Office for Nuclear Regulation

New Reactors Division

Step 4 Assessment of Spent Fuel Interim Storage for the UK Advanced Boiling Water Reactor

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EXECUTIVE SUMMARY

Hitachi-GE Nuclear Energy Ltd (Hitachi-GE) is the designer and Requesting Party for the United Kingdom Advanced Boiling Water Reactor (UK ABWR). Hitachi-GE commenced Generic Design Assessment (GDA) for the UK ABWR in 2013 and completed the process in 2017.

This report is the Office for Nuclear Regulation's (ONR) Step 4 assessment of the UK ABWR design in the topic area of Spent Fuel Interim Storage (SFIS) and has been completed by ONR's Nuclear Liabilities Regulation specialism (NLR).

The scope of the Step 4 assessment is to review in detail the safety, security and environmental aspects of the UK ABWR by examining the evidence, supporting the claims and arguments made in the safety documentation and building on the regulatory assessments already carried out for Steps 2 and 3. In addition ONR has provided a judgement on the adequacy of the information contained within the Pre-Construction Safety Report (PCSR) and its supporting documentation.

Hitachi-GE's proposed strategy for managing the UK ABWR spent fuel consists of the following main steps:

- Immediately after spent fuel is removed from the reactor it will be stored underwater for approximately 10 years in the Spent Fuel Pool (SFP) within the Reactor Building.
- When decay heat levels have fallen sufficiently, spent fuel assemblies will be loaded into a multi-purpose canister (MPC), within a transfer cask, in the SFP Cask Pit.
- Once fully loaded, the MPC and its transfer cask will be lifted onto a Cask Stand within the Cask Pit and the MPC internals will then be dried, pressurised with inert gas and the MPC lid welded.
- After welding the MPC will be exported out of the Reactor Building within its transfer cask on a Low Profile Transporter (LPT), then taken to a storage building elsewhere on site by a Cask Transporter.
- Within the storage building the MPC will be removed from the transfer cask, then placed inside a large scale concrete over-pack prior to undergoing an extended period of dry storage.
- Within a hot cell local to the store, the spent fuel will ultimately be removed from MPCs, re-packaged into disposable containers and consigned off-site to the UK's planned Geological Disposal Facility (GDF).

This assessment has considered the robustness of Hitachi-GE's proposals for the on-site dry cask storage of spent fuel, together with key parts of the preceding processes whose efficacy will underpin the safety of the dry storage period. This assessment does not give detailed consideration to the adequacy of Hitachi-GE's proposals for the wet storage period that spent fuel will undergo in the SFP, as specific aspects of the wet storage arrangements have been assessed by several other ONR specialisms throughout the GDA. At all points in the process, Hitachi-GE has been obligated to provide a demonstration that the risks associated with spent fuel export and storage are capable of being reduced So Far As Is Reasonably Practicable (SFAIRP).

Management of spent fuel is a multi-disciplinary interest. Therefore production of this report was integrated with regulatory assessment of other elements of the overall safety case, which included Reactor Chemistry, Fuel and Core, Structural Integrity, Human Factors, Fault Studies, Conventional Safety, Radiological Protection and Criticality, Mechanical Engineering, Internal Hazards, and Control & Instrumentation.

ONR also considered the compatibility of Hitachi-GE's approach with relevant parts of UK government policy, including key strategic-level assumptions in the government's Base Case for the expected lifecycle of new nuclear power stations associated with The Energy Act 2008.

For example, the Base Case includes an expectation that operators of new nuclear power stations should plan on the basis that their spent fuel will not be reprocessed.

GDA concerns the early stages of design and provides Requesting Parties an opportunity to present proposals at a conceptual level for systems that are not integral to the reactor operations. With the exception of the Reactor Building Crane, Fuel Handling Machine, SFP and systems that condition the SFP water, the remainder of the infrastructure to manage spent fuel will not be needed until approximately 10 years after the UK ABWR starts generating electricity. The first ever deployment of dry cask spent fuel storage in the UK took place at Sizewell B during 2017 and the technology is subject of ongoing development programmes globally, such that changes to relevant good practice may occur prior to the planned application to the UK ABWR. In light of these circumstances, Hitachi-GE chose not to carry out detailed design of the SFIS infrastructure within GDA and did not wish to constrain a future operator to having to deploy one of the currently available SFIS systems.

Within its generic safety case Hitachi-GE therefore sought to demonstrate that it is technically feasible for the UK ABWR to accommodate safe interim storage of spent fuel, with current technology used to illustrate ‘proof of concept’, while showing the design provides a future operator flexibility to develop other options for the detailed engineering that will be finalised nearer the time the SFIS infrastructure is needed.

GDA focusses on technical aspects of proposed reactor designs, but does not include an assessment of the financial arrangements a licensee will need to put in place to cover the costs of managing and disposing of spent fuel. The Energy Act 2008 requires operators of new nuclear power stations to have secure finances in place to meet the full costs of decommissioning and waste management, which for the purpose of the Act includes spent fuel management. The Act calls for a Funded Decommissioning Programme (FDP) to be put in place, which must be approved by the Secretary of State before construction of a new nuclear power station begins. Impartial scrutiny of the financial arrangements that underpin FDPs and associated advice to the Secretary of State is provided by the Nuclear Liabilities Financing Assurance Board (NLFAB).

ONR’s main assessment conclusions are:

- Hitachi-GE provided an adequate consideration of the credible options for SFIS and the selected approach of dry cask storage with concrete over-packs is a proven technology that takes account of current global good practice.
- Hitachi-GE’s strategic-level approach to SFIS is compatible with the expectations of the UK government and UK regulators.
- To a conceptual level within GDA, Hitachi-GE provided an adequate demonstration that the UK ABWR can accommodate the design, operational constraints and infrastructure requirements to implement dry cask storage of spent fuel with risks capable of being reduced SFAIRP.
- The anticipated UK ABWR spent fuel is expected to be disposable at the UK’s planned Geological Disposal Facility (GDF).
- The requirement for an extended period of on-site dry cask storage of spent fuel has been appropriately incorporated into all the relevant UK ABWR strategies and plans.

ONR’s judgement is based upon the following factors:

- Alignment of Hitachi-GE’s proposals for management of spent fuel with UK Government policy, including strategic-level assumptions in the Base Case for the lifecycle of new nuclear power stations associated with The Energy Act 2008.
- Hitachi-GE’s reference to one of the largest currently available dry cask storage systems (i.e. Holtec International’s HI-STORM FW with the HI-TRAC transfer cask) to provide an objective ‘proof of concept’ within GDA.

- Hitachi-GE's identification of key criteria for safe long-term dry cask storage and provision of systems to ensure compliance with those criteria, such that the integrity of the UK ABWR spent fuel should be maintained for the envisaged storage period.

- Hitachi-GE's accommodation within the UK ABWR safety case of Systems Structures and Components (SSCs) to support all the required steps in dry cask storage and the preceding steps of wet storage, MPC loading, MPC conditioning and welding, MPC export from the Reactor Building, monitored long-term storage, final re-packing and consignment to the GDF.

- Hitachi-GE's recognition of the need to provide a means of recovery from design basis faults, including the capability to safely retrieve spent fuel out of sealed MPCs should it prove to be necessary.

- Radioactive Waste Management Limited's (RWM Ltd) assessment of the disposability of the UK ABWR spent fuel at the GDF and Hitachi-GE's response to RWM Ltd.

The following matters remain, which are for a licensee to consider and take forward in its site-specific safety submissions. These matters do not undermine the generic safety submission but require licensee inputs/decisions at a specific site.

- Hitachi-GE's generic safety case identified that misloads of spent fuel assemblies with high decay heat, in place of assemblies with lower decay heat (i.e. 'thermal misloads'), could threaten the integrity of the fuel cladding and MPCs. Hitachi-GE claimed that the likelihood of a thermal misload is infrequent, but this was not supported by ONR's analysis of the provided data. The generic case identified a range of potential risk reduction measures to detect and prevent thermal misloads that are not foreclosed to a future licensee and may be reasonably practicable to implement during detailed design but were not formally adopted into the UK ABWR reference design during GDA.

  Therefore the licensee shall:

  - Substantiate the claim that the likelihood of a thermal misload occurring is sufficiently low so as to be considered infrequent in the terms of ONR's deterministic and probabilistic criteria.
  - Demonstrate that all reasonably practicable engineered measures can be deployed to detect the presence of thermal misloads and prevent their progression to significant radiological consequences.

- Hitachi-GE's generic safety case for the loading and preparation operations associated with the dry cask storage system was at a concept level of design and identified a number of potential risk reduction measures that may be reasonably practicable to implement. Whilst some of these measures were not formally adopted into the UK ABWR design within GDA, Hitachi-GE demonstrated that they were not foreclosed to a future operator.

  ONR understands that the licensee may not make a definitive choice of dry cask storage system until some years after the UK ABWR starts generating electricity.

  Therefore, until such time as detailed design of the dry cask storage system takes place, the licensee shall ensure that its options to deploy risk reduction measures for the loading and preparation activities are not foreclosed by the UK ABWR design. This shall include:

  - The scope of activities associated with the Cask Pit and Preparation Pit.
  - Measures to enable the condition of spent fuel to be inspected, prior to assemblies being loaded into MPCs.
  - Retention of the MPC lid prior to it being welded.
  - Measures to reduce risks to workers from drops of unsealed loaded MPCs.

- Hitachi-GE's generic safety case identified the following systems that are required to ensure adequate levels of safety during the activities to prepare spent fuel for interim storage:

  - Cask Stand
  - Canister Cooling System (CCS)
  - Back-Up Canister Cooling System (BCCS)
  - Forced Helium Dehydration system (FHD)
  - Over Temperature Protection System (OTPS)
  - Multi-Purpose Canister lid retention paddles

  As Hitachi-GE's consideration of these systems was at a concept level of design within GDA, it was not practicable for the generic case to provide a full substantiation of the claimed system reliabilities and their functionality during fault conditions.

  During detailed design of the spent fuel export and interim storage systems, the licensee shall therefore:

  - Substantiate that the design and claimed reliability of all auxiliary systems needed to support spent fuel export and interim storage will reduce the mitigated risks of all relevant design basis faults SFAIRP.
  - Demonstrate that the systems used to dry and inert canisters are capable of monitoring a sufficient range of parameters to identify any thermal excursions and/or failures in the fuel cladding that may become apparent during the drying, inerting or welding processes.

- Hitachi-GE's generic safety case identified a number of credible causes of blockages to the inlet vents of concrete over-packs that may take place inside the spent fuel interim store. The case predicted that significant vent blockages had the potential to lead to spent fuel cooling faults that could threaten fuel clad integrity. The case however, made no safety claims on the storage building itself and placed a dependency on operators to carry out inspections of the concrete over-pack vents every 24 hours. This does not align with ONR's expectation for safety functions to be allocated to automatic systems where reasonably practicable, therefore the licensee shall:

  - Ensure the design of the spent fuel interim store includes all measures to reduce, SFAIRP, the potential sources of over-pack vent blockages, including the site specific external hazards.
  - Demonstrate that the safety functions necessary to maintain safe storage conditions have been allocated to engineered systems so far as is reasonably practicable, in preference to placing duties on human intervention.

- The potential exists for faults to occur whilst the spent fuel is held inside the MPCs within the spent fuel interim store. During the operational phase of the UK ABWR, Hitachi-GE proposed to transport any degraded MPCs/stored spent fuel from the spent fuel interim store to the SFP to allow the MPCs to be reopened for examination and any required remediation. Once the SFP has been decommissioned Hitachi-GE proposed that a hot cell will be constructed local to the spent fuel interim store to maintain the site's capability to inspect/remediate stored spent fuel and to achieve the final re-packaging of spent fuel for consignment off-site for disposal.

  The robustness of Hitachi-GE's strategy for recovery from the design basis faults that may occur in the spent fuel interim store is dependent on the detailed design of the dry cask storage system. Hitachi-GE's consideration of this system in the generic safety case was limited to a 'proof of concept' and detailed design will not be carried out until the site-specific stage. Consequently the generic safety case did not provide a full demonstration that risks associated with the return of loaded MPCs to the SFP during the station's operational phase will be reduced SFAIRP and achievement of this legal requirement is dependent on detailed design decisions that will need to be made by a future licensee.

  Therefore the licensee shall ensure that:

- Options to remediate design basis faults that may occur within the spent fuel interim store during the operational phase are not foreclosed by the detailed design of the UK ABWR. This should include (but not be limited to) provision of sufficient space and services to deploy all reasonable options to recover from faults that may affect the MPCs and/or spent fuel.
- At an appropriate step during licensing/construction, assess all remediation options and adopt the method(s) that reduce risks SFAIRP.

To conclude, I am broadly satisfied with the claims, arguments and evidence laid down within the UK ABWR generic PCSR and supporting documentation for the Spent Fuel Interim Storage topic. Therefore, from the perspective of Spent Fuel Interim Storage I have no objection to Hitachi-GE's UK ABWR design being awarded a Design Acceptance Confirmation (DAC).

LIST OF ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
BAT	Best Available Techniques
BCCS	Backup Canister Cooling System
BSL	Basic Safety Level
BSO	Basic Safety Objective
CAE	Claims, Arguments and Evidence
CCS	Canister Cooling System
DAC	Design Acceptance Confirmation
DSP	Dryer Separator Pit
ENSREG	European Nuclear Safety Regulators Association
EPR2016	Environmental Permitting Regulations 2016
ERIC-PD	Eliminate, Reduce, Institutional Controls, Personal Protective Equipment, Discipline
FDP	Funded Decommissioning Programme
FHM	Fuel Handling Machine
FPCMs	Fuel Pool Cooling, Clean-up and Makeup systems
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
GEP	Generic Environmental Permit
HAW	Higher Activity Wastes
HAZID	Hazard Identification
HLSF	High Level Safety Function
IAEA	The International Atomic Energy Agency
LPT	Low Profile Transporter
MDEP	Multi-national Design Evaluation Programme
MPC	Multi-Purpose Canister
NDA	Nuclear Decommissioning Authority
NLFAB	Nuclear Liabilities Financing Assurance Board
NLR	Nuclear Liabilities Regulation (the specialism within ONR that is responsible for producing this report)
NRW	Natural Resources Wales
OECD-NEA	Organisation for Economic Co-operation and Development Nuclear Energy Agency
ONR	Office for Nuclear Regulation
OTPS	Over Temperature Protection System
P&ID	Process and Information Document
PIE	Post Irradiation Examination
PCSR	Pre-construction Safety Report
PSA	Probabilistic Safety Assessment

RBC	Reactor Building Overhead Crane
RGP	Relevant Good Practice
RI	Regulatory Issue
RO	Regulatory Observation
RWM	Radioactive Waste Management Limited
RP	Requesting Party
RPV	Reactor Pressure Vessel
RQ	Regulatory Query
SAPs	Safety Assessment Principles
SCDM	Safety Case Development Manual
SFAIRP	So Far As Is Reasonably Practicable
SFC	Safety Functional Claim
SFE	Spent Fuel Export
SFIS	Spent Fuel Interim Storage
SFP	Spent Fuel Pool
SGTS	Standby Gas Treatment System
SoDA	Statement of Design Acceptance
SPC	Safety Property Claim
SSC	System, Structures and Components
TAG	Technical Assessment Guide
TSC	Technical Support Contractor
UK ABWR	United Kingdom Advanced Boiling Water Reactor
US NRC	United States (of America) Nuclear Regulatory Commission
WENRA	Western European Nuclear Regulators' Association

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1 INTRODUCTION

1.1 Background to GDA

1. Information on the Generic Design Assessment (GDA) process is provided in a series of documents published to a dedicated area of ONR's website (http://www.onr.org.uk/new-reactors/index.htm). GDA consists of a rigorous regulatory assessment of the design of a proposed new nuclear power station, which if completed successfully will result in the Requesting Party being awarded a Design Acceptance Confirmation (DAC) from ONR and a Statement of Design Acceptability (SoDA) from the Environment Agency and Natural Resources Wales (NRW).

2. Hitachi-GE is the Requesting Party for the UK ABWR design that commenced GDA in 2013 and completed the process in 2017. Full technical details of the UK ABWR are available via http://www.hitachi-hgne-uk-abwr.co.uk/.

3. GDA consists of four steps. A report to summarise the outputs from Step 3 for the UK ABWR was published on ONR's website (Ref.1).

4. Step 4 consists of a detailed assessment of the Requesting Party's safety, security and environmental evidence. Through the review of information provided to the regulators, the Step 4 process should confirm that Hitachi-GE:

   - Has properly justified the higher-level claims and arguments.
   - Has progressed the resolution of any issues identified during Steps 2 and 3.
   - Has provided sufficient detailed analysis to allow ONR to come to a judgement on whether a DAC can be issued.

5. During Step 4 ONR has therefore undertaken a detailed assessment, on a sampling basis, of the safety and security case evidence. The full range of items that might form part of such an assessment is outlined in ONR's GDA Guidance to Requesting Parties (Ref.2). This includes:

   - Judging against the Safety Assessment Principles (SAPs) (Ref.3) and relevant Technical Assessment Guides (TAGs) whether the proposed design will reduce the risks associated with management of spent fuel so far as is reasonably practicable (SFAIRP).
   - Establishing whether the system performance, safety classification, and reliability requirements are adequately substantiated.
   - Arrangements to ensure that safety claims and assumptions are realised in the final as-built design.
   - Clear and traceable links between underpinning data, Topic Reports, supporting documents and the generic PCSR.
   - An objective demonstration that the design reflects UK law, government policies, standards and other regulatory expectations applicable to SFIS.
   - Arrangements to ensure any significant impacts on SFIS from design changes and process modifications are properly recognised and taken into account.
   - An assessment of the disposability of the expected UK ABWR spent fuels.

6. All of the regulatory issues (RIs) and regulatory observations (ROs) issued to Hitachi-GE during GDA as part of ONR's assessment have been published on ONR's website, together with the corresponding Hitachi-GE resolution plans and confirmation of their closure: http://www.onr.org.uk/new-reactors/uk-abwr/index.htm

1.2 Scope of this Assessment

7. At the start of Step 4, the scope of ONR's assessment for SFIS was detailed in an assessment plan, ONR-GDA-AP-15-011 (Ref.4).

8. Irrespective of the required storage duration, the choice of wet or dry storage and the ultimate management route, ONR expects that an operator's safety case for SFIS should include a consideration of:

- The feasible management options for SFIS.
- The design, operational requirements and infrastructure required to implement the selected option(s).
- Reduction of risks SFAIRP.
- Avoidance of any design or operational actions that would foreclose onward transport, processing or disposal of the spent fuel.
- Lessons learned from national and international experience and research in the storage of spent fuel.

9. This assessment was based on a targeted sample of Hitachi-GE's GDA submissions, in accordance with the key principle of ONR's Enforcement Policy Statement (Ref.5) that the requirements of safety should be applied in a manner that is commensurate with the magnitude of the hazard. As management of spent fuel will take place in several stages that involve a broad range of radiological and conventional safety hazards, ONR prioritised its attention on those steps that had the greatest potential to cause harm.

10. This assessment did not consider in detail the period of wet storage that spent fuel will undergo in the Spent Fuel Pool (SFP). Specific aspects of Hitachi-GE's proposals for the wet period of storage have been assessed by several other ONR specialisms throughout the GDA, principally within the Reactor Chemistry Assessment Report ONR-NR-AR-17-019 (Ref.6).

11. GDA concerns the early stages of design and provides Requesting Parties an opportunity to present proposals at conceptual level for the systems that are not integral to reactor operations.

12. Hitachi-GE has proposed that the UK ABWR will deploy a system of dry cask storage for spent fuel, preceded by 10 years of wet storage in the SFP in the Reactor Building. Therefore, with the exception of the Reactor Building Crane (RBC), Fuel Handling Machine (FHM), SFP and the support systems that condition the SFP water, the infrastructure for spent fuel storage will not be needed until 10 years after the UK ABWR begins generating electricity.

13. The first deployment of dry cask spent fuel storage in the UK took place at Sizewell B during 2017 and the technology is subject of ongoing research and development programmes globally, giving a likelihood of changes in good practice prior to the planned application to the UK ABWR. In light of these circumstances, Hitachi-GE chose not to carry out detailed design of the SFIS infrastructure within GDA and did not wish to commit a future operator to having to deploy one of the currently available dry cask storage systems.

14. Hitachi-GE's generic safety case therefore sought to demonstrate that it was technically feasible for the UK ABWR to accommodate safe storage of spent fuel for the timescales required, with a currently available dry cask system used as 'proof of concept'. However Hitachi-GE also wished to show that the UK ABWR design is sufficiently flexible to provide a future operator with a range of alternative options for

the detailed engineering that will be finalised nearer the time the SFIS infrastructure is needed.

15. In order to deliver a targeted and proportionate assessment of Hitachi-GE's proposals, ONR's strategy was tailored to match the status of the UK ABWR design within GDA. ONR's identified priorities were:

- For Hitachi-GE's strategy, plan and proposed techniques for SFIS to be compliant with relevant UK law, compatible with UK government policy and aligned with other sources of regulatory expectations (such as international standards).
- For Hitachi-GE's 'proof of concept' to provide an objective demonstration that the UK ABWR design can enable the safe interim storage of spent fuel.
- To ensure the UK ABWR design does not foreclose the detailed design options available to a future operator to reduce the risks of SFIS SFAIRP.
- To confirm the UK ABWR spent fuel is expected to be disposable at the UK GDF and that the preceding management steps will protect the integrity of the spent fuel to ensure this disposal route remains viable.
- Assurance that Hitachi-GE's proposals for SFIS are based on a precautionary approach to uncertainty, such that the technical viability of the intended SFIS techniques does not depend on overly optimistic assumptions on how the UK ABWR will perform in practice.
- To ensure the requirements for SFIS were recognised in all relevant areas of the generic safety case, including the sections dedicated to engineering, conventional safety and radiological protection.

16. ONR's considerations included normal SFIS operations and the robustness of Hitachi-GE's proposals for dealing with design basis faults.

17. Hitachi-GE's overall approach for management of spent fuel was divided into the following phases:

- **Wet storage in the SFP:** Immediately after being removed from the reactor by the FHM, spent fuel assemblies will be placed underwater in racks in the SFP within the Reactor Building and maintained in a sub-critical state for a period of approximately 10 years. During this time the Fuel Pool Cooling, Clean-Up and Makeup systems (FPCMs) will treat the SFP water to remove decay heat, ensure adequate water coverage and maintain water quality. On the basis of Hitachi-GE's current plans, the first batch of spent fuel will be wet stored from approximately 2025 to 2035. The adequacy of Hitachi-GE's proposals for this phase of storage has been considered in various ONR assessment reports, including Reactor Chemistry, Fuel and Core, Mechanical Engineering, Radiological Protection and Internal Hazards and therefore has not been considered in detail in this report.
- **Spent Fuel Export (SFE):** Once levels of decay heat are sufficiently reduced, spent fuel will be transferred by the FHM from the racks on the floor of the SFP into a dry cask storage system within the Cask Pit. After being loaded into a Multi-Purpose Canister (MPC), spent fuel will be dried, the MPC will be pressurised with inert gas and the MPC lid will be welded and leak tested. The MPC is placed into a transfer cask which is moved by the RBC to above the hoist well then lowered to the truck bay onto a Low Profile Transporter (LPT). The transfer cask is then detached from the RBC and removed from the Reactor Building on the LPT, for collection by the cask transporter – the cask transporter lifts the transfer cask and MPC from the LPT and moves it into the on-site interim storage facility.
- SSCs that support the MPC loading process include the Canister Cooling System (CCS), Back-Up Canister Cooling System (BCCS), Forced Helium Dehydration (FHD) and the Over-Temperature Protection System (OTPS).

- **Dry Spent Fuel Interim Storage:** Following cross-site transfer, loaded and sealed MPCs will be removed from their transfer casks and placed inside a concrete over-pack within the store building. Hitachi-GE envisaged that the UK ABWR spent fuel may need to be held in dry storage on site for up to 140 years in order for the fuel to be sufficiently cool to be placed within disposal containers, during which time its condition will be monitored to ensure its ongoing integrity and containment of fission products.
- **Re-packing and consignment:** A hot cell local to the store will be used to re-package the spent fuel into final disposal canisters, which will then be transported off-site for disposal at the GDF. Radioactive Waste Management Limited (RWM Ltd), a subsidiary of the Nuclear Decommissioning Authority (NDA), is responsible for delivering the GDF and has advised that the GDF may be able to receive spent fuel from new build reactors around 2130.

18. This assessment focussed on the robustness of Hitachi-GE's proposals for on-site dry cask storage of spent fuel, together with key parts of the preceding processes (excluding wet storage in the SFP) whose efficacy will underpin the safety of the dry storage period. Specifically this includes a consideration of whether the spent fuel will be safely:

    - Loaded into the dry cask storage system.
    - Cooled and monitored during the processes of MPC drying, inerting and welding.
    - Transport of the loaded MPC within a transfer cask on a Cask Transporter and subsequent placement into concrete over-packs within the interim store.
    - Held within the interim store for the required duration.
    - Re-packaged into a disposable form and consigned to the GDF.

19. Fuel and Core Design and Radiation Protection are separate ONR assessment topics within GDA and have respectively considered Hitachi-GE's derivation of the relevant fuel safety limits and modelling of fuel performance, criticality safety and radiation doses through the cask loading and dry storage conditions (Ref.7 and Ref.8).

20. The adequacy of specific aspects of Hitachi-GE's proposals for the wet storage period that spent fuel will undergo within the SFP has been assessed by several other ONR specialisms throughout the GDA, principally by the Reactor Chemistry specialism in Ref.6.

21. To enable a meaningful assessment within GDA, ONR required Hitachi-GE to provide a sufficient level of design information to demonstrate that the intended UK ABWR SFIS concepts are in line with relevant good practice, capable of delivering sufficient safety margins and tolerance to faults, apply a fitting hierarchy of hazard controls and will protect the structural integrity of the spent fuel over the envisaged storage period.

22. ONR also considered the compatibility of Hitachi-GE's proposals for SFIS with relevant parts of UK government policy, including key strategic level assumptions in the Government's Base Case for the lifecycle of new nuclear power stations associated with The Energy Act 2008.

23. The adopted scope of assessment was appropriate for GDA in light of the status of the UK ABWR design within GDA, integration with the scope of assessment carried out by other ONR technical disciplines, the importance of Hitachi-GE's proposals being aligned with the UK Government's Base Case for new nuclear power stations, the novelty of dry cask storage in the UK and the significance of the hazards associated with both normal operations and design basis faults involving spent fuel.

1.3 Method

24. This assessment complies with ONR's internal guidance on the mechanics of assessment (Ref.9).

25. The steps in management of spent fuel involve many technical disciplines. Some specific technical aspects (e.g. the fitness for purpose of the FHM to perform mechanical handling of spent fuel assemblies) were appropriately assessed by ONR's specialists in other GDA topics and have therefore been presented in alternative Step 4 reports. Further information on the key multi-disciplinary interfaces is provided in Section 2.3.

2 ASSESSMENT STRATEGY

2.1 Standards and criteria

26. The standards and criteria adopted within this assessment are principally ONR's Safety Assessment Principles (SAPs) (Ref.3), a range of relevant Technical Assessment Guides (TAGs), other relevant national and international standards and relevant good practice informed from existing practices adopted on UK and international nuclear sites.

2.1.1 Safety Assessment Principles

27. The key SAPs applied within the assessment are listed in Annex 1.

2.1.2 Technical Assessment Guides

28. The main TAGs that are relevant to this assessment are listed in Annex 2.

2.1.3 National and international standards and guidance

29. The key international standards and guidance that have been used as part of this assessment are listed in Annex 3.

2.2 Use of Technical Support Contractors (TSCs)

30. It is usual in GDA for ONR to use TSCs, for example to provide additional capacity, to give ONR access to independent advice and experience, analysis techniques and models, and to enable ONR's Inspectors to focus on regulatory decision making.

31. A single TSC from Quintessa Ltd was engaged during Step 4 to support ONR's assessment of SFIS for the UK ABWR. Table 1 sets out the broad areas in which this technical support was used.

Table 1

Use of Technical Support Contractor
Technical reviews of Hitachi-GE's submissions against the SAPs, TAGs, legislation and other relevant regulatory expectations
Reporting of any shortfalls against regulatory expectations identified during reviews of Hitachi-GE's submissions and comment on their significance
Provision of independent technical advice
Support ONR in meetings with the Requesting Party
Draft reports and requests for additional information (Regulatory Queries) and advise ONR on the adequacy of Hitachi-GE's responses to those requests

32. While the TSC undertook detailed technical reviews, this was done under ONR's direction and supervision and the regulatory judgement on the adequacy of Hitachi-GE's case for SFIS has been made exclusively by ONR.

2.3 Integration with other assessment topics

33. GDA requires the Requesting Party to submit a coherent and holistic generic safety case that considers all the relevant contributors to risk at an appropriate level of detail for the early stages of design. Management of spent fuel involves a wide range of interests for safety and environmental protection, which are spread across multiple

technical disciplines. Therefore this assessment had to be integrated with the work of several other topics - the following list explains the key interfaces.

- **Fuel and Core:** ONR's Fuel and Core Specialism has considered Hitachi-GE's case in relation to the design and operation of the nuclear fuel in the UK ABWR reactor itself, in addition to assessing the criteria that the SFIS systems must be considerate of in order to protect the long-term structural integrity of the spent fuel assemblies. This assessment can be found at ONR-NR-AR-17-019 (Ref.7).

- **Security:** Compliance with the requirements of nuclear safeguards and measures to address threats from hostile third parties in relation to the storage of spent fuel are matters for consideration of ONR's Security Division, whose assessment of the UK ABWR can be found at ONR-NR-AR-17-026 (Ref.10).

- **Conventional Health and Safety:** SFIS gives rise to numerous hazards that are not radiological in nature, such as work at height, work in a confined space, high temperatures, working over water, dropped loads and potential asphyxiation risks from the use of inert gas. Hitachi-GE's approach to managing matters of conventional health and safety has been assessed by a dedicated ONR Specialist Inspector of Conventional Safety in ONR-NR-AR-17-027 (Ref.11).

- **Internal Hazards:** Some steps in the processes of SFIS have associated internal hazards, which include; potential internal floods; fires; toppling or collapses, and; dropped loads. ONR's assessment of the relevant parts of Hitachi-GE's safety case can be found in ONR-NR-AR-17-033 (Ref.12).

- **Fault Studies and Probabilistic Safety Analysis:** Design Basis Analysis and Probabilistic Safety Analysis, incorporating estimated event frequencies and consequences from reasonably foreseeable faults, has been used throughout Hitachi-GE's safety case to inform expected system reliabilities and ensure sufficient levels of redundancy and diversity.

  Interactions on these aspects have taken place with the ONR's Specialist Inspectors of Fault Studies and Probabilistic Safety Analysis throughout GDA and the significant outcomes are discussed in assessment reports ONR-NR-AR-17-016 (Ref.13) and ONR-NR-AR-17-014 (Ref.14) respectively.

- **Human Factors:** ONR expects that safety cases should substantiate the way actions are allocated between humans and technology, such that the dependence on humans to maintain a safe state is minimised. ONR's Specialist Inspector for Human Factors has considered Hitachi-GE's generic approach to optimising the demands placed on workers and minimising the potential for human error to give rise to significant consequences in ONR-NR-AR-17-23 (Ref.15). Aspects of Human Factors that are specific to the SFIS concept designs have been considered within this report.

- **Mechanical Engineering:** SFIS includes several significant items of mechanical plant that support the handling, lifting and export of spent fuel assemblies, such as the RBC and FHM. Compliance of those elements of the design with ONR's expectations for Mechanical Engineering has been considered in ONR-NR-AR-17-22 (Ref.16).

- **Radiological Protection:** ONR has considered whether Hitachi-GE's proposals for radiological protection are sufficient to meet the UK's legislative requirements and reduce risks to workers and the public SFAIRP. This includes the application of a fitting hierarchy of hazard control measures, assumed evacuation times in response to radiological releases, criticality safety and minimising occupational exposures. This assessment has been carried out by ONR's Radiological Protection specialism and is reported in ONR-NR-AR-17-20 (Ref.8).

- **Reactor Chemistry:** Assessment of the regime of wet storage and cooling of spent fuel that takes place in the SFP immediately prior to the preparations for dry cask storage is beyond the scope of this report and principally resides with ONR's Reactor Chemistry specialism, whose Assessment Report is ONR-NR-AR-17-019 (Ref.6)

- **Structural Integrity:** The robustness of Hitachi-GE's claims, arguments and evidence relating to the long term structural integrity of the SFIS MPCs has been considered by ONR's specialists of Structural Integrity and is reported in ONR-NR-AR-17-37 (Ref.17).

- **Civil Engineering:** Aspects of the SFIS systems rely upon the performance of civil engineering structures, such as the SFP, which have been assessed by ONR's Civil Engineering specialists and the details can be found in Assessment Report ONR-NR-AR-17-001 (Ref.18).

- **Management of Radioactive Wastes:** SFIS will generate secondary radioactive wastes. Hitachi-GE intends that the dry cask storage system used for spent fuel will also be deployed to manage the solid High Level Wastes that are expected to be generated from the reactor operations (principally used control rods). These elements have been considered in ONR-NR-AR-17-025 (Ref.19).

- **Decommissioning:** Hitachi-GE's strategy and plan to decommission the UK ABWR needed to be compatible with the proposals for SFIS and have been assessed in ONR-NR-AR-17-034 (Ref.20).

- **Environmental Protection:** is an important consideration within SFIS, particularly with respect to potential fault conditions and spent fuel retrieval, and the need for spent fuel to be maintained in a condition that will enable its ultimate disposal.

  Consideration of these aspects has required close liaison between ONR and the environmental regulators throughout GDA, due to common interests and the need to regulate in a coordinated manner. Joint working between the regulators has been delivered throughout the GDA process in accordance with established memorandums of understanding, to ensure an efficient and integrated oversight of Hitachi-GE's proposals in terms of both nuclear safety and environmental protection.

2.4 Sampling strategy

34. It is seldom possible, or necessary, to assess a safety case in its entirety, therefore sampling is used to limit the areas scrutinised, and to improve the overall efficiency of the assessment process. Sampling is done in a focused, targeted and structured manner with a view to revealing any topic-specific, or generic, weaknesses in the safety case.

35. Throughout this assessment ONR prioritised its attention on the functions of greatest importance to safety and maintenance of spent fuel integrity during the SFIS process, namely avoidance of canister misloading, sufficient removal of decay heat, maintenance of shielding and containment, prevention of criticality and condition monitoring.

36. Adequate arrangements to deliver these functions are necessary to avoid the three main hazards associated with handling spent fuel in the UK ABWR, which are:

    - Direct exposure of workers to high levels of radiation.
    - Criticality.
    - Loss of fuel clad integrity, leading to a loss of containment of fission products.

2.5 Out-of-Scope Items

37. Table 2 sets out the most significant items that were agreed with Hitachi-GE as being outside the scope of the SFIS Step 4 GDA.

Table 2

Items Deemed Out-Of-Scope of the Step 4 SFIS Assessment	
Financial arrangements for meeting the future costs of management and disposal of spent fuel	The UK Government legislated in The Energy Act 2008 to ensure operators of new nuclear power stations have secure finances in place to meet the liabilities of decommissioning and waste management. For the purposes of the Act, spent fuel was considered to be a radioactive waste. The Act requires future operators to put in place a Funded Decommissioning Programme (FDP), approved by the Secretary of State, before construction of a new nuclear power station begins. Impartial scrutiny of the financial arrangements that underpin FDPs and associated advice to the Secretary of State is provided by the Nuclear Liabilities Financing Assurance Board (NLFAB).
Environmental Protection	The environmental regulators are responsible for enforcing the applicable requirements of the Environmental Permitting Regulations 2016 (EPR2016) in relation to discharges and disposal of radioactive wastes from UK nuclear sites. These requirements were therefore out-of-scope of ONR's assessment.
Spent Fuel Pool operations	Assessment of the regime of wet storage and cooling of spent fuel that takes place in the SFP immediately prior to the preparations for dry cask storage is beyond the scope of this report. ONR's consideration of these aspects can be principally found in the Reactor Chemistry Assessment Report (Ref.6).

38. The Energy Act 2008 requires operators of new nuclear power stations to develop an FDP, which needs to be approved by the Secretary of State before nuclear-related construction on the site can begin. The FDP must include the plans for SFIS, estimate the associated costs and describe how the operator will ensure it has sufficient assets/funds available to meet those costs (Ref.21).

39. The Nuclear Liabilities Financing Assurance Board (NLFAB), an independent advisory non-departmental public body, will scrutinise the financial provisioning systems underpinning the FDP and provide advice to the Secretary of State.

40. To ensure the Secretary of State and NLFAB have a consistent benchmark against which to assess the cost estimates produced by operators, the government developed a 'Base Case' which laid out key strategic assumptions to define the expected lifecycle of new power stations. Certain of these assumptions are relevant to SFIS, such as:

- New nuclear power stations will use uranium or uranium oxide fuel.
- Spent fuel from new nuclear power stations will not be reprocessed.
- Spent fuel will be kept in interim storage on the site and then disposed of in the UK's planned GDF.
- Spent fuel will be encapsulated immediately prior to transfer to the GDF.
- In the absence of proposals for centralised packaging facilities, it should be assumed that encapsulation will be carried out on the originating site.

- On site storage facilities must ensure that the spent fuel will meet the GDF operator's conditions for acceptance at the date scheduled for its disposal.

41. To ensure that Hitachi-GE's proposals were aligned with government policy, ONR ensured that the safety case was either; compatible with the above key assumptions, or; any deviations from the Base Case were adequately justified. However GDA does not include an assessment of the arrangements for financial provisioning that a future operator of a UK ABWR will need to put in place to ensure sufficient monies are available to cover the costs of future management of spent fuel.

3 REQUESTING PARTY'S SAFETY CASE

42. Throughout Step 4 the Requesting Party submitted a number of PCSR Chapters, Topic Reports, Basis of Safety Case documents and other supporting references to underpin its safety case for the management of spent fuel. The main documents assessed by ONR are listed in Table 3.

Table 3

Principal Hitachi-GE Safety Case Documentation for SFIS in Step 4 Assessed by ONR	
Document I.D.	**Title**
GA91-9101-0101-19000, Revision C, August 2017	Generic PCSR Chapter 19: Fuel Storage and Handling (Ref.22)
GA91-9101-0101-32000, Revision C, August 2017	Generic PCSR Chapter 32: Spent Fuel Interim Storage (Ref.23)
GA91-9101-0101-23000, Revision C, August 2017	Generic PCSR Chapter 23: Reactor Chemistry (Ref.24)
GA91-9201-0003-00458, Revision 0, March 2015	High Level Optioneering on Spent Fuel Interim Storage (Ref.25)
GA91-9201-0001-00246, Revision 1, June 2017	Topic Report on Safety Case of Fuel Route (Ref.26)
GA91-9201-0001-00244, Revision 2, November 2016	Topic Report for High Level Safety Case on Concept Design of Spent Fuel Interim Storage System (Ref.27)
GA91-9201-0001-00082, Revision 3, July 2017	Topic Report on Fault Assessment for SFP and Fuel Route (Ref.28)
GA91-9201-0003-01562, Revision 0, September 2016	Preliminary Basis of Safety Case on Spent Fuel Export System (Ref.29)
GA91-9201-0003-00200, Revision 2, July 2017	GE14 Fuel Integrity Evaluation During Interim Storage (Ref.30)
GA91-9201-0003-00437, Revision 5, April 2017	Basic Specification of Operation Process and Equipment for Concrete Cask Storage System (Ref.31)
GA91-9201-0003-01674, Revision 0, October 2016	Evaluation for Spent Fuel Misloading (Response to RQ-ABWR-1050) (Ref.32)
GA91-9201-0003-02028, Revision 0, April 2017	Consequences from the Drop of an Unsealed Loaded Canister into the Cask Pit (Response to RQ-ABWR-1320) (Ref.33)
GA91-9201-0003-00528, Revision 1, May 2016	Consideration of Internal Hazard for Spent Fuel Export and Spent Fuel Interim Storage (Ref.34)
GA91-9201-0003-00527, Revision 1, May 2016	Consideration of External Hazard for Spent Fuel Export and Spent Fuel Interim Storage (Ref.35)
GA91-9201-0003-00526, Revision 4, June 2017	Consideration of Faults for Spent Fuel Export and Spent Fuel Interim Storage (Ref.36)
GA91-9201-0003-00501, Revision	Preliminary Evaluation for Sub-Criticality Safety

Principal Hitachi-GE Safety Case Documentation for SFIS in Step 4 Assessed by ONR	
Document I.D.	**Title**
1, March 2015	(Ref.37)
GA91-9201-0003-00607, Revision 1, July 2016	Preliminary Evaluation for Containment Safety (Ref.38)
GA91-9201-0003-00615, Revision 0, May 2015	Preliminary Evaluation for Undetected Misloading (Ref.39)
GA91-9201-0003-00500, Revision 0, January 2015	Preliminary Evaluation for Heat Removal of Loaded Cask in Normal Operation (Ref.40)
GA91-9201-0003-00525, Revision 2, April 2017	Preliminary Evaluation for Heat Removal of Loaded Cask in Fault Condition (Ref.41)
GA91-9201-0003-01019, Revision 0, April 2016	Management of Damaged Fuel (Ref.42)
GA91-9201-0003-01563, Revision 0, September 2016	ALARP Report for Spent Fuel Export (Ref.43)
GA91-9201-0003-00539, Revision 0, May 2015	Maintenance of Integrity of SFIS Systems Structures and Components during Interim Storage with EMIT and AMP (Ref.44)
GA91-9201-0003-01150, Revision 0, September 2016	Response to RWM Assessment Report on UK ABWR Waste and Spent Fuel Disposability (Ref.45)

3.1 Strategic Level SFIS Optioneering

43. Hitachi-GE firstly identified four strategic-level options for SFIS, each of which were currently proven approaches drawn from worldwide OPEX. Hitachi-GE judged that it was technically feasible for each of the four options to be implemented on a licensed site in the UK to provide storage for the required timescales:

- Wet storage in a purpose-built pool (i.e. separate from the Reactor Building SFP).
- Dry storage in metal canisters with concrete over-packs.
- Dry storage in metal casks.
- Dry storage in vaults.

44. The relative strengths and weaknesses of the four options were considered against a list of factors (i.e. nuclear safety, industrial safety, technical, environmental impact and financial) and scored, with the result that the concept of dry storage in metal canisters with concrete over-packs was selected for application to the UK ABWR.

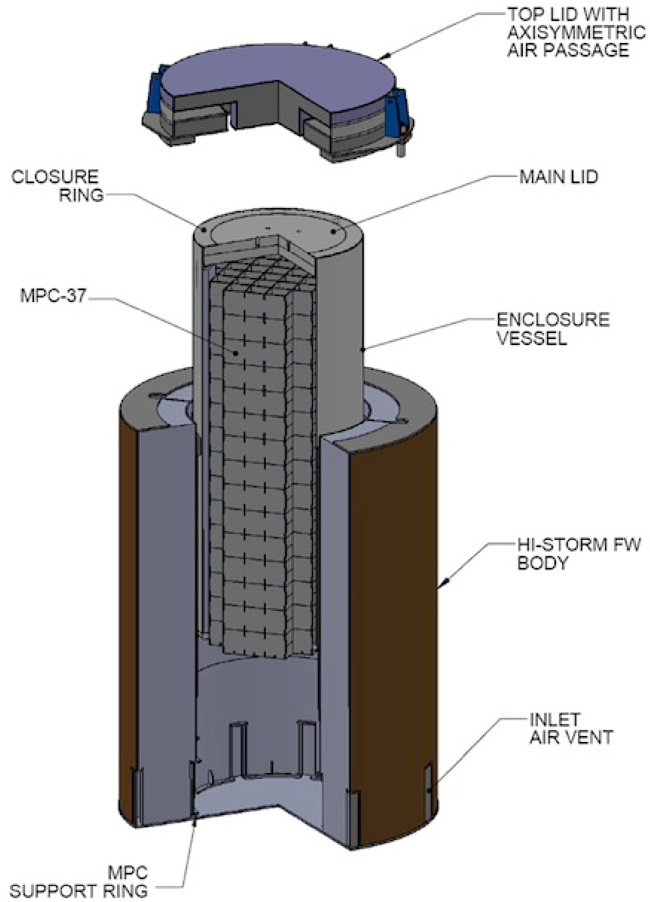
45. The remainder of Hitachi-GE's generic safety case was then scoped to demonstrate the application of this technology to the UK ABWR by:

- Using a currently available system as 'proof of concept'.
- Showing that the UK ABWR design is sufficiently flexible that alternative options for detailed design are not foreclosed to a future operator.

46. In order to bound its case for 'proof of concept', Hitachi-GE selected one of the largest currently available dry cask storage systems, namely Holtec International's HI-STORM

(i.e. the 'Holtec International Storage Module'), which features an MPC with a capacity of 89 spent fuel assemblies.

Figure 1
Schematic of a Typical Holtec HI STORM SFIS System



47. The balance of Hitachi-GE's case had to include a large number of auxiliary systems that will be needed to support the implementation of dry cask storage by maintaining adequate levels of safety through all the required process steps. These include but are not limited to:

- Spent Fuel Pool (SFP): the SFP civil structure, Cask Pit, SFP gates, fuel storage racks, FHM, the Fuel Pool Cooling, Clean-up and Makeup systems (FPCMs).
- Spent Fuel Export (SFE): MPCs, Canister Fuel Basket, Transfer Cask, Reactor Building Overhead Crane (RBC), Cask Stand, Impact Limiters, Canister Cooling System (CCS), Backup Canister Cooling System (BCCS), Canister Welding System, Forced Helium Dehydration (FHD), Over Temperature Protection System (OTPS). MPC leak detection system and Low Profile Transporter (LPT).
- Spent Fuel Interim Storage (SFIS): MPCs, LPT, Cask Transporter, Canister Mating Device, MPC over-packs, condition monitoring instrumentation, and SFIS Repackaging Facility.

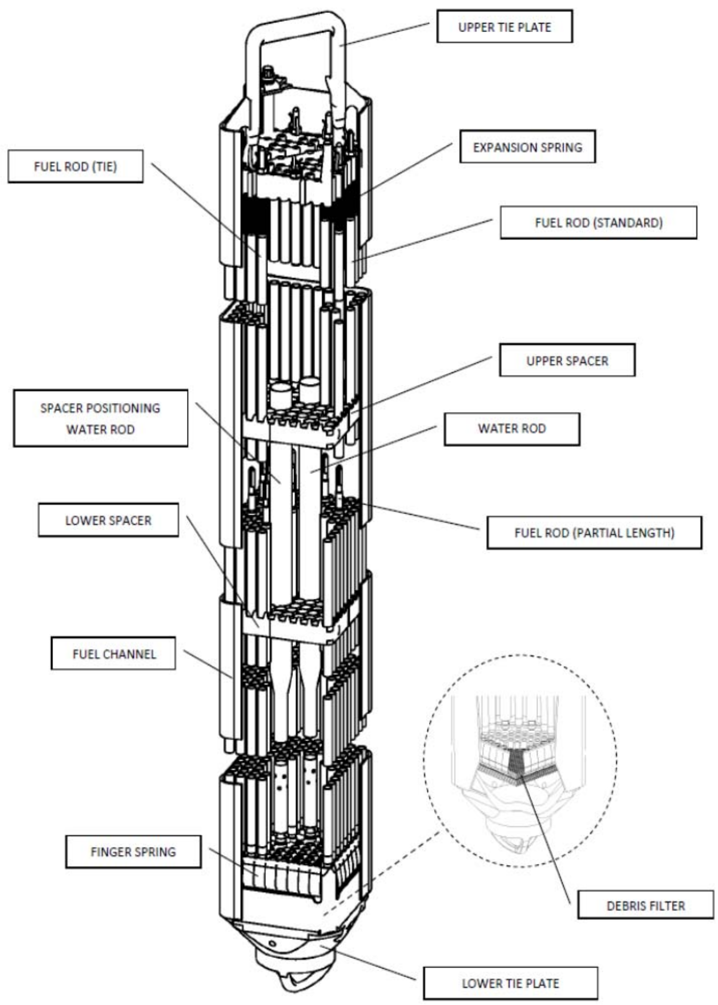
48. Within its Basic Specification, Hitachi-GE applied 'proof of concept' to demonstrate that the use of a bounding current SFIS system was not foreclosed by the design of the UK ABWR Reactor Building or any of the other interfacing SSCs (including the RBC and FHM).

3.2 Fuel-Related Criteria for Interim Storage

49. Having selected dry cask storage with concrete over-packs as its preferred SFIS strategy, Hitachi-GE adopted the GE14 design of fuel assembly as the baseline for relevant parts of its safety case within GDA. Within its report 'GE14 Spent Fuel Integrity Evaluation in Storage' Hitachi-GE aimed to:

- Evaluate the performance of GE14 spent fuel during the UK ABWR's envisaged on-site storage period (including both the wet and dry stages of on-site storage).
- Develop design limits to protect the integrity of the spent fuel during on-site storage, with which the UK ABWR SFE and SFIS systems needed to comply.
- Describe methods for evaluating spent fuel integrity during interim storage that could be applied to alternative designs of fuel assembly.

Figure 2
General Arrangement of the GE14 Fuel Assembly



50. The report's considerations included:

- The range of expected spent fuel conditions and properties (including burn-up, oxide thickness, hydrogen content, internal fuel pin pressures and decay heat profile).

- The potential fuel failure mechanisms during on-site storage, that the UK ABWR design aimed to prevent (including plastic instability, corrosion, hydride cracking, creep and stress corrosion cracking).

- Limiting criteria, for both the storage environment and external loads applied to the fuel, compliance with which was assessed as being sufficient to protect the spent fuel's integrity.

51. The fuel cladding is claimed as the first containment barrier in preventing the release of fission products during on-site storage. Therefore outputs from this part of Hitachi-GE's safety case set important design constraints for the systems used in SFE and SFIS. Data on the expected performance of spent fuel in off-normal storage conditions also informed the subsequent analysis of SFE and SFIS design basis faults.

52. Hitachi-GE defined a requirement that the average temperature of spent fuel cladding should remain below 400°C throughout its lifecycle in order to maintain its integrity over the envisaged storage period. This criteria aligned with precursors that would take a significant length of time to cause a fuel pin failure, hence Hitachi-GE referred to 400°C as a 'long-term temperature limit'.

53. Hitachi-GE also identified a 'short-term temperature limit' of 570°C to cover off-normal transients and accident conditions, above which a sudden rupture of the fuel cladding may occur.

54. It is noted that both the long and short-term temperature limits are dependent on a number of assumptions, the validity of which will require a review by a future licensee prior to the final selection of SFE and SFIS systems.

55. Therefore outputs from this study have informed parts of this assessment. However the robustness of the technical underpinning of Hitachi-GE's evaluation was outside the scope of this assessment and was scrutinised by ONR's Fuel and Core specialism in Assessment Report ONR-NR-AR-17-019 (Ref.7).

3.3 Spent Fuel Pool

56. Detailed consideration of the initial wet storage of spent fuel in the SFP is outside the scope of this assessment, however, given its importance in setting the context for the subsequent steps of SFE and SFIS a high-level summary is provided here for completeness.

57. Hitachi-GE's generic case is based on a single UK ABWR operating for 60 years, with a refuelling outage undertaken every 18 months.

58. During each outage the RBC is used to remove the Reactor Well Shield Plug, slot plugs, Primary Containment Vessel Head, Reactor Pressure Vessel (RPV) insulator and RPV head. The RBC then transfers the Dryer and Separator from within the Reactor Well into the Dryer Separator Pit (DSP).

Figure 3
Sectional View of the UK ABWR Steam Dryer Separator Pit, Reactor Well and Spent Fuel Storage Pool

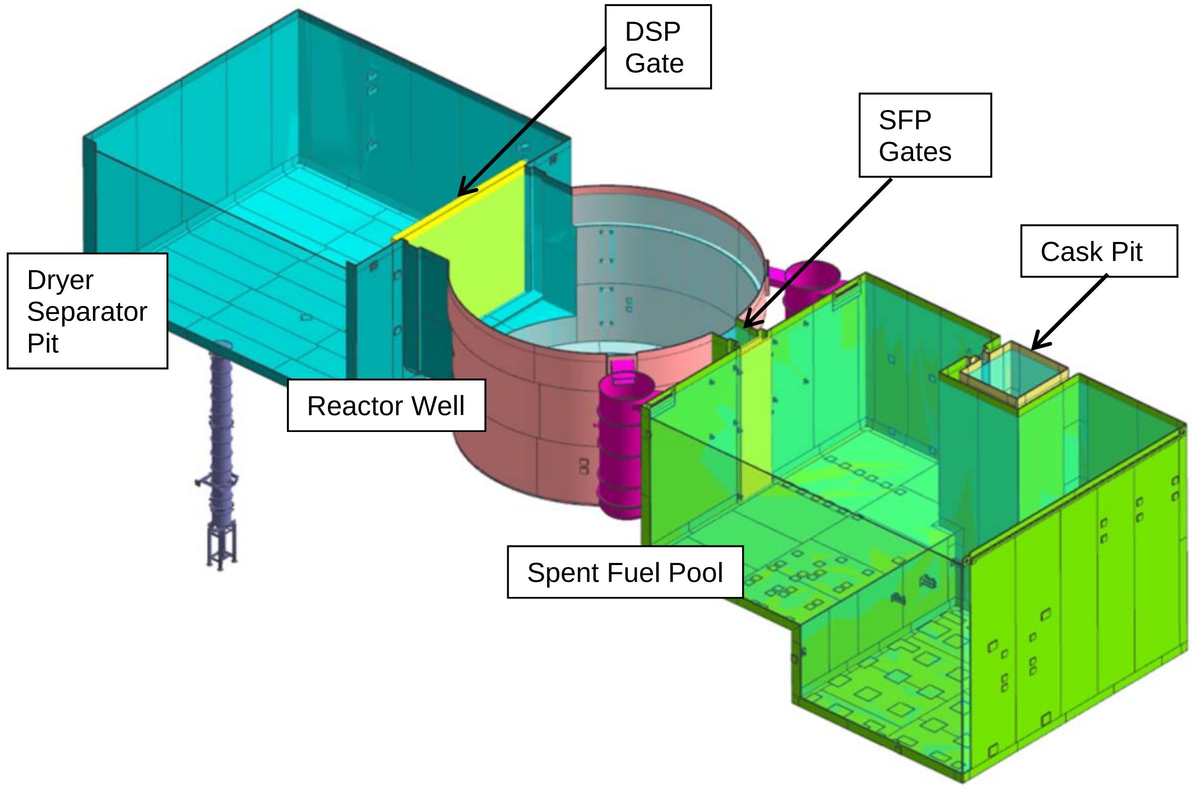
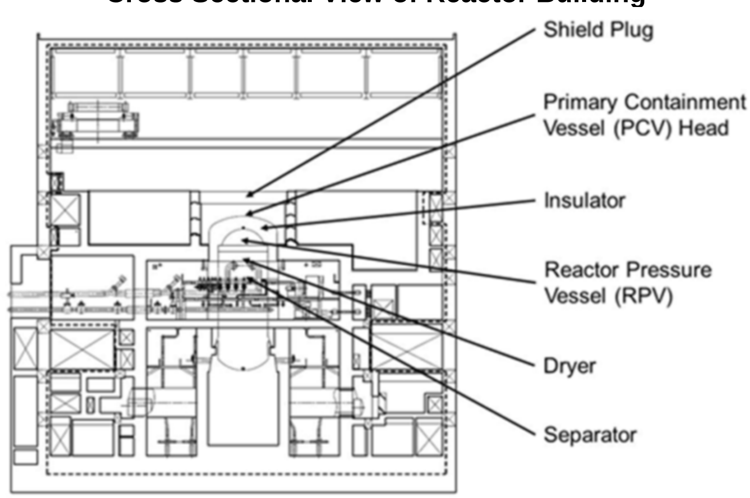


Figure 4
Cross Sectional View of Reactor Building



59. The two gates that segregate the Reactor Well from the Spent Fuel Pool (SFP) are then opened, which has the effect of linking the DSP, SFP and reactor well beneath a single body of water. This allows the FHM to efficiently remove spent fuel assemblies from the reactor and complete a submerged transfer into dedicated racks in the SFP. The racks are arranged in a square grid and bolted to the SFP floor and in addition to containing neutron-absorbing boron are geometrically designed to prevent criticality. The fuel will be stored in the SFP for approximately 10 years whilst its decay heat reduces to a level that allows the subsequent spent fuel management steps to occur safely. During the wet storage period the Fuel Pool Cooling, Clean-up and Makeup

systems (FPCMs) processes the SFP water to remove decay heat, maintain water quality and ensure sufficient water coverage.

60. The capacity of the storage racks is more than 300% of a full reactor core load and is sized to provide enough space to store the spent fuel generated during 10 years of operation, with a conservative contingency.

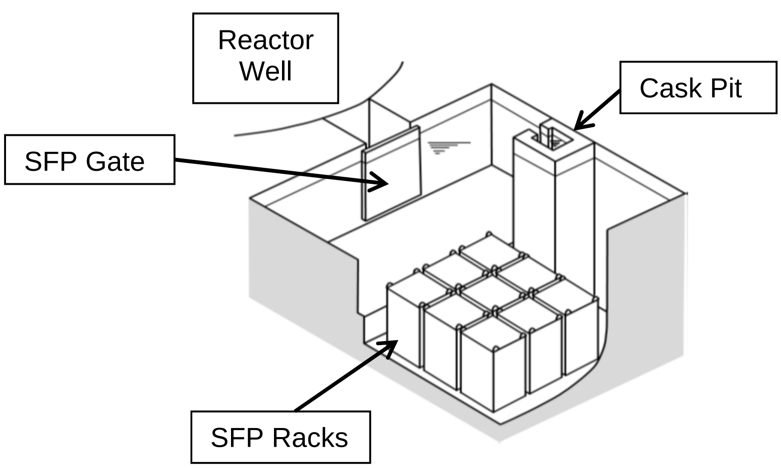
61. For the purposes of GDA, Hitachi-GE assumed that any fuel that has become damaged during the reactor operations will be stored in the SFP until the end of the station's operational phase. Hitachi-GE envisaged there were no credible scenarios where damaged fuel would need to be removed from the SFP immediately. Chapter 19 of the PCSR stated that the UK ABWR fuel route will be capable of safely handling damaged fuel, while noting that a bespoke risk assessment may be needed to identify additional measures (such as special handling equipment or containers) when specific details on the nature of the damaged fuel are available.

62. Hitachi-GE identified a number of potential solutions to handle damaged fuel of different types within the SFIS system, ranging from options that are currently commercially available to options that are conceptual and require research and development before they could be deployed. Hitachi-GE therefore concluded that it was not appropriate to determine an exact strategy for managing damaged fuel within GDA, as the choice of methods to identify, handle and store the damaged fuel will depend on the number and nature of damaged fuel assemblies that arise during the site's operational phase.

3.4 Spent Fuel Export

63. After approximately 10 years of wet storage, the Cask Pit gate will be opened and the FHM will transfer the spent fuel from the SFP racks into the Cask Pit, where the spent fuel will be introduced to a dry cask storage system in readiness for export from the Reactor Building.

Figure 5
Spent Fuel Pool Schematic



64. Within the Cask Pit spent fuel assemblies will firstly be placed inside a submerged MPC that is held inside a transfer cask. The MPC consists of two discrete components, an enclosure vessel and fuel basket – the basket ensures spent fuel is held in a sub-critical array and assists heat transfer. The transfer cask allows heat to be transferred to the surrounding environment while providing shielding for workers and physical protection for the MPC against the consequences of a dropped load or other impacts.

65. The MPC remains underwater in the Cask Pit during the fuel loading operations, with the Cask Pit gate open. Therefore during this step, removal of decay heat will continue to be provided by the bulk SFP water and FPCMs.

66. Once the MPC has been fully loaded with spent fuel assemblies, the canister lid is secured in place using temporary lid retention paddles and the Cask Pit gate is closed. At this point the spent fuel and water within the MPC is effectively isolated from the main bulk of the SFP water and the link to the FPCMs. The water inside the MPC therefore provides a limited volume heat sink for decay heat removal, which requires a 'time to boil clock' to be initiated. In the case of a Holtec HI STORM FW fully loaded with UK ABWR spent fuel of the anticipated burn-up, Hitachi-GE calculated that it will take 10.9 hours for the onset of boiling within the canister to occur on the following basis:

- A maximum design basis heat load of 46.36kW for the loaded MPC.
- 2998.7kg of water contained within the MPC.
- Initial canister water temperature of 52°C, aligned with the SFP bulk water temperature.
- Calculated rates of heat transfer between the transfer cask, canister, basket and fuel.

67. The concept designs proposed by Hitachi-GE within GDA demonstrate that the feasible options to monitor the temperature of spent fuel are available throughout the spent fuel export and interim storage activities. The temperature is utilised to indicate the temperature of the fuel clad and infer the likelihood of fuel clad failure occurring. Maintenance of the fuel clad integrity is required due to the safety claim that the cladding will act as the first containment barrier to the release of gaseous fission products. Thermal limits are therefore put in place to ensure the fuel clad integrity is not threatened – this in turn places design criteria on the spent fuel systems.

68. Hitachi-GE's final GDA case includes an assumption that the Canister Cooling System (CCS) will be pre-connected to the transfer cask prior to emplacement into the Cask Pit. The CCS is a Category A/Class 1 system whose function is to pump a cooling medium (demineralised water) through an annulus between the outer wall of the MPC and the inner surface of the transfer cask. The step of pre-connection would allow the CCS to be initiated immediately once the canister lid has been placed on top of the MPC, thereby increasing safety margins. Once annulus cooling via the CCS is fully established, the 'time to boil clock' can be reset.

69. To ensure adequate cooling of the spent fuel in the event of a CCS failure, a Backup Canister Cooling System (BCCS) is provided which is diverse and redundant from the CCS. The BCCS comprises a pump and flexible hoses which allow SFP water to be decanted directly into the main body of the MPC, thus reducing the internal water temperature inside the MPC to that of the bulk pond water. Hitachi-GE has stated that it is also technically feasible for the BCCS to use an alternative source of coolant water, should this be necessary.

70. Once loaded and lidded, the MPC and its transfer cask are raised from the bottom of the Cask Pit by the RBC and seated onto a Cask Stand. The Cask Stand is a bespoke engineered structure within the Cask Pit which allows the top of the MPC to be raised above the Cask Pit water level such that the MPC can be accessed for the purposes of lid decontamination, lid welding, drying and pressurisation with inert gas.

71. Through a consideration of OPEX, Hitachi-GE identified that two broad types of Cask Stand have been deployed elsewhere in the world to date – a hollow cylindrical column that sits on the bottom of the Cask Pit (requiring the MPC and transfer cask to be raised through the centre of the Cask Stand), or an alternative system of hooks that are installed proximal to the Cask Pit wall.

72. Once secured on the Cask Stand, the MPC is partially drained of water and the Canister Welding System is deployed onto the MPC lid.

73. The lid of the MPC is then welded to the shell of the MPC. Once welding is complete, the FHD and OTPS are connected to the canister lid and water is removed from inside the MPC. The MPC lid features vent and drain ports which are utilised to remove moisture from the MPC and backfill the canister with a specified amount of inert gas (typically helium). Multiple lines of temperature sensing will be deployed during this step, if excessive temperatures are detected the OTPS has the capability to automatically shut-down the FHD.

74. Pre-heated helium is forced through the MPC to remove residual moisture. The helium is pressurised within the canister to a level that will optimise heat transfer to cool the spent fuel during its time in interim storage. The vent and drain ports are closed, cover plates are installed and seal welded before the closure ring is welded in place.

75. Once the loaded MPC is sealed, dried and pressurised, the transfer cask lid is secured and the RBC is used to lift the MPC and transfer cask out of the Cask Pit, over the Operating Deck and down the Hoist Well. Decontamination may take place within the Cask Pit itself, in the neighbouring Preparation Pit or in a dedicated area of the Operating Deck. Impact Limiters are incorporated into the base of both the Cask Pit and Hoist Well in order to protect the MPC and civil structure against potential dropped loads.

76. After being lowered down the hoist well, the MPC and transfer cask are placed onto the Low Profile Transporter (LPT) in the Reactor Building for haulage to the Cask Transporter and transfer to the on-site store.

77. Table 4 summarises the Safety Functional Claims and associated provisions that Hitachi-GE identified, associated within its concept design for these SFIS and SFE processes.

Table 4

Spent Fuel Export Process Safety Functional Claims and Provisions	
Safety Functional Claim	**Provision**
Cooling: Temperature of spent fuel will be maintained within specified limits such that the fuel clad does not fail due to overheating during unsealed SFE operations and associated fault conditions	Temperature of the fuel cladding will be maintained by either two active lines of cooling or a single passive means.
Cooling: Temperature of spent fuel will be maintained within specified limits such that the fuel clad does not fail due to overheating during sealed SFE operations and associated fault conditions	Temperature of the fuel cladding will be maintained by either two active lines of cooling or a single passive means. During infrequent faults a single line of active or passive cooling is utilised.

Spent Fuel Export Process Safety Functional Claims and Provisions	
Safety Functional Claim	**Provision**
Containment: Containment function will be maintained during SFE unsealed canister operations and associated fault conditions.	Multiple containment barriers maintained during normal operations and frequent faults/hazards. Single containment barrier maintained during infrequent faults.
Containment: Containment function will be maintained during SFE sealed canister operations and associated fault conditions.	Multiple containment barriers maintained during normal operations and frequent faults/hazards. Single containment barrier maintained during infrequent faults.
Criticality: Fuel remains in a subcritical condition during operations under normal and fault conditions	Canister basket will be designed to ensure sub-criticality. This configuration will be maintained in accident scenarios.
Radiological Protection / Shielding: Shielding from spent fuel will minimise dose to operators during normal SFE operations and associated fault conditions.	During SFE canister loading operations, the SFP provides adequate shielding to operators. Once the cask is removed from the Cask Pit, both the Transfer Cask and canister lid provide the shielding functions to ensure dose to operators is kept ALARP.
Handling and Retrieval: Handling of spent fuel within canister shall not compromise other safety functional claims and the spent fuel and casks shall remain retrievable during normal operation and following frequent faults.	Retrievability of the spent fuel / casks will be maintained using the standard handling equipment during normal operations and frequent faults without compromising any other SFCs on site.
Handling and Retrieval: Canister deceleration during design basis drop faults shall remain below allowable limits.	Utilisation of an impact limiter where applicable.

3.5 Spent Fuel Interim Storage

78. Upon arrival at the storage building the transfer cask will be taken off the Cask Transporter, the loaded and sealed MPC will then be removed and placed within a substantial concrete over-pack via a Cask Interface. The over-pack is intended to protect the MPC and provide a substantial amount of shielding throughout the period of dry storage, while allowing sufficient convective heat transfer through an inner annulus connected to engineered vents in the over-pack base and top.

79. Throughout the dry storage period each MPC will be subjected to a regime of condition monitoring that will ensure the observed storage parameters are within the expected range, compatible with protecting the long term structural integrity of the spent fuel. This is expected to include remote monitoring of the temperature at the base and top of the MPC.

80. Although custom and practice elsewhere in the world includes the long-term storage of over-packed MPCs outdoors, Hitachi-GE assumed that the UK ABWR store will take the form of a lightweight civil structure similar to that in current use at Sizewell B. However Hitachi-GE believes it will not be necessary to place any safety claims on the store building itself.

Figure 6
Holtec International Over-Packed MPCs at Sizewell B – ***copyright of EDF Energy***

81. In the event of a deviation from the expected conditions, Hitachi-GE recognised a potential need to safely re-open MPCs to facilitate direct inspection and/or recovery of spent fuel, or to investigate fault conditions that can threaten the MPC integrity (such as a weld failure).

82. During the UK ABWR's operational phase, Hitachi-GE intends that any MPCs that require re-opening will be removed from the store and returned to the SFP in the Reactor Building by reversing the steps of spent fuel export. Hitachi-GE claimed that all the required safety functions during the return of MPCs to the SFP (principally shielding and containment) will be sufficiently well delivered using similar SSCs as during the original export process (noting that some additional SSCs, such as a weld removal system, are required for the reverse process).

83. When the UK ABWR enters decommissioning and the SFP is taken out of service, Hitachi-GE proposed that a hot cell would be constructed local to the store in order to provide:

- An ongoing capability to safely re-open an MPC in the event of a fault.
- The facility to carry out any required Examination, Inspection, Maintenance and Testing (EIMT) of spent fuel and/or the MPC internals.
- Final re-packing of spent fuel out of the MPCs into alternative containers that will be compatible with onward off-site transport and disposal at the GDF.

84. Blockage of the concrete over-pack vents was identified by Hitachi-GE as the bounding design basis cooling fault in the store. Based on the Holtec HI-STORM FW system, Hitachi-GE calculated that if 100% of the air vents became blocked the short-term fuel clad temperature limit of 570^{o}C would not be exceeded for 32 hours.

85. As described previously, Hitachi-GE's generic safety case presented the UK ABWR SFIS system as a 'proof of concept'. As this level of design did not include the specification of specific SSCs, Hitachi-GE's consideration of SFIS was not well suited

to the formal Claims, Argument, Evidence (CAE) safety case structure that is asked for in Ref.2 and therefore the production of Safety Functional Claims and Safety Property Claims. To account for this, Hitachi-GE developed an alternative method based on a text based approach to CAE which was compliant with Hitachi-GE's Safety Case Development Manual. While this approach did not include a formal CAE assessment, for the majority of areas that this report covers it was possible to link back to High Level Safety Functions that Hitachi-GE identified in order to quantify the safety functional requirements that need to inform the subsequent design phases. These have been listed in Table 5.

Table 5

Spent Fuel Interim Storage Safety Functions	
High Level Safety Function and associated SFIS Safety Claim	**Additional information**
HLSF 2-6: Functions to Maintain Spent Fuel Temperature during processes of spent fuel removal from cask pit to storage area and during interim storage period. The temperature of spent fuel will be maintained within specified limits such that the fuel clad does not fail due to overheating during SFIS operations and associated fault conditions.	During normal operation, and under consideration of frequent faults / hazards, there shall be a single passive means of cooling the spent fuel, monitoring on the containment to identify a fault, and sufficient time to react to an identified fault without risk of damaging the fuel cladding.
HLSF 4-14: Functions to Provide Containment barrier during processes of spent fuel removal from cask pit to storage area and during interim storage period. Containment function on the spent fuel cladding (first barrier), canister (second barrier) and concrete overpack (shielding) will be maintained for all normal and fault conditions.	During normal operations and frequent faults containment is maintained and monitored for assurance. Retrievals and repacking if required will support this claim for frequent and infrequent faults.
HLSF 1-10: Functions to Maintain Sub-Criticality of Spent Fuel during processes of spent fuel removal from cask pit to storage area and during interim storage period. Fuel remains in a sub-critical condition during operations under normal and fault conditions.	The fuel basket design and fabrication will maintain fuel geometry in normal and fault conditions.
HLSF 4-16: Functions to Provide Radiation Shielding during processes of spent fuel removal from cask pit to storage area and during interim storage period. The SFIS facility will be designed such that the Basic Safety Objectives (BSOs) for dose to the public and workers are met for all operations.	Shielding from spent fuel will reduce dose to operators and public ALARP during normal SFE operations and associated fault conditions.

Spent Fuel Interim Storage Safety Functions	
High Level Safety Function and associated SFIS Safety Claim	**Additional information**
HLSF 5-16: Functions to Provide Handling and Retrievability during processes of spent fuel removal from cask pit to storage area and during interim storage period. Handling of spent fuel within canister shall not compromise other safety functional claims and the spent fuel and casks shall remain retrievable during normal operation and following frequent faults.	During normal operations and faults, the SFIS casks and associated items shall remain retrievable and manageable using the equipment / facilities installed to support the function of the SFIS.
HLSF 5-22: Function to Limit Deceleration Loading to canister containment boundary during credible cask drop faults. Canister deceleration during design basis drop faults shall remain below allowable limits.	This claim focusses on preventing failure of Canister containment boundary by limiting the deceleration loading onto it and concerns the Impact Limiter. The Impact Limiter delivers a Category A function and is designed to meet Safety Class 1 requirements.

3.6 Spent Fuel Disposability

86. In accordance with the regulators' Guidance to Requesting Parties, during GDA Hitachi-GE engaged Radioactive Waste Management Ltd (RWM Ltd) – the prospective licensee responsible for delivering the UK's GDF – to complete a disposability assessment of the expected UK ABWR spent fuels and Higher Activity Wastes.

87. RWM Ltd reported the levels of radioactivity in similar present-day UK waste streams, normalised the data to facilitate a like-for-like comparison, then showed that the radionuclide contents expected to occur in the UK ABWR streams was comparable to those from the pre-existing PWR at Sizewell B.

88. From its assessment of Hitachi-GE's data (Ref.47), RWM Ltd identified 27 areas for further consideration (23 relating to management of ILW and 4 relating to spent fuel), none of which were considered to challenge the fundamental disposability of the UK ABWR wastes and spent fuel. The 4 matters relating to spent fuel were:

- The storage of spent fuel in water ponds means that drying techniques will need to be put in place to avoid the potential for internal pressurisation of storage/ disposal containers and to ensure that they would comply with existing transport regulations.

- Storage conditions will need to be managed to maintain integrity of the fuel assembly (particularly the fuel cladding) and any storage/disposal container during storage operations. If a wet storage strategy were to be implemented, a key requirement would be to maintain conditions to preserve the integrity of any stainless steel components (e.g. tie bars). If a dry storage regime were implemented, control of temperature and relative humidity would be required to minimise the potential for degradation (e.g. by hydride embrittlement) of fuel assembly components and any disposal container.

- RWM recommended that a future operator should consider the extension of safeguards provisions through to disposal, particularly for spent fuel, and consider working with RWM, whether and how the safeguards status of spent fuel will be terminated.

- Further confirmation would be sought during future interactions under the Disposability Assessment process that all chemotoxic species have been identified in the UK ABWR spent fuel.

89. RWM Ltd therefore concluded that the spent fuel expected to arise from operation of a UK ABWR should be compatible with eventual off-site transport and geological disposal at the UK's planned GDF.

3.7 Consideration of SFE and SFIS Faults

90. Within its generic case, Hitachi-GE applied established fault analysis techniques (such as Design Basis Analysis) to all aspects of UK ABWR irradiated fuel handling and provided a Topic Report which gave particular consideration to the faults associated with SFE and SFIS. The main purposes of this Topic Report were:

- To identify the credible faults during SFE and SFIS.
- To provide a preliminary assessment of the fault sequences, their potential consequences and identify protection and mitigation measures.
- To assess the implications for the SSCs that will deliver SFE and SFIS.
- To consolidate a preliminary fault schedule for SFE and SFIS that demonstrated the UK ABWR's ability to fulfil the required High Level Safety Functions.

91. Throughout the above considerations Hitachi-GE's mechanism to apply the principles of ALARP was its GDA ALARP Methodology (Ref.46).

92. As SFIS was limited to a concept level of design within GDA, Hitachi-GE considered it was not appropriate to provide full design substantiation or to assess exact fault magnitudes for all the identified faults at this time. Therefore Hitachi-GE sought to demonstrate a conservative approach, within which it was assumed that certain faults were credible, to enable those faults to be assessed and potential additional safety measures to be identified.

93. Given the lack of detailed design information, it was necessary for the assessment of SFIS faults to include a number of assumptions (such as system reliability figures). To ensure these assumptions were conservative and realistic, Hitachi-GE sourced relevant data from current operational experience and data sources available in the global nuclear industry. Key assumptions and requirements that were identified as having the potential to constrain the future steps of detailed design were identified in a high-level Assumption List, for the reference of a future licensee.

94. The analysis considered eight groups of SFE and SFIS faults, these were; cooling faults, impacts to unsealed canisters, impacts to sealed canisters, degradation, single fuel assembly handling (i.e. dropped load), fuel misloads, shielding, other faults (that were not included in the fault schedule, having been deemed highly unlikely to occur or assumed to be eliminated at the detailed design stage).

95. The Topic Report concluded that all the SFE and SFIS High Level Safety Functions will be adequately maintained during the assessed fault conditions.

4 ONR STEP 4 ASSESSMENT

96. This assessment focussed on the robustness of Hitachi-GE's proposals for the on-site dry cask storage of spent fuel, together with key parts of the preceding processes whose efficacy will underpin the safety of the dry storage period.

4.1 Scope of Assessment Undertaken

97. During the course of the GDA, ONR has:

- Assessed all submitted revisions of the Hitachi-GE documents listed in Table 3 of this report.
- Requested and assessed additional detailed references from Hitachi-GE.
- Held technical discussions in Level 4 meetings with Hitachi-GE.
- Provided advice and guidance to Hitachi-GE on ONR's expectations for an adequate consideration of SFIS within GDA.
- Raised Regulatory Queries (RQs) (see Annex 5).
- Assessed the adequacy of Hitachi-GE's responses to the RQs.
- On a multi-disciplinary basis considered the inter-linkages between Hitachi-GE's SFIS submissions and other relevant parts of the UK ABWR safety case.

98. No Regulatory Issues (RIs) or Regulatory Observations (ROs) were raised by ONR against Hitachi-GE's submissions for SFIS. However SFIS was a relevant consideration to several RIs and ROs that were raised in other assessment disciplines through the GDA – these are listed in Annex 4 and the key contents are summarised in Section 4.3 and 4.4.

99. In accordance with ONR's Guidance to Requesting Parties, residual matters were recorded as GDA Assessment Findings if one or more of the following applied:

- Resolution of the matter required site-specific information.
- Resolution of the matter depended on future licensee design choices.
- The matter related to other licensee-specific features / aspects / choices associated with future operational philosophy.
- Resolution of the matter required a greater level of detail on the design than can reasonably be expected in GDA.
- Resolution of the matter was not practicable until the plant enters the phases of construction or commissioning.

100. Management of spent fuel involves a wide range of radiological and conventional safety hazards. Priorities for ONR's scrutiny were informed by the key principle of ONR's Enforcement Policy Statement – that the requirements of safety should be applied in a manner that is commensurate with the magnitude of the hazard. Therefore during this assessment ONR targeted the features of the UK ABWR that were of greatest relevance to protecting against the hazards and risks of SFIS.

101. The specific evidence sought by ONR included:

- A demonstration that the design complies with the expectations of UK law, policies and other regulatory standards applicable to SFIS.

- A clearly defined and expressed SFIS strategy, consistent with all other relevant strategies and plans.
- A demonstration that Hitachi-GE's proposals for SFIS are deliverable using current technology as a 'proof of concept'.
- Justification of assumptions, to demonstrate that Hitachi-GE had adopted a precautionary approach to any significant uncertainties to which the design may have a sensitivity.
- Challenge of specific design features, targeted on areas of the plant that will be important in protecting the workforce and public from the greatest hazards and risks of SFIS.
- A demonstration that the intended operational regime had been challenged to reduce the hazards and risks of SFIS SFAIRP.
- Arrangements to ensure any significant impacts on SFIS are taken into account during design changes and process modifications.
- A demonstration that the design will allow a future licensee to deploy a fitting hierarchy of hazard control measures during SFIS, in respect of the principles of: Eliminate, Reduce, Isolate, Control, Personal Protective Equipment and Discipline (widely known as 'ERIC–PD').
- A demonstration that all Systems, Structures and Components (SSCs) expected to play a role in SFIS can realistically meet the duties claimed of them, in terms of both functionality and length of service.
- Clear and traceable links between underpinning data, Topic Reports, the Pre-Construction Safety Report (PCSR) and other parts of the safety case which concern the engineering of relevant SSCs.

4.2 Assessment

Strategic Approach to SFIS

102. Hitachi-GE's strategy for SFIS was selected and justified in a two-step approach reported in, 'High Level Optioneering on Spent Fuel Interim Storage' (Ref.25).

103. Within this report Hitachi-GE adopted an open and transparent approach to identify four feasible strategic-level options for SFIS and determine their relative merits. The four options were based on proven current technology and assessed by Hitachi-GE as being capable of meeting all minimum requirements for application to the UK ABWR. The scoring exercise was conducted by suitably experienced and qualified personnel, whom applied a set of attributes that reflected the principles of reducing risks SFAIRP, use of Best Available Techniques (BAT) to protect the environment and good practices in management of spent fuel.

104. The report also considered how the chosen option of dry cask storage with concrete over-packs could be developed to meet Hitachi-GE's objectives for GDA. During dry storage, the integrity of the fuel cladding is protected by maintaining adequate cooling while the fuel is isolated in an inert gas environment and these criteria need to be protected for the envisaged storage period.

105. Having recognised the potential for the SFIS system to be a bounding consideration for the export route from the Reactor Building and footprint of the interim store, Hitachi-GE adopted one of the largest currently available dry cask systems, the Holtec HI STORM FW, for the purpose of providing a 'proof of concept' within GDA. This system is in current use internationally, having been licensed by the United States Nuclear

Regulatory Commission (US NRC) in 2011 and is compatible with Holtec's HI-TRAC transfer casks.

106. In its response to RO-ABWR-80, Hitachi-GE later provided further evidence to demonstrate that the availability of space within the UK ABWR hoist well will not unduly constrain future design options for a site licensee in relation to the export of spent fuel from the Reactor Building.

107. Hitachi-GE applied several minimum requirements and assumptions to its consideration of options, which I judged to be compatible with the UK Government's Base Case for the lifecycle of new nuclear power stations and included:

- The safety case reflects the maximum length of time for spent fuel to be in dry cask storage on the site to be 140 years.
- Following dry storage, the spent fuel will have to be re-packaged onsite, prior to being consigned to the GDF for final disposal.

108. Whilst Hitachi-GE identified the potential need to sustain a regime of dry storage on the UK ABWR site for up to 140 years, an additional assumption was made for the purpose of Hitachi-GE's consideration of options that the MPCs used in SFIS will have a design life of 100 years and will therefore need to be over-packed during the envisaged storage period. The specified design life of MPCs is a matter for ONR's assessment report for the Structural Integrity topic (Ref.17), noting that over-packing of MPCs would increase the required number of nuclear lifts and result in higher volumes of radioactive wastes.

109. Throughout its GDA case, the assumed baseline conditions of the UK ABWR spent fuel aligned with the GE14 Fuel Integrity Evaluation During Interim Storage, the basis of which has been judged as adequate by ONR's Fuel and Core Specialism (Ref.7).

110. From this section of assessment, I was content that Hitachi-GE had adopted a suitably justified strategic approach to SFIS for the UK ABWR, based on dry cask storage with concrete over-packs, aligned with regulatory expectations and UK government policy.

111. I was also content that Hitachi-GE had suitably integrated its proposals for SFIS with other parts of its safety case, most importantly the decommissioning strategy and plan – within which the requirement for an extended period of on-site dry cask storage of spent fuel and maintenance of a capability to re-open MPCs had been appropriately recognised.

Misloading of Spent Fuel into MPCs

112. ONR identified spent fuel misloading events as a particular area of interest during this assessment, due to lessons learned from misloads that have occurred elsewhere in the world and the potential for some types of misload to lead to significant radiological consequences.

113. Initiators for misloading events can include errors in planning or during the execution of the loading process, such that fuel with properties outside of the expected scope is introduced into an MPC by the FHM.

114. Hitachi-GE identified three groups of misloading events, which I judged to be comprehensive:

- Misload of new fuel in place of irradiated fuel, leading to a criticality hazard.
- Misload of damaged fuel in place of intact fuel, creating containment and handling hazards.

- Misload of high decay heat fuel in place of low decay heat fuel ('thermal misload'), giving rise to elevated temperatures.

115. In the case of new fuel misloads Hitachi-GE provided assurance that bounding criteria will be applied to the geometry of the MPC basket, such that every position in the basket could be filled with new fuel without causing a criticality event. Through this design measure sub-criticality will be guaranteed following any type of misload. I noted that Hitachi-GE's approach implied the criticality safety case will not include any claims for burn-up credit, which may have the potential to allow more spent fuel to be stored inside each MPC (subject to a satisfactory safety case to address all the other relevant factors, such as decay heat limits). However as the final choice of MPC and detailed design of the fuel basket was not completed within GDA, options are not foreclosed to a future licensee.

116. In relation to damaged fuel Hitachi-GE identified the following targeted measures to prevent a misload going undetected, which I judged to be a reasonably practicable approach:

- Damaged fuel will be stored in a dedicated area of the SFP, within which movement of the FHM will be restricted, to minimise the likelihood of a damaged fuel assembly being selected in error.
- Semi-automatic FHM operation and independent FHM programme verification will be used to ensure correct fuel selection.
- During loading, independent visual verification of the fuel assembly's identification number will take place to ensure the correct selection has taken place.
- Prior to the MPC lid being welded, the water within the MPC will be sampled to detect if there has been any release of fission products from damaged fuel within the canister.

117. Hitachi-GE sub-divided thermal misloads into the following 3 categories:

- Minor thermal misloads, where the design basis may be exceeded but the deviation is small and therefore fuel clad integrity and MPC integrity are not threatened.
- Significant thermal misloads, where the deviation from the design basis is large enough to threaten the integrity of fuel cladding (requiring the clad temperature to rise above 400^{o}C for long-term effects or 570^{o}C for short-term effects), but the MPC will remain fully functional.
- Severe thermal misloads, where both the fuel cladding and MPC integrity are threatened (in the case of the HI STORM FW MPC this would require the heat load to exceed 46.36kW, noting the UK ABWR design basis heat load is [redacted]).

118. Although minor thermal misloads may give rise to issues of nuclear material accountancy for the spent fuel, they would not challenge the safety margins or give rise to any radiological consequences. Therefore the remainder of ONR's assessment focussed on the robustness of the measures in place to detect and prevent significant and severe thermal misloads, as the consequences of such events may include:

- Premature onset of boiling of water inside the canister (i.e. faster than the expected time to boil of 10.9 hours in the case of the HI STORM FW).
- Increased dose rates on the Operating Deck during the MPC conditioning and export, from direct radiation.
- Fuel clad failure due to over-heating, during the MPC conditioning.

- Fuel clad failure due to over-heating, during interim storage.
- Fuel clad and canister failure due to over-heating, during interim storage.

119. In light of these potential consequences, it is particularly important for any misloaded fuel assemblies with high levels of decay heat to be detected prior to the MPC being removed from the Cask Pit if reasonably practicable, due to the radiological implications during subsequent SFE and SFIS operations.

120. An important element of Hitachi-GE's case was a prediction that an undetected misload would be an infrequent event (<IE-3/year) for the purpose of fault analysis, which implied that a single barrier against release would be sufficient for the fault conditions to meet ONR's probabilistic and deterministic criteria.

121. Hitachi-GE initially claimed that two barriers would be in place to mitigate the consequences of a misloading event, provided by the fuel clad and the Reactor Building (combined with the Standby Gas Treatment System, SGTS). However ONR noted that whilst the Reactor Building and SGTS would constrain the levels of radioactivity released into the external environment, they would not protect workers on the Operating Deck. Whilst a loaded MPC is unsealed, workers in the vicinity will only be protected by a single barrier from a release of radioactive material occurring within the MPC. Therefore for ONR to be satisfied that this aspect of the UK ABWR design and operations will comply with the deterministic and probabilistic criteria, it was necessary for Hitachi-GE to provide further evidence in support of its claim that the likelihood of a misload would be infrequent. ONR consequently raised RQ-ABWR-1050, to seek a further explanation of Hitachi-GE's reasoning.

122. In its response to RQ-ABWR-1050, Hitachi-GE indicated that its predicted frequency of misloading events was based on the USNRC report "Estimating the Probability of Misload in a Spent Fuel Cask" (Ref.48), together with a consideration of the UK ABWR design specifics. Inspectors from several ONR GDA topics reviewed both the USNRC data and relevant Hitachi-GE submissions. ONR concluded that, in the event the proposed preventative measures were limited to multiple steps of verification by operators, the likelihood of a misload occurring should be considered to be frequent.

123. ONR therefore raised RQ-ABWR-1369 to seek assurance that the detection and prevention of significant and severe thermal misloads will not rely purely on manual verification processes and risks will be reduced SFAIRP. Specifically ONR sought further evidence that Hitachi-GE had considered the potential for human errors in each step of the loading process, with the incorporation of reasonably practicable engineered measures to detect the presence of a significant or severe thermal misload and enable timely recovery actions.

124. Within its response to RQ-ABWR-1369 and a subsequent revision to its report *'Consideration of Faults for Spent Fuel Export and Spent Fuel Interim Storage'*, Hitachi-GE presented analysis of how the misloading of varying numbers of fuel assemblies with varying cooling times may lead to over-heating and affect the integrity of the fuel cladding and canister. While ONR robustly challenged the data presented, Hitachi-GE's final case presented a clear understanding of the causes and potential consequences of misloading.

125. Hitachi-GE claimed that a number of detection measures for significant and severe thermal misloads had been incorporated into the baseline UK ABWR design. These measures included:

- Operators observing (possibly via a CCTV system) convective currents and/or bubbles escaping from around the edge of the canister lid, due to the onset of boiling within the MPC, during the process of putting the MPC lid into place when the MPC is at the bottom of the Cask Pit.

- Increase in dose rates as the MPC and its transfer cask are raised from the bottom of the Cask Pit.
- Measurement of the rate of temperature increase within the MPC via a sensor.

126. In the event that a significant or severe misload is detected prior to the MPC lid being welded, the fault can be recovered by returning the MPC to the bottom of the Cask Pit, followed by removal of the MPC lid and Cask Pit gate to re-instate cooling via the bulk SFP water and FPCMs.

127. The Step 4 submissions also identified several additional potential risk reduction measures that Hitachi-GE had considered but not adopted into the UK ABWR baseline design within GDA. These included:

- Additional temperature measurements.
- Thermal imaging.
- Additional radiation monitoring by gamma/neutron measurement.
- Specification of a minimum time gap between a refuelling outage and a campaign of loading spent fuel into MPCs, to limit the potential thermal heat load of a misloaded assembly.

128. Rather than provide an argument that adoption of these additional measures was not reasonably practicable, Hitachi-GE based its GDA case on a demonstration that the additional measures were not foreclosed to a future licensee.

129. Following consideration of Hitachi-GE's further evidence, I concluded:

- Some of the misload detection measures that are included in the UK ABWR reference design would not comply with ONR's expectation that safety functions should be delivered by an engineered means in preference to placing duties on the actions of individuals.
- It was not practicable for Hitachi-GE to fully substantiate the effectiveness of the proposed misload detection measures within GDA, due to the lack of detailed design information and Hitachi-GE's stated preference to leave the selection of a specific SFIS system to a future licensee.
- The system for planning spent fuel loading campaigns, which is an important source of potential human error, is the responsibility of a future licensee and therefore out-of-scope of GDA.
- Implementation of additional measures to reduce the risks of a significant or severe thermal misload may be reasonably practicable, had not been foreclosed by the UK ABWR reference design and will require assessment by a future licensee during SFIS detailed design.

130. While this additional evidence allowed me to conclude that the UK ABWR is capable of reducing the risks associated with misloads of spent fuel SFAIRP, full resolution of the matter requires a greater level of detail than was provided in GDA and is dependent on future licensee design choices. I have therefore captured this residual matter within **Assessment Finding AF-ABWR-SFIS-01**, as detailed in Annex 6.

Non Foreclosure of Options in the Design of the Cask Pit and Preparation Pit

131. During the spent fuel loading process MPCs remain fully submerged at the base of the Cask Pit and the safety provisions align with those for wet storage in the SFP. Once fully loaded the canister lid is secured in place using temporary lid retention paddles

and the Cask Pit gate is closed. The MPC and its transfer cask are then raised from the bottom of the Cask Pit by the RBC and seated onto a Cask Stand.

132. The Cask Stand is an engineered structure within the Cask Pit which allows the MPC to be seated securely with its top section above the Cask Pit water level to enable canister sealing, draining, drying and inerting to take place. Cask Stands similar to that proposed for the UK ABWR have previously been deployed at multiple sites in the United States.

133. Hitachi-GE decided to adopt a Cask Stand into the UK ABWR reference design following a Hazard Identification exercise (HAZID) carried out during Step 4, in order to remove some of the risks associated with the alternative approach of conditioning MPCs in the neighbouring Preparation Pit. Incorporation of a Cask Stand removes the need for unsealed loaded MPCs to be lifted entirely out of the Cask Pit and traversed across the Operating Deck before being lowered into the Preparation Pit, thereby reducing the extent of nuclear lifting and eliminating the risk of an unsealed loaded MPC toppling during the transit to the Preparation Pit.

134. Locating the processes of MPC drying, inerting and welding in the Cask Pit (with the lower sections of the MPC surrounded by pond water) will also reduce worker doses when compared to using the dry Preparation Pit.

135. Although adoption of a Cask Stand apparently eliminated the need to use the Preparation Pit, ONR noted that Hitachi-GE chose to retain the Preparation Pit within the UK ABWR civil structural design.

136. Within report GA91-9201-0003-00526 Hitachi-GE stated that, "*It should be noted that option of using the preparation pit for further decontamination of the cask remains open to the licensee. No options are foreclosed to the future licensee for any other canister preparation activities, such as lid welding and helium drying and backfilling, to be carried out within the preparation pit instead of the cask pit should it be deemed an ALARP solution at a later stage.*".

137. As the expected scope of activities within the Preparation Pit was unclear, ONR raised RQ-ABWR-1215 to seek further clarification and ensure the design of the Preparation Pit and Cask Pit will not foreclose options to reduce the risks of the activities that may take place in them SFAIRP.

138. In response Hitachi-GE explained that although the option of using a Cask Stand within the Cask Pit was the baseline for the purposes of GDA, it was only one of the possible options available to a future site licensee. Hitachi-GE further noted that options for utilising the Preparation Pit had not been foreclosed and the exact final process for SFE and SFIS will need to be decided by the site licensee during future stages of design.

139. As resolution of this matter depends on the licensee's site specific design choices and requires a greater level of design detail than was available in the generic safety case, I have incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-02**, as detailed in Annex 6.

Protection of Workers in the Vicinity of Unsealed Canisters

140. Prior to the completion of MPC welding, the canister is defined as 'unsealed' and cannot be claimed as a secondary containment barrier. Consequently workers on the Operating Deck are protected from fission products by a single barrier to release, provided by the fuel cladding, whilst the loaded MPC is lifted from the base of the Cask Pit onto the Cask Stand, the spent fuel is dried, the canister is filled with inert gas and the canister lid is welded.

141. ONR raised RQ-ABWR-1097 to ensure that Hitachi-GE had:

- Identified all design basis faults that may give rise to a fuel clad failure within an unsealed canister.
- Appropriately assessed the unmitigated consequences for workers in the vicinity of a fuel clad failure within an unsealed canister.
- Defined adequate limits to safe operation, engineering requirements and associated arrangements to ensure risks to workers from a fuel clad failure within an unsealed canister will be reduced SFAIRP, with any inherent uncertainties addressed by the use of appropriate conservatism.
- Provided an adequate safety case in respect of beyond-design-basis plant states associated with fuel clad failures within unsealed canisters, wherein the potential consequences may be severe.

142. ONR also raised RQ-ABWR-1320 to seek a further explanation of Hitachi-GE's analysis of the particular fault of an unsealed and loaded MPC being dropped into the Cask Pit following a failure of the Reactor Building Crane and how that analysis related to the provision of safety measures.

143. Within its responses to these RQs and in other relevant Step 4 submissions Hitachi-GE confirmed the basis of its fault analysis and adoption of related safety measures, which included:

- For the purpose of estimating unmitigated consequences, all the fuel assemblies within a loaded unsealed MPC were conservatively assumed to fail in the event of the MPC being dropped into the Cask Pit.
- For the purpose of estimating unmitigated consequences, the time taken for workers to evacuate the Operating Desk in response to a dropped MPC was 30 minutes, which complied with ONR's expectations in Radiological Protection.
- For the purpose of estimating unmitigated consequences, the MPC lid retention paddles were not claimed to provide any sealing to restrict the release of radioactive gases or fine particulate from a dropped MPC.
- There are no credible failure modes of the RBC that may lead to a dropped MPC becoming wedged in a tilted orientation in the top of the Cask Stand.
- A lift yoke extension was included into the RBC baseline design, such that a loaded MPC can only be lifted to the height necessary to be placed on the Cask Stand and the Cask Stand itself will be designed to tolerate the load of the maximum possible drop.
- A formal design change had been introduced within GDA to increase the depth of the Cask Pit, to accommodate an impact limiter of [redacted] and thereby ensure that in the event of an MPC being dropped the resulting deceleration when it meets the bottom of the Cask Pit (at a depth of [redacted] will be below the canister design basis limit of 60g.

144. Within RQ-ABWR-1320, ONR specifically asked Hitachi-GE to justify how the range of SSCs identified against a drop of an unsealed loaded MPC will deliver the ERIC-PD hierarchy and reduce the associated risks to workers ALARP, including a consideration of removing the need for workers to be in the locality of the Cask Pit during such lifts. In its RQ response, Hitachi-GE presented the following options:

- Automatic latch mechanisms that would support the MPC in the event of a drop.
- A braking system between the MPC and Cask Stand to arrest a falling MPC.

- A hydraulic damper to arrest a falling MPC.
- A passive or active load follower to support the MPC from below if it were dropped.
- A bolted MPC lid to provide an additional containment boundary to prevent a release in the event that an MPC is dropped.
- Undertaking all unsealed lifting operations remotely so that workers would not be exposed to a release in the event of a drop.

145. Rather than provide an argument that adoption of these additional measures was not reasonably practicable, Hitachi-GE based its GDA case on a demonstration that the measures were not foreclosed to a future licensee.

146. While this additional evidence allowed me to conclude that the UK ABWR is capable of reducing the risks associated with a drop of an unsealed loaded MPC into the Cask Pit SFAIRP, full resolution of the matter requires a greater level of detail than was provided in GDA and is dependent on future licensee design choices. I have therefore incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-02**, as detailed in Annex 6.

147. ONR also specifically challenged:

- The basis on which Hitachi-GE had not placed any safety claims on the MPC lid retention paddles.
- Whether the method used to deploy the lid retention paddles will ensure effective delivery of any required safety functions.
- That the doses to workers incurred whilst deploying the lid retention paddles will be reduced SFAIRP.

148. Hitachi-GE explained that the function of the paddles is to retain the un-welded MPC lid in place during a cask drop event thereby ensuring containment of fuel, but the paddles had not been claimed to provide a sealing function against a release of radioactive gases and fine particulate.

149. Hitachi-GE intended that the paddles will be engaged and disengaged manually by operators using a long-handled tool within the Cask Pit. The tool would be positioned over each paddle and on turning the tool the operator would be able to physically feel the paddle lock into place. Hitachi-GE noted there were several other options to ensure correct deployment of the paddles and therefore based its GDA case on a demonstration that alternative measures were not foreclosed to a future licensee.

150. While this additional evidence allowed me to conclude that the UK ABWR can support the deployment of lid retention paddles with associated risks reduced SFAIRP, full resolution of the matter requires a greater level of detail than was provided in GDA and is dependent on future licensee design choices. I have therefore incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-02** as detailed in Annex 6.

Cooling During MPC Drying, Inerting and Welding

151. Hitachi-GE defined the following four states of cooling during the SFE and SFIS processes:

- State 1 – while the loaded MPC is located in the Cask Pit with no lid attached, decay heat removal is provided via the bulk SFP water and FPCMs.
- State 2 – once the MPC lid is put in place, the entrained water within the MPC provides a heat sink for decay heat removal and standard practice is to apply a

'time to boil' clock (calculated as 10.9 hours for the HI STORM FW). The CCS can also be available during State 2, to re-start the 'time to boil' clock, in the event it is pre-connected to the transfer cask.

- State 3 – when water is removed from inside the MPC, until the canister is welded and pressurised with inert gas, decay heat removal is guaranteed by availability of the CCS, BCCS and the operating parameters of the Forced Helium Dehydration system (FHD) complemented by the Over Temperature Protection System (OTPS).

- State 4 – once the canister has been sealed and pressurised with inert gas, passive cooling is sufficient to maintain fuel clad temperatures below the required limits.

152. During Step 4 of GDA ONR sought additional clarification on the design of all the key active cooling systems via RQ-ABWR-1091 (BCCS Proof of Concept), RQ-ABWR-1093 (OTPS Proof of Concept) and RQ-ABWR-1094 (CCS Proof of Concept).

153. Within the generic case the CCS is assumed to be Category A/Class 1 system that delivers demineralised water through an annulus between the outer surface of the MPC and inner surface of the transfer cask. Hitachi-GE intends that the CCS will be a closed loop system incorporating a water storage tank (with sufficient capacity to guarantee adequate cooling) and a heat exchanger with ambient air providing the ultimate heat sink.

154. Hitachi-GE's generic case assumes the CCS will be pre-connected to the transfer cask prior to the loading of spent fuel in the Cask Pit, in order that the CCS can be available to provide annulus cooling as soon as the contents of the MPC are isolated from the bulk SFP water – providing additional margin to the time constraints associated with the 'time to boil' clock.

155. To ensure the CCS is capable of running should the UK ABWR suffer a Loss of Off-Site Power, the CCS power supply will be backed up by the Emergency Diesel Generators.

156. During the canister preparations decay heat removal has to be provided by a minimum of two available active systems in order to meet ONR's deterministic criteria. Hitachi-GE therefore intends that the CCS will be supported by a Category A/Class 2 BCCS. To ensure the BCCS will be diverse and redundant from the CCS, it will use an alternative method to provide cooling – by pumping water directly into the MPC's internal void. The BCCS power supply will be supported by the diverse Backup Building Generator.

157. Hitachi-GE noted that a capability to pre-connect the BCCS (to the MPC lid) could be provided, but pre-connection of the CCS and BCCS at the same time would need to be precluded in order to avoid common cause failure.

158. The CCS is shut-down at the point that the Forced Helium Dehydration (FHD) system is initiated for the purpose of drying the MPC internals. The FHD system is connected to the MPC after the lid is welded and the bulk of the entrained water is blown down via a vent port and returned to the SFP. After the bulk water is removed, the FHD pre-heats helium and pumps it into the canister to evaporate the remaining moisture, which exits the canister as vapour through a drain port. On exiting the MPC, the vapour passes through a chiller which re-condenses the water and segregates it from the helium gas flow. The operating temperature of the FHD is envisaged to be around 150^{o}C, which allows a significant margin to the long-term fuel clad limit of 400^{o}C.

159. If the SFP water is not entirely removed from the MPC, there is potential for corrosion of the fuel cladding during interim storage, which may give rise to clad failures. Hitachi-

GE therefore intends that limits will be placed on the remaining levels of moisture, which will need to be fully substantiated by a future licensee during detailed design.

160. Once the inside of the MPC is sufficiently dry, the FHD pre-heaters are switched off and the FHD system pressurises the canister to a gas density that optimises convective heat transfer within the MPC for the purpose of the subsequent interim storage period. The canister vent and drain ports are then closed, the FHD is disconnected, the vent and drain valves are removed and the ports are welded over with cover plates to make a permanent seal.

161. The design specifies that during the drying process the CCS will be available to provide annulus cooling should a fault be detected by the Category A/Class 1 Over-Temperature Protection System (OTPS).

162. The OTPS ensures that a failure of the FHD will not lead to overheating of the fuel by deploying temperature sensors, linked to a capability to shut-down the FHD automatically. Established custom and practice worldwide is for OTPS systems to be software-based. While detailed design of the OTPS was not completed within GDA, Hitachi-GE confirmed that the OTPS will be capable of providing an alarm in the event of insufficient helium flow and the option of enabling the OTPS to automatically start the CCS in the event of an FHD fault was not foreclosed to a future licensee.

163. As Hitachi-GE's considerations of SFE and SFIS and the associated SSCs were at concept level in the generic case, it was not possible for Hitachi-GE to fully substantiate the reliability figures it used in the assessment of mitigated risks for SFE and SFIS faults. These claims will need to be fully substantiated by the licensee during detailed design.

164. Operator intervention to maintain adequate cooling of the fuel was claimed by Hitachi-GE against two fault scenarios:

- Concurrent failure of both the CCS and BCCS, which would require operators to reinstate one system, or return the MPC to the base of the Cask Pit and remove the lid in order that cooling could be provided by the bulk SFP water and FPCMs.
- Concurrent failure of both the FHD and OTPS, which would require operators to respond to an increase in helium temperatures by manually tripping the FHD (noting that a credible fault is for the FHD to provide too much heat to the helium). From the point helium is present within the MPC at atmospheric pressure Hitachi-GE believes passive cooling would be sufficient to maintain adequately low fuel clad temperatures (for further consideration of this claim see the section on Cooling of Welded MPCs, below). Therefore in this situation Hitachi-GE claimed that a trip of the FHD would be sufficient to protect the fuel and operators would not need to manually start the CCS or BCCS.

165. From this section of assessment I concluded that Hitachi-GE provided an adequate demonstration that the UK ABWR is capable of ensuring adequate cooling of spent fuel during the processes of MPC drying, inerting and welding with risks reduced SFAIRP.

166. As the associated SSCs were at a concept level of design in GDA, Hitachi-GE was not able to fully substantiate the reliability figures claimed for safety functions that inform the assessment of the mitigated risks of faults. Therefore it was not practicable for the reduction of risks SFAIRP to be fully demonstrated in GDA and this will need to be addressed by the licensee during detailed design. I have therefore incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-03**, as detailed in Annex 6.

167. ONR noted that Hitachi-GE's concept designs for the FHD and OTPS did not contain instrumentation capable of detecting a fuel clad failure within the canister, should a

failure occur whilst the spent fuel is dried and the MPC is filled with inert gas. If a fuel clad failure became apparent at this point, it would lead to a release of contamination and radioactive gas into the helium stream with implications for worker dose and a need to isolate the damaged fuel. I have therefore incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-03**, as detailed in Annex 6.

Cooling of Welded MPCs

168. Once loaded MPCs are fully welded and pressurised with inert gas, two barriers are in place to prevent dispersal of nuclear material – i.e. the fuel cladding and the MPC itself – and the design intent is for adequate cooling of the spent fuel to be provided by passive means. The effectiveness of passive cooling relies on having sufficient conduction via the fuel basket and MPC structure, convection between the fuel and MPC internal surface and convection between the MPC outer surface and ambient atmosphere.

169. During interim storage, ONR expects that MPCs will be monitored to ensure the integrity of the spent fuel within them. Higher than expected temperatures may identify a fault (such as a failure of the canister integrity and loss of inert gas pressure, a thermal misload or a blockage of the concrete over-pack vents). Hitachi-GE's EMIT Report (Ref.44) includes details of monitoring during storage, including canister temperatures which would alert operators to potential increased temperatures within the canister and allow a retrieval process to be commenced.

170. As pressurised helium has greater convective properties than atmospheric air, it can reasonably be expected that if helium were to escape from inside an MPC the system's heat transfer capability will lessen and fuel clad temperatures will subsequently increase. Within its consideration of faults during SFIS, Hitachi-GE argued that any through-wall defect from the credible degradation mechanisms for MPCs in interim storage (the most likely cause being stress-corrosion cracking) would be limited in size so that the time taken for inert gas to escape will be long enough for operators to become aware of the fault and take mitigative action before the integrity of the fuel clad is threatened.

171. ONR's Fuel and Core specialist judged that even a relatively small hole in an MPC would result in loss of the inert gas in a few days due to normal UK barometric variations, so Hitachi-GE was asked to confirm that the fuel clad 'long-term temperature limit' of 400^{o}C would not be exceeded in the event of a fault that led to spent fuel becoming surrounded by an air atmosphere at 1 bar within an MPC. Hitachi-GE confirmed this in Ref.30 and Ref.42 to the satisfaction of ONR's Fuel and Core Specialist, however ONR noted that Hitachi-GE's calculation relied on a series of assumptions whose validity will need to be reviewed against the final SFE and SFIS detailed design.

172. The levels of decay heat that can be tolerated in dry cask storage will be dependent on the thermal design of the MPC, which in turn has implications for fuel burn-up levels and the required dwell time in the SFP. ONR has therefore raised an assessment finding within its report on Fuel and Core to ensure a future licensee will substantiate that the fuel assembly dwell time in the SFP prior to dry cask storage is consistent with maintaining the fuel clad temperature within design requirements during credible faults in interim storage.

173. The Holtec system that Hitachi-GE selected as 'proof of concept' for the concrete over-pack includes eight bottom inlet vents to enable convective cooling of the outer surface of the MPC via an annular space between the over-pack and MPC. Hitachi-GE identified the credible causes of vent blockages as:

- Accumulation of wind-borne debris.

- Vermin activity.
- Snow.

174. Hitachi-GE noted that flooding may be a credible mechanism for vent blockages, dependent on the site specific details – but was outside the design basis for the UK ABWR generic site as defined for GDA. Hitachi-GE further noted that the identified causes of vent blockages could be eliminated by a suitable design of the spent fuel storage overbuilding. However ONR noted that the building had not been the subject of any safety claims within the generic case. I have therefore incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-04**, as detailed in Annex 6.

175. Hitachi-GE estimated that should 50% of the over-pack inlet vents become blocked (even on a permanent basis) the temperature of the fuel cladding would never exceed the fuel cladding ‘long-term limit’ of 400^{o}C, such that fuel clad integrity will not be challenged.

176. However Hitachi-GE estimated that in the event of 100% blockage of the vents, fuel clad temperatures may increase above the ‘long-term temperature limit’ of 400°C in less than 32 hours. Hitachi-GE further stated that a prolonged time period would be required in order for the fuel clad temperatures to reach the ‘short-term temperature limit’ of 570°C.

177. The implicit claim that the ‘short-term temperature limit’ of 570°C would not be breached within 32 hours is dependent on a number of factors including:

- Fuel choice
- Cooling time in the spent fuel pool
- Canister detailed design
- Over-pack detailed design

178. The above factors are dependent on licensee design choices, therefore the claim that the ‘short-term temperature limit’ of 570°C will not be exceeded within 32 hours of 100% vent blockage occurring could not be fully substantiated within GDA and this will need to be provided by a future licensee during detailed design, in accordance with ONR’s assessment of Fuel and Core Design (Ref.7).

179. Within its report ‘Maintenance of Integrity of SFIS Systems Structures and Components during Interim Storage with EMIT and AMP’ (Ref.44), Hitachi-GE indicated that an operator will inspect the over-pack vents every 24 hours as a means of ensuring the effective limit of a vent blockage lasting for 32 hours will not be breached.

180. ONR’s expectations concerning appropriate allocation of safety functions are set out in a number of SAPs and TAGs. The primary reference is SAP EHF.2 which states: *“when designing systems, the allocation of safety actions between humans and technology should be substantiated and dependence on human action to maintain a safe state should be minimised”*. SAP ERL.3 is also important: *“Where reliable and rapid protective action is required, automatically initiated engineered features should be provided”.*

181. Therefore ONR would expect the dependence on manual inspections to maintain safe storage conditions should be minimised, especially in light of the strong likelihood of a human error occurring over the envisaged 140-year storage period. I believe it is reasonably foreseeable that during such an extended storage period the specified 24 hour manual inspection regime may not be complied with at all times. I have therefore

incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-04**, as detailed in Annex 6.

Recovery from Faults in the Spent Fuel Store

182. Potential exists for faults to become apparent whilst spent fuel is held inside MPCs within the store, which may give rise to a need for the spent fuel and/or MPC internals to be inspected. In light of the long storage period, this could credibly include faults caused by degradation of the spent fuel or the MPC itself.

183. During the UK ABWR's operational phase Hitachi-GE intends that the SFP will provide a capability to re-open loaded MPCs. Therefore if a loaded MPC were to fail within the store during the 60 years of reactor operations, Hitachi-GE believes it would be feasible for the MPC to be returned to the SFP by reversing the SFE process, i.e.:

- The MPC will be removed from the concrete over-pack and placed into a transfer cask.
- The Cask Transporter will transport the MPC and transfer cask across site to the Reactor Building.
- The MPC and transfer cask will be lifted onto the LPT and moved to the Hoist Well.
- The Reactor Building Crane will raise the MPC and transfer cask up the Hoist Well.
- The MPC and transfer cask will be traversed across the Operating Deck and lowered into the SFP Cask Pit.
- The MPC will then be re-opened.

184. Throughout the above steps, Hitachi-GE believes it will be feasible for adequate safety to be provided by similar SSCs that are employed during routine SFE transfers - which includes claims on the MPC structural integrity for both normal operations and design basis faults.

185. After the UK ABWR ceases generating electricity the SFP will be decommissioned whilst spent fuel is still stored on the site. Therefore Hitachi-GE proposes that when the SFP becomes unavailable, the capability to re-open loaded MPCs and directly inspect the stored spent fuel will be sustained by constructing a hot cell local to the SFIS building. During the final part of decommissioning the hot cell will also be used to re-pack the site's lifetime arising of spent fuel out of MPCs and into disposable containers, prior to its consignment off-site for disposal at the GDF.

186. The robustness of Hitachi-GE's strategy is dependent on the likelihood of a fault occurring that may undermine the operator's ability to return a loaded MPC from the store to the SFP safely using normal equipment. In turn this will depend on the design specifics of the SFIS system that is finally implemented by a future licensee. As resolution of this matter requires future licensee design choices I have incorporated this residual matter into **Assessment Finding AF-ABWR-SFIS-05**, as detailed in Annex 6.

Management of Failed Fuel

187. Failed fuel could arise as a result of manufacturing defects, faults during reactor operations or faults that may occur whilst spent fuel assemblies are in wet storage (such as dropped loads, chemical excursions or mechanical clashes). In ONR's experience the majority of failed fuel does not require special handling and can be safely stored in the same manner as intact fuel.

188. To ensure that options for storage and disposal of failed fuel have not been foreclosed to a future licensee, ONR raised a number of RQs during GDA which requested further details on relevant parts of Hitachi-GE's strategy and safety case (including RQ-ABWR-0036, RQ-ABWR-0039, RQ-ABWR-0071, RQ-ABWR-0102, RQ-ABWR-0183, RQ-ABWR-1149, RQ-ABWR-1293 and RQ-ABWR-1294).

189. Hitachi-GE's chosen approach is to hold any identified damaged fuel within the SFP until the station reaches the end of its operational life, during which time the SFP (supported by the FPCMs) will ensure workers are adequately protected – this aspect has been assessed by ONR's Reactor Chemistry specialism (Ref.6).

190. This strategy will allow a future licensee time to determine the optimal approach to handle and export damaged fuel (informed by the actual number of damaged assemblies and types of clad failure that occurred during the station's life) and is supported by several arguments - the robustness of which have been considered by ONR's Fuel and Core specialism (Ref.7).

191. ONR has therefore raised an Assessment Finding against its assessment of Fuel and Core, to ensure a future licensee will review the technology available for the storage of damaged fuel and provide sufficient equipment and arrangements to ensure that suitable measures can be taken to meet the requirements for the storage of damaged fuel with levels of risk reduced SFAIRP.

192. Hitachi-GE's expectation is that the UK ABWR will not need to incorporate specific arrangements to facilitate Post-Irradiation Examination (PIE) of failed fuel. The robustness of this position has been considered within ONR's Fuel and Core assessment, which has accepted the view that there is a large body of experience of BWR fuel operation globally and that for well-established designs, PIE may not be required unless anomalies in the failure rates or failure characteristics are identified. ONR therefore accepted Hitachi-GE's argument that routine in-cave PIE of damaged fuel may not be required.

Disposability of Spent Fuel

193. In accordance with the GDA Guidance to Requesting Parties and the environmental regulators' Process and Information Document (P&ID), Hitachi-GE sought an assessment from RWM Ltd (on behalf of NDA) of the disposability of the HAW and spent fuels expected to arise from operation and decommissioning of the UK ABWR. RWM Ltd reported that: *"ILW and spent fuel from the operation and decommissioning of a UK ABWR should be compatible with plans for transport and subsequent disposal of higher activity wastes and spent fuel… and the assessment process has not identified any significant issues that challenge fundamental disposability of the wastes and spent fuel expected to be generated from operation of such a reactor".*

194. In the course of its assessment, RWM Ltd identified 27 areas for further consideration (23 related to management of ILW and 4 related to spent fuel), which was consistent with expectations at this stage of the design due to the preliminary nature of Hitachi-GE's proposals and the relatively high-level assessments performed.

195. Some of RWM's findings were addressed by developments of the UK ABWR design secured during GDA. RWM Ltd made its findings in expectation that further development of the inventories, packaging plans and performance of the packaged spent fuels will be undertaken by either the requesting party or future licensee. Within its response to RWM Ltd, Hitachi-GE noted that the absence of any major issues suggested all of the further work would be best addressed at the site specific phase of design.

196. Full resolution of RWM Ltd's advice requires the input of a future licensee. Potential also exists for a future licensee to make choices on the UK ABWR detailed design and

operations that may have an impact on the disposability of spent fuel. ONR has therefore raised a Minor Shortfall within its assessment of Management of Radioactive Wastes (Ref.19) to cover the work the licensee will need to complete to ensure disposability of the Higher Activity Wastes (HAW) and spent fuel expected to arise from operation of the UK ABWR.

197. As a result of this section of assessment, I was able to conclude that Hitachi-GE provided an adequate level of confirmation that the spent fuel expected to be generated by the UK ABWR should be disposable at the UK's planned GDF.

4.3 Regulatory Observations

198. Regulatory Observations (ROs) are raised within GDA when ONR identifies a potential regulatory shortfall which requires action and new work by the RP for it to be resolved. Each RO can have several associated actions.

199. No ROs were raised from ONR's assessment of SFIS, however SFIS was a relevant consideration in several ROs that were raised by other assessment disciplines – these are listed in Annex 4 and summarised below.

- **RO-ABWR-011** (Fault Studies) required Hitachi-GE to provide further evidence of its consideration of faults associated with the SFP and fuel route by incorporating design basis analysis, probabilistic safety analysis and severe accident analysis.
- **RO-ABWR-021** (Fuel and Core) required Hitachi-GE to define and substantiate a set of limits and conditions that will ensure the integrity of the fuel cladding transferred to dry fuel storage.
- **RO-ABWR-036** (Radwaste & Decommissioning) required Hitachi-GE to provide a robust demonstration to show that the approach taken to the management of radioactive waste reduces risks SFAIRP.
- **RO-ABWR-037** (Fault Studies, PSA, Radwaste & Decommissioning) required Hitachi-GE to identify faults associated with all buildings, systems, processes and activities on the UK ABWR site which could, in a fault condition, result in a person receiving a significant radiation dose despite the reactor core being unaffected.
- **RO-ABWR-056** (Radwaste & Decommissioning) required Hitachi-GE to show that for spent fuel removal out of the reactor building adequate optioneering had been carried out to demonstrate risks will be reduced SFAIRP.
- **RO-ABWR-080** (Civil Engineering) required Hitachi-GE to perform an analysis of the hoist well civil structure to determine the extent to which it could accommodate variations at later stages of design for the purpose of mechanical handling during SFE.

4.4 Overseas regulatory interface

200. ONR has formal information exchange agreements with a number of international nuclear safety regulators, and collaborates through the work of the International Atomic Energy Agency (IAEA), the Organisation for Economic Co-operation and Development Nuclear Energy Agency (OECD-NEA), the European Nuclear Safety Regulators Association (ENSREG) and Western European Nuclear Regulators Association (WENRA). This enables ONR to utilise overseas regulatory assessments of reactor technologies, where they are relevant to the UK. It also enables the sharing of regulatory assessment findings, which can expedite assessment and helps promote consistency.

201. ONR also represents the UK on the Multinational Design Evaluation Programme (MDEP).This seeks to:

- Enhance multilateral co-operation within existing regulatory frameworks
- Encourage multinational convergence of codes, standards and safety goals
- Implication of MDEP products in order to facilitate the licensing of new reactors, including those being developed by Gen IV international Forum

202. Specific to the SFIS assessment, data on established international practices in dry cask storage was obtained from a series of bilateral meetings with US NRC and the Swedish Radiation Safety Authority that has informed ONR's judgements.

203. Through bilateral discussions with the German regulator, ONR became aware of a concern relating to pellet swelling in prolonged dry storage conditions caused by accumulation of helium bubbles in the fuel material. This was raised with Hitachi-GE in the topic of Fuel and Core. Hitachi-GE confirmed that for the UK ABWR the swelling will not be sufficient to close the gap between the pellet and the cladding and therefore this swelling will not impair the containment function of the fuel pin cladding. A generic study by USNRC reached a similar conclusion.

4.5 Assessment findings

204. During this assessment residual matters were identified for a future licensee to take forward in its site-specific safety submissions. Details of these are contained in Annex 6.

205. These matters do not undermine the generic safety submission and are primarily concerned with the provision of site specific safety case evidence, which are expected to become available as the project progresses through the detailed design, construction and commissioning stages.

206. In accordance with ONR's Guidance to Requesting Parties, matters were recorded as GDA Assessment Findings if one or more of the following applied:

- Resolution of the matter required site-specific information.
- Resolution of the matter depended on future licensee design choices.
- The matter related to other licensee-specific features / aspects / choices associated with future operational philosophy.
- Resolution of the matter required a greater level of detail on the design than can reasonably be expected in GDA.
- Resolution of the matter was not practicable until the plant enters the phases of construction or commissioning.

207. Assessment Findings are residual matters that must be addressed by a future licensee and the progress of this will be formally monitored by ONR.

5 CONCLUSIONS

208. This report presents the findings of ONR's Step 4 assessment of Hitachi-GE's UK ABWR in the topic area of Spent Fuel Interim Storage.

209. I am broadly satisfied with the claims, arguments and evidence laid down within the UK ABWR generic PCSR and supporting documentation for the Spent Fuel Interim Storage topic. Therefore, from the perspective of Spent Fuel Interim Storage I have no objection to Hitachi-GE's UK ABWR design being awarded a Design Acceptance Confirmation (DAC).

210. No GDA Issues were identified during this assessment.

211. Assessment findings were identified during this assessment and are detailed in Annex 6, these are for a future licensee to consider and take forward in its site-specific safety submissions. These matters do not undermine the generic safety case that was provided by Hitachi-GE.

5.1 Key Findings from the Step 4 Assessment

212. My main assessment conclusions are:

- Hitachi-GE provided an adequate consideration of the credible options for SFIS and the selected approach of dry cask storage with concrete over-packs is a proven technology that takes account of current global good practice.
- Hitachi-GE's strategic-level approach to SFIS is compatible with the expectations of the UK government and UK regulators.
- To a conceptual level within GDA, Hitachi-GE provided an adequate demonstration that the UK ABWR can accommodate the design, operational constraints and infrastructure requirements to implement dry cask storage of spent fuel with risks reduced SFAIRP.
- The anticipated UK ABWR spent fuel is expected to be disposable at the UK's planned Geological Disposal Facility (GDF).
- The requirement for an extended period of on-site dry cask storage of spent fuel has been appropriately incorporated into all the relevant UK ABWR strategies and plans.

213. My judgement is based upon the following factors:

- Alignment of Hitachi-GE's proposals for management of spent fuel with UK Government policy, including strategic-level assumptions in the 'Base Case' for the lifecycle of new nuclear power stations associated with The Energy Act 2008.
- Hitachi-GE's reference to one of the largest currently available dry cask storage systems (i.e. Holtec International's HI-STORM FW with the HI-TRAC transfer cask) to provide an objective 'proof of concept' within GDA.
- Hitachi-GE's identification of key criteria for safe long-term dry cask storage and provision of systems to ensure compliance with those criteria, such that the integrity of the UK ABWR spent fuel should be maintained for the envisaged storage period.
- Hitachi-GE's accommodation within the UK ABWR safety case of SSCs to support all the required steps in dry cask storage of – the preceding period of wet storage, MPC loading, MPC conditioning and welding, MPC export from the Reactor

Building, monitored long-term storage, final re-packing and consignment to the GDF.

- Hitachi-GE's recognition of the need to provide a means of recovery from design basis faults, including the capability to safely retrieve spent fuel out of sealed MPCs should it prove to be necessary.
- RWM Ltd's assessment of the disposability of the UK ABWR spent fuel at the GDF and Hitachi-GE's response to RWM Ltd.

214. To conclude, I am broadly satisfied with the claims, arguments and evidence laid down within the UK ABWR generic PCSR and supporting documentation for the Spent Fuel Interim Storage topic. Therefore, from the perspective of Spent Fuel Interim Storage I have no objection to Hitachi-GE's UK ABWR design being awarded a Design Acceptance Confirmation (DAC).

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33. Hitachi-GE Nuclear Energy Ltd., Consequences from the Drop of an Unsealed Loaded Canister into the Cask Pit (Response to RQ-ABWR-1320), GA91-9201-0003-02028, Revision 0, April 2017.

34. Hitachi-GE Nuclear Energy Ltd., Consideration of Internal Hazard for Spent Fuel Export and Spent Fuel Interim Storage, GA91-9201-0003-00528, Revision 1, May 2016.

35. Hitachi-GE Nuclear Energy Ltd., Consideration of External Hazard for Spent Fuel Export and Spent Fuel Interim Storage, GA91-9201-0003-00527, Revision 1, May 2016.

36. Hitachi-GE Nuclear Energy Ltd., Consideration of Faults for Spent Fuel Export and Spent Fuel Interim Storage, GA91-9201-0003-00526, Revision 4, June 2017.

37. Hitachi-GE Nuclear Energy Ltd., Preliminary Evaluation for Sub-Criticality Safety, GA91-9201-0003-00501, Revision 1, March 2015.

38. Hitachi-GE Nuclear Energy Ltd., Preliminary Evaluation for Containment Safety, GA91-9201-0003-00607, Revision 1, July 2016.

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40. Hitachi-GE Nuclear Energy Ltd., Preliminary Evaluation for Heat Removal of Loaded Cask in Normal Operation, GA91-9201-0003-00500, Revision 0, January 2015.

41. Hitachi-GE Nuclear Energy Ltd., Preliminary Evaluation for Heat Removal of Loaded Cask in Fault Condition, GA91-9201-0003-00525, Revision 2, April 2017.

42. Hitachi-GE Nuclear Energy Ltd., Management of Damaged Fuel, GA91-9201-0003-01019, Revision 0, April 2016.

43. Hitachi-GE Nuclear Energy Ltd., ALARP Report for Spent Fuel Export, GA91-9201-0003-01563, Revision 0, September 2016.

44. Hitachi-GE Nuclear Energy Ltd., Maintenance of Integrity of SFIS Systems Structures and Components during Interim Storage with EMIT and AMP, GA91-9201-0003-00539, Revision 0, May 2015.

45. Hitachi-GE Nuclear Energy Ltd., Response to RWM Assessment Report on UK ABWR Waste and Spent Fuel Disposability, GA91-9201-0003-01150, Revision 0, September 2016.

46. Hitachi-GE Nuclear Energy GDA ALARP Methodology, Revision 1, GA10-0511-0004-00001, XD-GD-0037, December 2015.

47. Radioactive Waste Management Ltd, Generic Design Assessment: Disposability Assessment for Wastes and Spent Fuel arising from Operation of the UK ABWR Part 1: Main Report, Issue 1, September 2015.

48. US Nuclear Regulatory Commission, “Estimating the Probability of Misload in a Spent Fuel Cask”, June 2011 http://www.nrc.gov/docs/ML1131/ML113191144.pdf , http://www.nrc.gov/docs/ML1131/ML113191144.pdf

Annex 1
Safety Assessment Principles

SAP No	SAP Title	Description
EKP.1	Inherent safety	The underpinning safety aim for any nuclear facility should be an inherently safe design, consistent with the operational purposes of the facility.
EKP.3	Defence in depth	A nuclear facility should be so designed and operated so that defence in depth against potentially significant faults or failures is achieved by the provision of multiple independent barriers to fault progression.
ENM.1	Strategies for managing nuclear matter	The strategies should be consistent with Government policy and integrated with other national strategies.
ENM.3	Transfers and accumulation of nuclear matter	Unnecessary or unintended generation, transfer or accumulation of nuclear matter should be avoided.
ENM.4	Control and accountancy of nuclear matter	Nuclear matter should be appropriately controlled and accounted for at all times.
ENM.5	Characterisation and segregation	Nuclear matter should be characterised and segregated whenever practicable to facilitate its safe management.
ENM.6	Storage in a condition of passive safety	When nuclear matter is to be stored on site for a significant period of time it should be stored in a condition of passive safety whenever practicable and in accordance with good engineering practice.
ENM.7	Retrieval and inspection of stored nuclear matter	Storage of nuclear matter should be in a form and manner that allows its to be retrieved and, where appropriate, inspected.
EHT.4	Failure of heat transport system	Provision should be made in the design to prevent failures of the heat transport system that could adversely affect the heat transfer process, and to maintain the facility in a safe condition following such failures.
ECR.1	Safety measures	Wherever a significant amount of fissile material may be present, there should be safety measures to protect against unplanned criticality.

ECR.2	Double contingency approach	Criticality safety cases should employ the double contingency approach.
RP.5	Decontamination	Suitable and sufficient arrangements for decontaminating people, the facility, its plant and equipment should be provided.
RP.6	Shielding	Where shielding has been identified as a means of restricting dose, it should be effective under all normal operation and fault conditions where it provides this safety function.
RP.7	Radiation Protection	The duty holder should establish a hierarchy of control measures to optimise protection in accordance with IRR99

Annex 2

Technical Assessment Guides

TAG Ref	TAG Title
NS-TAST-GD-003 Revision 7	Safety Systems
NS-TAST-GD-004 Revision 5	Fundamental Principles
NS-TAST-GD-005 Revision 8	Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)
NS-TAST-GD-009 Revision 3	Examination, Inspection, Maintenance and Testing of Items Important to Safety
NS-TAST-GD-016 Revision 5	Integrity of Metal Structures, Systems and Components
NS-TAST-GD-020 Revision 3	Civil Engineering Containments for Reactor Plants
NS-TAST-GD-021 Revision 3	Containment: Chemical Plants
NS-TAST-GD-022 Revision 4	Ventilation
NS-TAST-GD-023 Revision 4	Control of Processes Involving Nuclear Matter
NS-TAST-GD-024 Revision 5	Management of Radioactive Materials and Radioactive Waste on Nuclear Licensed Sites
NS-TAST-GD-035 Revision 4	Limits and Conditions for Nuclear Safety (Operating Rules)
NS-TAST-GD-036 Revision 4	Diversity, Redundancy, Segregation and Layout of Mechanical Plant
NS-TAST-GD-037 Revision 2	Heat Transport Systems
NS-TAST-GD-038 Revision 6	Radiological Protection
NS-TAST-GD-041 Revision 4	Criticality Safety
NS-TAST-GD-043 Revision 3	Radiological Analysis – Normal Operations
NS-TAST-GD-045 Revision 3	Radiological Analysis – Fault Conditions
NS-TAST-GD-051 Revision 4	The Purpose, Scope and Content of Safety Cases
NS-TAST-GD-056 Revision 3	Nuclear Lifting Operations
NS-TAST-GE-064 Revision 2	Allocation of Function Between Human and Engineered Systems
NS-TAST-GD-075 Revision 0	Safety of Nuclear Fuel in Power Reactors
NS-TAST-GD-081 Revision 2	Safety Aspects Specific to Storage of Spent Nuclear Fuel
NS-TAST-GD-088 Revision 1	Chemistry of Operating Civil Nuclear Reactors

Annex 3
National and International Standards and Guidance

National and International Standards and Guidance
Safety of Nuclear Power Plants: Design. Safety Requirements. IAEA Safety Standards Series No. NS-R-1, 2000 http://www-pub.iaea.org/MTCD/publications/PDF/Pub1099_scr.pdf
Storage of Spent Nuclear Fuel, IAEA Safety Standards, SSG-15, 27th March 2012 http://www-pub.iaea.org/MTCD/publications/PDF/Pub1503_web.pdf
Design of Fuel Handling and Storage Systems in Nuclear Power Plants, IAEA Safety Series No. NS-G-1.4, 8th August 2003. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1156_web.pdf
Core Management and Fuel Handling for Nuclear Power Plants Safety Guide, IAEA Safety Series No. NS-G-2.5, 5th June 2002. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1125_scr.pdf
WENRA Waste and Spent Fuel Storage Safety Reference Levels, Report of Working Group on Waste and Decommissioning (WGWD), Version 2.2, April 2014, http://www.wenra.org/media/filer_public/2014/05/08/wgwd_storage_report_final.pdf
WENRA Statement on Safety Objectives for New Nuclear Power Plants, November 2010.
WENRA Reactor Reference Safety Levels, September 2014.
Approved Code of Practice, Managing Health and Safety in Construction – Construction (Design and Management) Regulations 2015.
Approved Codes of Practice, Working with Ionising Radiation – Ionising Radiations Regulations 1999.

Annex 4
Regulatory Issues / Observations

RI / RO Ref	RI / RO Title	Description	Date Closed	Section Reference within this Report
RO-ABWR-011	Safety Case for Spent Fuel Pool and Fuel Route	Required Hitachi-GE to provide further evidence of its consideration of faults associated with the SFP and fuel route within the UK ABWR PCSR, sufficient to meet ONR expectations in SAPs FA.1 to FA.16 by incorporating design basis analysis (DBA), probabilistic safety analysis (PSA) and severe accident analysis (SAA).	June 2017	4.3 – Regulatory Observations
RO-ABWR-021	Limits and conditions of operation for interim dry storage	Required Hitachi-GE to define and substantiate by deterministic analysis, a set of and conditions of operation that will ensure the integrity of fuel cladding irradiated in accordance with the design of the UK ABWR and transferred to dry fuel storage after a suitable period of wet cooling.	September 2015	4.3 – Regulatory Observations
RO-ABWR-036	Demonstration that the approach taken to radioactive waste management reduces risks SFAIRP	Required Hitachi-GE to provide a robust demonstration to show that the approach taken to the management of radioactive waste reduces risks SFAIRP	November 2017	4.3 – Regulatory Observations
RO-ABWR-037	Safety case for faults not directly related to the reactor	Required Hitachi-GE to identify faults associated with all buildings, systems, processes and activities on the UK ABWR site which could, in a fault condition, result in a person receiving a significant radiation dose or to a significant quantity of radioactive material escaping from its designated place of residence, despite the reactor core being unaffected.	August 2017	4.3 – Regulatory Observations
RO-ABWR-056	Demonstration that adequate optioneering has been carried out for the removal of spent fuel from the Reactor Building	Required Hitachi-GE to show that for spent fuel removal out of the reactor building adequate optioneering had been carried out and that the approach being taken can demonstrate that the design reduces risks So Far As Is Reasonably Practicable (SFAIRP), covering removal of spent fuel from the Spent Fuel Pool, loading the spent fuel into the transfer container and its export from the Reactor Building.	March 2017	4.3 – Regulatory Observations

RO-ABWR-080	Development of Spent Fuel Export contingency arrangements	Required Hitachi-GE to perform an analysis of the hoist well civil structure to determine the extent to which it could be modified, as part of contingency arrangements to accommodate variations for SFE required at later stages of the design development so as not to foreclose options for SFE.	May 2017	4.3 – Regulatory Observations

Annex 5
Regulatory Queries Relevant to SFIS

RQ ID	RQ Title	Response Received (from Hitachi-GE)
RQ-ABWR-0035	Fuel Characteristics – cooling period	Full
RQ-ABWR-0036	Packaging options – defective fuel	Full
RQ-ABWR-0039	Repair of Failed Fuel	Full
RQ-ABWR-0071	Fuel Degradation Mechanism Relevant to Spent Fuel Interim Storage	Full
RQ-ABWR-0102	Implications of failed fuel for the disposal inventory	Full
RQ-ABWR-0178	Corrosion and Hydrating	Full
RQ-ABWR-0181	Effectiveness of spray cooling of uncovered fuel in storage	Full
RQ-ABWR-0183	Management of Failed Fuel	Full
RQ-ABWR-0184	Safety Case for Pellet- Cladding Interaction	Full
RQ-ABWR-0303	Decay heat dependences on fuel assumptions, calculations and nuclide library selection	Full
RQ-ABWR-0501	Further information on the Safety Case arguments for the risk of successive fuel misloading	Full
RQ-ABWR-0546	Cask Transfer Operations	Full
RQ-ABWR-0676	Holtec Thermal Modelling in Dry Storage	Full
RQ-ABWR-0699	Limits and Conditions to avoid PCI Failure	Full
RQ-ABWR-0706	Limits and Conditions to avoid Fuel Damage by Ballooning	Full
RQ-ABWR-0708	Cask Drop Source Term	Full
RQ-ABWR-0800	Recovery from Faults in the Interim Storage Building	Full
RQ-ABWR-0872	Spent Fuel Cladding Temperatures Following Cask Failure	Full
RQ-ABWR-1050	Misloading of Spent Fuel	Full
RQ-ABWR-1089	Request for Confirmation of Modelling of gas pressure in dry storage	Full
RQ-ABWR-1091	Backup Canister Cooling System (BCCS) Proof of Concept	Full

RQ ID	RQ Title	Response Received (from Hitachi-GE)
RQ-ABWR-1092	Robustness of the claim that “Gross failure of the canister boundary is not considered credible” and the need for a precautionary approach to associated uncertainties	Full
RQ-ABWR-1093	Over Temperature Protection System (OTPS) Proof of Concept	Full
RQ-ABWR-1094	Canister Cooling System (CCS) Proof of Concept	Full
RQ-ABWR-1097	Protection of workers from fuel clad failures that may occur within loaded unsealed SFIS canisters	Full
RQ-ABWR-1149	Demonstration that damaged fuel management options are not foreclosed	Full
RQ-ABWR-1200	Overpack Vent Blockages during SFIS	Full
RQ-ABWR-1213	Queries arising from assessment of "Topic Report for High Level Safety Case on Concept Design of Spent Fuel Interim Storage System"	Full
RQ-ABWR-1214	Time to boil calculation/recovery from fault	Full
RQ-ABWR-1215	Cask Preparation Pit	Full
RQ-ABWR-1293	Request for more information on arrangements for storage of extensively damaged fuel in pond	Full
RQ-ABWR-1294	Request for more information on fuel assembly dismantling and inspection station	Full
RQ-ABWR-1298	Spent Fuel Interim Storage: Dry Canister Time to Consequence	Full
RQ-ABWR-1320	Spent Fuel Interim Storage: Consequences from the Drop of an Unsealed Loaded Canister into the Cask Pit	Full
RQ-ABWR-1359	Request for more information on arrangements for fuel assembly dismantling and inspection	Full
RQ-ABWR-1369	Spent Fuel Mis-Loading Faults	Full

Annex 6
Assessment Findings

<table>
<tr><th>Assessment Finding Number</th><th>Assessment Finding</th><th>Report Section Reference</th></tr>
<tr><td>AF-ABWR-SFIS-01</td><td>Hitachi-GE’s generic safety case identified that misloads of spent fuel assemblies with high decay heat, in place of assemblies with lower decay heat (i.e. ‘thermal misloads’), could threaten the integrity of the fuel cladding and Multi-Purpose Canisters (MPCs). Hitachi-GE claimed that the likelihood of a thermal misload is infrequent, but this was not supported by ONR’s analysis of the provided data. The generic case identified a range of potential risk reduction measures to detect and prevent thermal misloads that are not foreclosed to a future licensee and may be reasonably practicable to implement during detailed design but were not formally adopted into the UK ABWR reference design during GDA.

Therefore the licensee shall:
▪ Substantiate the claim that the likelihood of a thermal misload occurring is sufficiently low so as to be considered infrequent in the terms of ONR’s deterministic and probabilistic criteria.
▪ Demonstrate that all reasonably practicable engineered measures can been deployed to detect the presence of thermal misloads and prevent their progression to significant radiological consequences.</td><td>4.2

Misloading of Spent Fuel into MPCs</td></tr>
<tr><td>AF-ABWR-SFIS-02</td><td>Hitachi-GE’s generic safety case for the loading and preparation operations associated with the dry cask storage system was at a concept level of design and identified a number of potential risk reduction measures that may be reasonably practicable to implement. Whilst some of these measures were not formally adopted into the UK ABWR design within GDA, Hitachi-GE demonstrated that they were not foreclosed to a future operator.

ONR understands that the licensee may not make a definitive choice of dry cask storage system until some years after the UK ABWR starts generating electricity.

Therefore, until such time as detailed design of the dry cask storage system takes place, the licensee shall ensure that its options to deploy risk reduction measures for the loading and preparation activities are not foreclosed by the UK ABWR design. This shall include:
▪ The scope of activities associated with the Cask Pit and Preparation Pit.
▪ Measures to enable the condition of spent fuel to be inspected, prior to assemblies being loaded into Multi-Purpose Canisters (MPCs).
▪ Retention of the MPC lid prior to welding.
▪ Measures to reduce risks to workers from drops of unsealed loaded MPCs.</td><td>4.2

Non Foreclosure of Options in the Design of the Cask Pit and Preparation Pit

Protection of Workers in the Vicinity of Unsealed Canisters</td></tr>
</table>

AF-ABWR-SFIS-03	Hitachi-GE's generic safety case identified the following systems that are required to ensure adequate levels of safety during the activities to prepare spent fuel for interim storage: ■ Cask Stand. ■ Canister Cooling System (CCS). ■ Back-Up Canister Cooling System (BCCS). ■ Forced Helium Dehydration system (FHD). ■ Over Temperature Protection System (OTPS). ■ Multi-Purpose Canister (MPC) lid retention paddles. As Hitachi-GE's consideration of these systems was at a concept level of design within GDA, it was not practicable for the generic case to provide a full substantiation of the claimed system reliabilities and their functionality during fault conditions. During detailed design of the spent fuel export and interim storage systems, the licensee shall therefore: ■ Substantiate that the design and claimed reliability of all auxiliary systems needed to support spent fuel export and interim storage will reduce the mitigated risks of all relevant design basis faults SFAIRP. ■ Demonstrate that the systems used to dry and inert canisters are capable of monitoring a sufficient range of parameters to identify any thermal excursions and/or failures in the fuel cladding that may become apparent during the drying, inerting or welding processes.	4.2 Cooling During MPC Drying, Inerting and Welding
AF-ABWR-SFIS-04	Hitachi-GE's generic safety case identified a number of credible causes of blockages to the inlet vents of concrete over-packs that may take place inside the spent fuel interim store. The case predicted that significant vent blockages had the potential to lead to spent fuel cooling faults that could threaten fuel clad integrity. The case however, made no safety claims on the storage building itself and placed a dependency on operators to carry out inspections of the concrete over-pack vents every 24 hours. This does not align with ONR's expectation for safety functions to be allocated to automatic systems where reasonably practicable, therefore the licensee shall: ■ Ensure the design of the spent fuel interim store includes all measures to reduce, so far as is reasonably practicable, the potential sources of over-pack vent blockages, including the site specific external hazards. ■ Demonstrate that the safety functions necessary to maintain safe storage conditions have been allocated to engineered systems so far as is reasonably practicable, in preference to placing duties on human intervention.	4.2 Cooling of Welded MPCs

AF-ABWR-SFIS-05	The potential exists for faults to occur whilst the spent fuel is held inside the Multi-Purpose Canisters (MPCs) within the spent fuel interim store. During the operational phase of the UK ABWR, Hitachi-GE proposed to transport any degraded MPCs/stored spent fuel from the spent fuel interim store to the Spent Fuel Pool (SFP) to allow the MPCs to be reopened for examination and any required remediation. Once the SFP has been decommissioned Hitachi-GE proposed that a hot cell will be constructed local to the spent fuel interim store to maintain the site's capability to inspect/remediate stored spent fuel and to achieve the final re-packaging of spent fuel for consignment off-site for disposal. The robustness of Hitachi-GE's strategy for recovery from the design basis faults that may occur in the spent fuel interim store is dependent on the detailed design of the dry cask storage system. Hitachi-GE's consideration of this system in the generic safety case was limited to a 'proof of concept' and detailed design will not be carried out until the site-specific stage. Consequently the generic safety case did not provide a full demonstration that risks associated with the return of loaded MPCs to the SFP during the station's operational phase will be reduced so far as is reasonably practicable (SFAIRP) and achievement of this legal requirement is dependent on detailed design decisions that will need to be made by a future licensee. Therefore the licensee shall ensure that: ▪ Options to remediate design basis faults that may occur within the spent fuel interim store during the operational phase are not foreclosed by the detailed design of the UK ABWR. This should include (but not be limited to) provision of sufficient space and services to deploy all reasonable options to recover from faults that may affect the MPCs and/or spent fuel. ▪ At an appropriate step during licensing/construction, assess all remediation options and adopt the method(s) that reduce risks SFAIRP.	4.2 Recovery from Faults in the Spent Fuel Store