal-orientated regulatory approach that is not just focused on power reactors, we expect consideration to be given to support systems that ensure front line safety systems can operate, and to systems that ensure safety away from the reactor but where a significant radiological hazard still needs to be managed (for example the spent fuel pool).

## Safety benefit

Implementation by EDF and AREVA of its revised approach significantly improved the robustness of the UK EPR design in areas such as spent fuel pond cooling, the make‐up water plant and the ultimate diesel generators. In some cases, this has led to the provision of equipment of a higher reliability than that initially proposed. This has a lasting benefit, not just during design and procurement phases, but also throughout the operational life of the EPR, for example during maintenance activities or when systems need to be replaced over time.

## Impact

The design changes were proposed by the EDF and AREVA and agreed by ONR prior to the issue of the GDA Design Acceptance Confirmation (DAC). The changes adopted were not prescribed by ONR but came from the systematic application of the categorisation and classification methodology proposed by EDF and AREVA, to address the regulatory challenges raised by ONR on the adequacy of the original methodology. The design and requirements of most EPR systems were unchanged by the revised approach.

# Control and Instrumentation Architecture

## Overview

### Control & Instrumentation and safety functions

The control and instrumentation (C&I) systems of a nuclear power plant allow the operators to monitor and control the plant from the control room. They also perform automatic safety functions that step in if the plant conditions go beyond normal limits. These include the automatic reactor trip (scram) which rapidly shuts down the reactor.

If something goes wrong with the plant, these C&I safety functions are a barrier that stops the chain of events before there are significant consequences for the plant, environment, workers or public.

These safety functions are essential to the safety of the power station. Designers, operators, and regulators like ONR need to be confident that these systems will work correctly if they are ever needed.

### C&I architecture, independence and diversity

A nuclear power plant has a number of C&I systems that work together to provide all of the functionality that is needed. The arrangement of these systems, and how they communicate with each other, is known as the C&I architecture.

Where the potential nuclear safety consequences of the C&I system failing to work correctly following a fault on the reactor plant are high, the C&I architecture is designed so that there is more than one system delivering the objective of the safety function. That way, in the unlikely circumstances that one system fails, another system can still stop an accident sequence by itself.

This philosophy requires independence between the C&I systems delivering the safety function. If they are not independent, then there is a possibility that a fault in one system could affect the other system and stop both safety functions working.

The principle of independence within C&I architectures is internationally-recognised good practice. For example, Section 4 of the IAEA specific safety guide “Design of Instrumentation and Control Systems for Nuclear Power Plants” [9] discusses independence.

Diversity is part of the independence principle. In this context, diversity is about ensuring that two systems do not have common features that could mean they are both affected by the same fault at the same time, known as a common cause failure.

Diversity is a solution to common cause failure. The concept is that if two systems are sufficiently diverse, they won’t both contain the same errors, reducing the chances of a common cause failure and both systems being unavailable.

Computer based systems use software. It is widely accepted that software can contain errors, or ‘bugs’. A great deal of effort goes into minimising the risk of bugs in nuclear C&I software; however, the risk cannot be zero. These types of errors are hard to find, can lie hidden for a long time, and it might take a very specific set of circumstances to reveal them.

### Shortfall

ONR assessed the C&I architecture of the EPR design initially proposed for the UK during GDA and determined that the design did not satisfy the independence principle. This was because of:

* The complexity of the systems and the high degree of connectivity.
* The lack of diversity between systems.

Various overseas nuclear safety regulators assessing EPR designs proposed for deployment in their countries reached similar views about the initial C&I architecture proposed to them.

The C&I architecture of the original UK EPR design consisted of control and safety systems that were all software based. The two technologies used were originally developed by the same company.

As the systems were software based, they were vulnerable to systematic errors in the form of software bugs. Furthermore, because they had shared origins, this increased the risk that they might both contain the same errors, and that they might be vulnerable to a common cause failure.

Truly diverse systems would use different development methods and technology. ONR highlighted to EDF and AREVA that it would be challenging to justify the EPR’s proposed computer-based systems because of this lack of diversity.

ONR advised the addition of a hardwired backup system might be a solution that EDF and AREVA could consider. Hardwired systems are not computer-based, and therefore do not use software. They are a fundamentally diverse technology to the EPR’s proposed systems.

At the conclusion of the GDA process EDF and AREVA had recognised the underlying issue and improved various aspects of the architecture. Most significantly, the revised architecture proposed by EDF and AREVA now included a hardwired non-computer-based backup system.

## Differences in regulatory approaches

There was regulatory consistency between countries in this area, and the underlying issue with the initial designs was recognised by three regulators (ONR in the UK, STUK in Finland, and ASN in France).

ONR, STUK and ASN publicly issued a “Joint Regulatory Position Statement on the EPR Pressurised Water Reactor” [10]. This statement informed the public that all three regulators had identified the same issue and had asked EDF and AREVA to make improvements to the design. Modifications were then implemented in all three countries.

HPC and Olkiluoto 3 both feature a diverse hardwired backup system. At the point of GDA, the Olkiluoto 3 design[[1]](#footnote-2) already included this, which acted as an indicator to ONR that the effort of implementing this was not disproportionate.

The solution for the EPR at Flamanville 3 in France was different, involving duplication of some safety functions between the two existing systems [11]. However, Flamanville 3 was at a more advanced stage of the design process when the joint position was issued, and so a different solution was pursued to achieve a similar outcome.

## Safety benefit

The safety benefit of the C&I architecture being implemented at HPC over the original EPR design is that the high reliability claims required for a nuclear power plant’s C&I architecture can be demonstrated. With diverse protection systems using different technologies, assurance is provided that common cause failures are eliminated from the design and any fault associated with the operation of the reactor will be detected and halted before there are significant radiological consequences.

In the decade since GDA, another significant benefit of the hardwired backup system has been realised. Hardwired systems are resilient to a cyber-attack and will prevent escalation of a fault in the unlikely event that the computer-based systems are compromised. This alone would be a compelling case for the system, given the elevated cyber threat levels today.

Without the guarantee provided by the hardwired system, it would be necessary to expend much greater efforts on cyber protection of the software systems than has been required to date. This could represent an overall through-life cost benefit.

## Impact

This was a significant design modification that required a substantial amount of work in design, development, testing and approval. It also had further impacts on additional building space and cooling. However, it was identified early, and the overall C&I architecture has remained largely stable since GDA completion in 2012, allowing the HPC project to plan for, cost and schedule its implementation.

UK law and the goal-setting regulatory regime for health and safety (including nuclear) allows for dutyholders to weigh up the cost (time, trouble and effort) of a safety improvement (including a design modification) against its safety benefit. If there is a ‘gross disproportion’ between the two (the benefit is grossly outweighed by the cost) the dutyholder can make that argument and, if agreed by regulators, is not required to implement it.

We understand the level of effort required to implement these changes has proven to be higher than the EDF and AREVA estimated at the time of GDA. However, they did not put forward any gross disproportionality arguments for this or any other design modification as the cost impact became clearer.

# Additional Heating, Ventilation, and Air Conditioning

## Overview

Heating, ventilation and air conditioning (HVAC) systems should provide sufficiently cool (or warm in extremely low temperature conditions), often humidity-controlled air to the rooms that house equipment and systems. This ensures that (particularly for mechanical and C&I systems) they remain within the environmental parameters required to operate reliably.

The HVAC systems perform several safety-related functions, including:

* Removing the heat loads generated by operational equipment (for example to prevent failure due to overheating).
* Maintaining a suitable environment for equipment and structures (for example to reduce the risk of degradation).
* Maintaining a suitable environment for personnel (for example temperature and humidity to ensure workplaces are comfortable).

ONR’s GDA Step 4 assessment [12] identified that EDF and AREVA had not justified that the reactor design could tolerate the essential support systems (including the HVAC systems) not working. From a nuclear safety perspective, demonstrating the effectiveness of essential support systems is important because, without these systems, the front-line safety systems responsible for delivering the fundamental safety functions identified in section 4.1 will not function correctly. Confidence in the effectiveness of essential support systems is necessary for assurance that a front-line safety system will work, meaning that a fault will not escalate into an event with radiological consequences.

After GDA, NNB GenCo performed an analysis of the consequences of essential support systems not working as intended following a reactor fault. It determined that changes to the design of certain HVAC systems were necessary. These changes included:

* Reclassification of some HVAC systems in relation to their importance to safety.
* New, diverse, back-up trains on some HVAC systems to mitigate common cause failure.
* Diversification of mechanical, electrical and C&I components.

## Differences in regulatory approach

The expectation that essential support systems are suitably-designed and substantiated via the safety case, is a recognised international good practice and consistent throughout the world. ONR’s SAPs incorporate this good practice.

Consideration of whether loss of an essential support system may lead to failures of the safety-significant systems or components is an integral part in determining the categorisation and classification of such systems and components.

ONR’s conclusion in GDA that EDF and AREVA had not demonstrated the initial generic design could tolerate essential support systems not working was ultimately addressed post-GDA by NNB GenCo. It specifically considered the HPC design, taking into account design changes introduced for other reasons (for example the C&I modifications and a re-evaluation of the thermal modelling in C&I and electrical rooms within the safeguard buildings). It also considered site-specific aspects, including relevant extreme external air temperatures and the impact of climate change.

The designs of both Olkiluoto 3 (Finland) and Flamanville 3 (France) have also been modified from the original EPR design intent, and it is assumed they too have an HVAC system that has been analysed in accordance with international good practice. However, given the different build schedules, site-specific design changes and different geographical locations, it is not unexpected that they concluded it was not necessary or practicable to implement exactly the same solutions as those identified by NNB GenCo.

## Safety benefit

Providing suitably-engineered HVAC systems, sufficiently robust to ensure that the nuclear safety-related systems and components are maintained within appropriate environmental conditions, is fundamental for front line safety systems on the EPR to operate when required under the environmental conditions anticipated following a reactor fault, potentially for an extended period of time.

The improvements made by NNB GenCo provide additional diversity and assurance that the levels of reliability required from safety systems to prevent fault escalation can be achieved, on the design that is being built at HPC (as opposed to the generic design that was put forward by EDF and AREVA at the start of GDA). They also ensure the site-specific environmental conditions and anticipated climate change impacts during the station’s lifetime can be accommodated.

## Impact

The GDA was completed in 2012 and NNB GenCo established its HVAC Task Force in 2015 to determine a conceptual solution to the HVAC design and safety case shortfalls. NNB GenCo went on to re-design parts of the safeguard buildings, the layout of the systems and components within them, and source new, diverse equipment. NNB GenCo has subsequently set out what it considers are the consequential as a result of these endeavours:

1. The doubling of protection system C&I cabinets from 18 to 36.
2. HVAC architecture sizing and re-classification to Class 1.
3. Implementation of dedicated back up HVAC trains.
4. Impacts on protection and control systems.
5. Modifications for diversity requirements and single failure criterion.
6. Additional floor on two safeguard buildings.
7. Increase in classification of C&I turbine control system.

ONR’s view is that items ‎1 and ‎2 are most significant in relation to the HVAC design itself; increasing the heat loads inevitably increases the demand on the system. It is also acknowledged that increasing the classification of HVAC systems could have resulted in existing suppliers being unable to provide the required equipment and NNB GenCo may have needed to find new suppliers and different equipment.

Changes in equipment have the potential to require the HVAC systems to be resized. It is also recognised that the changes could also result in increases in the size of air handling units, the amount of pipework, ductwork, dampers and filters to deliver the additional ventilation. However, this would have been apparent and understood by NNB GenCo at the time it proposed the modifications necessary to allow it to demonstrate the effectiveness of its support systems.

In relation to the impact on protection and control systems (item ‎4 and item ‎7), when the HVAC system was re-classified to Class 1, it required a diverse Class 1 C&I system to control it. As such NNB GenCo used the new non-computerised HVAC C&I system. Because of re-considering diversity and redundancy, the turbine protection and control C&I system was also re-classified. Consequently, the ventilation system providing cooling to the C&I cabinets required improvements. However, ONR does not consider this to be a significant modification.

From a civil engineering perspective, the key change was the additional floor on two of the four safeguard buildings (item ‎6). When considering NNB GenCo’s own determination in 2016 of how much concrete this would add to the design, this equates to only a minor increase in concrete. That said, the effort involved in redesigning the building and the layout of the systems within it would not be.

NNB GenCo did not seek discussions with ONR to claim this, or any of the other modifications, to be disproportionate or unnecessary from a nuclear safety perspective.

# Use of fibre-free insulation

## Overview

In GDA, EDF and AREVA proposed to insulate the main reactor components in a fibrous material. ONR asked for a demonstration that this insulation could not become detached in particular event conditions (notably ‘loss of coolant accidents’), causing fine fibres to be transported and enter the fuel (and other areas).

ONR’s concern was that over an extended period of time, cooling to the fuel that had been initially successfully provided could be compromised, eventually resulting in the fuel cladding overheating and a loss of control of the previously-managed event. The primary protection against this happening in the original EPR design was filters on water intakes in the containment building, but dislodged or relocated debris has the potential to clog these filters.

At the time, ONR was advised that EDF and AREVA had carried out a substantial amount of development and tests and the issue was expected to be resolved satisfactorily. However, these did not demonstrate why the design option proposed reduced risks so far as is reasonably practicable.

In regulatory engagements post GDA, NNB GenCo notified ONR of its intention to minimise the use of fibrous insulation material within the containment, using Reflective Metal Insulation (RMI) to reduce or eliminate the hazard for HPC.

## Differences in regulatory approaches

During GDA, ONR highlighted to EDF and AREVA that fibrous insulation was avoided at the existing Sizewell B power station through the extensive use of metal foil insulation. Furthermore, consultation with other international regulators confirmed ONR’s view that the insulation offered in the UK EPR design was not aligned with international good practice, and other modern reactor designs (not just Sizewell B) had moved away from fibrous insulation.

This aspect of the design was also discussed with regulators participating in the MDEP, both in an EPR-specific context and for other reactor technologies. The need for reactor vendors to demonstrate the effectiveness of filters or strainers to ensure fuel cooling can be ensured was a regular topic for discussion. MDEP meetings provided an effective forum for sharing regulatory expectations and revealed a common expectation that regardless of the type of insulation used, there should be substantiation in safety cases of claims made on filters and strainers.

## Safety benefit

The need to provide effective cooling to the fuel in the reactor for an extended period of time following a loss of coolant accident is a fundamental safety function that needs to be demonstrated on a modern nuclear power plant.

That demonstration was not provided during GDA, but that internationally-recognised expectation was already accepted by EDF and AREVA, on the basis that they notified ONR of the significant amount of effort they were putting into this issue.

Other reactor vendors had already reached the conclusion that to provide the necessary demonstrations of effectiveness, alternatives to fibrous insulation should be adopted. Ultimately, NNB GenCo reached a similar conclusion.

Through the adoption of RMI, NNB GenCo is claiming that it has a design with a significantly reduced risk of fuel cooling being compromised. No equivalent demonstration was provided to ONR for the UK EPR original design that could achieve similar outcomes.

## Impact

NNB GenCo initially stated it was looking for a limited implementation of RMI. However, it ultimately decided that a ‘fibre free accident’ approach for the majority of the plant was the most appropriate policy to reduce the hazard in post-accident conditions. Whilst ONR was informed that implementation of RMI within the containment was challenging and time consuming, NNB GenCo confirmed that its impact on the plant and building work was manageable and could be incorporated within the design sequence.

NNB GenCo has stated that the impact of this change was a multi-year recovery project including:

* Insulation material inside the reactor building being changed from a fibrous material to RMI, and fibrous cable tray wrapping also replaced.
* Impact on the layout of SSCs as the volume required for the RMI was greater than the fibrous material to achieve the same thermal performance.
* Impact on the design, specification and manufacture of the filters in the In-containment Refuelling Water Storage Tank (IRWST).
* Additional qualification testing of pumps to cope with the modified debris, as the Flamanville 3 data was no longer representative.
* Re-assessment of Control Rod Drive Mechanism performance with RMI.

NNB GenCo has developed the HPC design in a series of modifications, from the GDA design that contained significant fibrous insulation, to one where almost all potential sources of fibrous debris in the containment have been replaced by alternatives. This process of design evolution culminated in the submission of a formal design change to ONR for Agreement in 2020. The key safety argument for this modification was that it would significantly reduce the risk of the containment and core cooling systems being blocked by insulation debris, in the event of an accident.

No specifics on the cost and time implications of this change are available to ONR. It is noted that a 7-year period elapsed between the end of the GDA and the submission of the formal design change. The reason for the delay in implementing changes has not been provided.

It is noted that a solution minimising fibre and using RMI has been adopted for the EPR2 design proposed for deployment in France.

# Greater use of concrete and steel

## Overview

It has been publicly-stated by NNB GenCo that 35% more steel and 25% more concrete was needed than originally planned and that this was because of British regulatory requirements. During our engagements for this review, NNB GenCo advised that the concrete quantities in the main civil works contract (which excludes marine works) are some 21% higher than the earliest available estimate in 2010 (i.e. pre-GDA conclusion). It is not clear if this relates to reinforcing steel, structural steel or a combination of the two, or which additional buildings have contributed to these estimates. However, it is accepted by ONR that, compared to the Flamanville 3 reference design, several new buildings have been added and a number of buildings have been modified.

It should be noted that during GDA, ONR’s assessment scope of the civil design was limited to nuclear island buildings. It did not include consideration of the design of the nuclear island raft thickness or the foundations for any other structures, and did not include site-specific structures, such as the pump house. There were discussions regarding the adequacy of proposed design codes for concrete and steel, however these were agreed by the end of GDA. The code changes agreed are not judged to have had a significant effect on overall quantities of concrete or steel.

## Differences in regulatory approach

There are many reasons why concrete and steel quantities may have increased since the pre-GDA stage. The most significant reasons are likely to include:

* Improvements made by NNB GenCo to the reference design, following learning from other projects.
* Site-specific buildings being different to those assumed in early estimates.
* New buildings being required to suit site-specific conditions.
* Post-Fukushima resilience enhancements in line with international standards.
* Agreed changes during the GDA process described earlier.

## Safety benefit

Some of the buildings did need to increase in size to accommodate design changes resulting from safety improvements, such as the C&I architecture and HVAC modifications. The details of the safety benefit are given in the discussion of these modifications.

## Impact

The key changes with respect to the nuclear island, which impacted the concrete volumes the most, are stated by NNB GenCo to be:

* Common raft thickness optimisation.
* Redesign of pre-stressing gallery.
* HVAC task force work that has added two levels in the safeguard buildings.
* Redesign of the diesel buildings, adding an extra level in the buildings.
* Redesign of the access tower, with an increase of the building footprint.
* Finalisation of the new buildings design and in particular the creation of a system extending the size of the effluent tank building.

Of the above changes, only those connected with the safeguard buildings and the diesel buildings are considered to have been influenced by ONR’s regulatory requirements.

The common raft and the foundations for other buildings were site-specific designs and it is likely that differing ground conditions at HPC, compared to that assumed in the reference design in France, resulted in an increase in concrete quantities. Any such change is not because of regulatory actions taken by ONR.

Whilst there have been changes to the safeguard buildings because of the C&I architecture and HVAC changes, the increased volume of concrete resulting from those changes is estimated to be less than 2% of the total concrete volume for the main civil works as estimated at GDA stage. Changes to the diesel buildings are likely to be of a similar magnitude.

The HPC main civil works quantities are significantly different to those of the generic reference design considered in GDA and include site-specific buildings and site-specific design elements, such as raft foundations. A valid comparison with the reference design would need to be made on a like-for-like basis.

ONR recognises modifications to some buildings resulting from agreed changes during GDA, including the safeguards and diesel buildings. The overall percentage increase in concrete and steel due to these modifications, compared with the total volume in the main civil works contract, is estimated to be less than 5%.

# Other Design Changes

NNB GenCo has identified several other design changes said to have been due to ONR’s regulatory requirements. Some of these appear to be the result of the modifications described earlier, however two of the topics are recognised by ONR and have been sampled and are described below.

## Fuel route - overview

During GDA, it was identified that the spent fuel pool and associated fuel handling areas/compartments required further safety case development, including consideration of the potential major failure of the penetrations/openings within the civil structure and the consequences of these failures. GDA issue GI-UKEPR-FS-03 [14] was raised to capture this shortfall.

While developing the response, EDF and AREVA proposed several modifications to the UK EPR design to reduce the probability of de-watering events in the spent fuel pool through penetrations. These proposals closed the GDA Issue but required further work by NNB GenCo through assessment findings. The resulting modifications aimed to provide a secondary barrier or removal of penetrations in the interconnected reactor cavity and spent fuel pool. The modifications proposed affected the fuel transfer tube, reactor cavity access arrangements and technical openings and fuel building access.

During GDA, ONR observed that leaks from some locations associated with spent fuel pool cooling systems and purification systems were not considered in the design basis fault analysis, despite the potential for the flow rates to exceed the capacity of normal duty systems to top up water inventory. EDF and AREVA initially justified the exclusion of these leaks by using an argument that the likelihood of failure of the relevant components was so low that it could be discounted.

These types of arguments are not uncommon in safety cases, but ONR’s expectation is that they should be rigorously substantiated and not put forward to avoid analysing the consequences of failure. The original safety case presented during GDA did not identify the spent fuel pool components as HIC components and the design was therefore not aligned with ONR SAPs or relevant good practice.

ONR required EDF and AREVA to provide a more detailed design basis safety case for the spent fuel pool leaks, previously not considered because of break preclusion arguments, and that this should include consequences analysis for the identified leaks and suitable arguments to justify the design.

## Fuel route - differences in regulatory approaches

Facilitated by MDEP, over the course of the GDA, two visits were made by ONR (accompanied by other international regulators) to operating French pressurised water reactors with similar fuel routes to that proposed for the EPR design. These visits established that the EPR fuel route design was informed by extensive French operating experience and demonstrably has extensive engineering and safety consideration included within it.

However, it became apparent that with the adoption of a well-established and proven design, EDF and AREVA’s initial safety case for the EPR presented to ONR in GDA did not attempt to demonstrate the adequacy of the design in a way which was consistent with that taken for the reactor, for example through the application of the same categorisation and classification process. ONR’s goal-orientated approach to regulation is informed by the radiological hazard and does not define specific requirements approaches for the reactor core that should not be applied to other areas or facilities. Given the radiological hazard present in an EPR spent fuel pool, ONR expects an appropriate and consistent level of safety case demonstration for it to that which is applied to the reactor itself.

## Fuel route - safety benefit

The EPR spent fuel pool has the capacity to store a large quantity of spent fuel, which if inadequately cooled or shielded, could pose a significant radiological hazard to both workers and the public.

It is provided with multiple features and safety systems to ensure these essential safety functions are provided in both normal operation and accident conditions. However, as a result of the ONR interventions in GDA, the relative importance of these different systems has been clarified, and their effectiveness demonstrated.

This greater understanding has relevance for the design and procurement phases of the HPC construction, but it can have safety benefits during the future operation of the power station. It will inform decisions made about the importance and sequencing of maintenance and testing, and judgements on the significance of degradation of performance over time due to ageing and obsolescence.

## Fuel route - impact

A design change ‘Modification of the Diverse Openings on the Fuel Path, the Fuel Transfer Tube and Associated Civil Works to cope with the Design Basis Analysis (DBA) of a Gross Failure’ was submitted for ONR Agreement in 2018. The modifications proposed by NNB GenCo were associated with providing a second containment barrier to leakage from the gross failure of a primary barrier bounding the spent fuel pool, reactor cavity and adjacent compartments during refuelling.

The modifications included:

* Changes to the civil structure around the fuel transfer tube.
* The fuel transfer tube design and construction.
* The introduction of additional barriers at the cavity access points and technical openings.

## UK standards on fire safety - overview

During Step 3 of GDA, ONR was informed that, where there are doors within safety fire compartments, it was not proposed to have any engineered systems in place to identify whether the door was left open. ONR was informed that the Flamanville 3 design did not have any measures to identify whether doors had been left open other than administrative (human) controls. Given the nuclear safety significance associated with potential breaches in important hazard barriers, ONR did not consider that administrative controls on their own were adequate. As a result, a regulatory observation was raised to address this shortfall, to which a response was provided during GDA Step 4 [15].

A design change was proposed by EDF and AREVA to address the regulatory concerns. This change described the door monitoring system principles and referred to a supporting specification document. This was assessed as satisfactory by ONR, with an assessment finding being raised to ensure that the door control systems were adequately specified, designed and implemented within a UK EPR by a future licensee.

## UK standards on fire safety - differences in regulatory approaches

The modified design is now in line with Olkiluoto 3. It is not known whether any subsequent design changes were made for Flamanville 3.

## UK standards on fire safety - safety benefit

Should barriers be left open inadvertently, there is the risk of fire being spread between fire compartments. This leaves the risk of significant escalation of an incident and potentially significant nuclear safety consequences.

## UK standards on fire safety - impact

While ONR does not have specific information on the impact of this change, it was agreed during GDA and improved the safety of the design so that it was aligned with relevant good practice and the design adopted at Olkiluoto 3.

# Conclusions

In order to understand the role it may have played in design changes to the UK EPR, ONR has engaged with NNB GenCo and conducted a review of those changes NNB GenCo identified as having the greatest impact on HPC’s cost and schedule.

Across the sample of modifications reviewed, ONR’s conclusions were broadly similar. All the identified changes were proposed by or discussed with EDF and AREVA during GDA in the period 2008 to 2012, allowing for early consideration of cost and schedule impact. On balance, ONR believes that the modifications reviewed were proportionate, and that its approach was broadly consistent with that of other international regulators, who in some instances required similar design improvements. EDF and AREVA did not make any arguments of gross disproportion during or after the GDA.

An intent of the GDA is to help reduce the developer’s commercial risks on costs and timescales by providing clarity on regulatory expectations and potential design modifications as soon as possible, and significantly before any on site construction takes place. The modifications reviewed were identified early and have remained largely unchanged since 2012, which supports this objective.

ONR accepts that there are lessons to be learnt and we have improved our GDA process as a result of our experience of this and subsequent GDAs.

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The information sources identified in this document are all publicly available. As an aide to the reader, the sources can be found at:

ONR website

[www.onr.org.uk/](http://www.onr.org.uk/)

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ONR Safety Assessment Principles

[www.onr.org.uk/publications/regulatory-guidance/regulatory-assessment-and-permissioning/safety-assessment-principles-saps/2014/11/saps-2014/](http://www.onr.org.uk/publications/regulatory-guidance/regulatory-assessment-and-permissioning/safety-assessment-principles-saps/2014/11/saps-2014/)

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UK EPR Generic Design Assessment Publications

[www.onr.org.uk/generic-design-assessment/assessment-of-reactors/uk-european-pressurised-reactor-uk-epr/](http://www.onr.org.uk/generic-design-assessment/assessment-of-reactors/uk-european-pressurised-reactor-uk-epr/)

1. Section 2.2 “*Outcome of review by Finnish regulator (STUK)*” of the pre-construction environmental report (PCER) sub chapter 1.5, safety assessment and international practice [18]. [↑](#footnote-ref-2)