Summary report of the Step 3 Generic Design Assessment (GDA) of Hitachi-GE Nuclear Energy's UK Advanced Boiling Water Reactor (UK ABWR)

Foreword

ONR's vision is to be an exemplary regulator that inspires respect, trust and confidence, and in that context I am pleased to present our second report on our assessment of the UK ABWR, which is the culmination of GDA Step 3. In accordance with our mission we continue to regulate to uphold the highest standards in engineering and analyses to achieve the safest designs for the public within the UK regulatory framework.

During Step 3 there have been a number of changes affecting the nuclear build landscape; including a change in Government with the intent to push forward nuclear new build, and increasing confidence in the UK market for new nuclear. As a result I continue to take steps to ensure that ONR is ready to respond to what we expect will be a significant growth in the industry. This is vital in continuing to provide confidence to our stakeholders that ONR as the independent safety and security regulator is well positioned to support such growth and innovation, and maintain public trust in our robust regulation. To this end ONR continues to examine options for recruitment, retention and technical support in an increasingly challenging labour market.

I can see clearly that we are realising the benefits of the upfront GDA process once again, as a number of challenging issues have been highlighted throughout the Step 3 phase, and we have agreed some significant design changes with Hitachi-GE, which will bring safety benefits to the UK. It is usual for design modifications to be required when a technology is assessed in a new regulatory environment, and early identification allows them to be addressed swiftly which reduces impacts later on in the overall programme.

I also support the early release of two Regulatory Issues, which is beneficial to Hitachi-GE as Step 4 can be used effectively to address these challenges, which will improve the overall UK ABWR safety case.

I am encouraged by the development of the collaborative working and establishment of the Hitachi-GE joint safety case office with Horizon Nuclear Power as the eventual owner operator of the UK ABWR; a holistic approach to infrastructure projects of this nature is key to achieving the Wylfa Newydd timescales. This is also key to transferring the safety case knowledge to those responsible for implementation. Our work to further integrate regulatory effort on GDA and new reactor licensing will help to enable the overall programme for Wylfa Newydd, and I am pleased that this is something we have been able to achieve for this GDA.

Your comments on this report would be welcome, and we will continue to publish our findings and operate with the openness that the public expects of us throughout this process.

Dr Richard Savage
Acting Chief Nuclear Inspector

Introduction

Image courtesy of Hitachi-GE Nuclear Energy Ltd

Shimane nuclear power plant at night

GDA is the UK nuclear regulators' (ONR and Environment Agency) process for assessing new nuclear power station designs proposed for construction in the UK. It is a well-established and documented process that was developed in 2006 and originally published in January 2007. There is a wealth of information on the process, and previous applications of the process available on our website[1]. We also provided a summary of the background to GDA in our UK ABWR GDA Step 2 Summary Report[2].

In essence GDA consists of four steps:

- GDA Step 1 is the preparatory phase, and does not involve technical assessment work. It involves the setting up of formal agreements between the regulators and the Requesting Party[3], and discussions on the requirements for GDA.
- GDA Step 2 is an overview of the fundamental acceptability of the reactor design within the nuclear regulatory regime of Great Britain. It aims to identify design or safety shortfalls that could

1 For more information on the GDA process see http://www.onr.org.uk/new-reactors/index.htm

2 Step 2 Summary Report http://www.onr.org.uk/new-reactors/uk-abwr/reports/step2/uk-abwr-step-2-summary-report.pdf

3 'Requesting Party' is the term for the reactor vendor organisation undertaking GDA, and recognises that they do not hold a nuclear site licence.

prevent the design from being acceptable for construction in Great Britain. It is focused on understanding the key assertions about the safety of the reactor (key safety claims)[4].

- GDA Step 3 progresses the Step 2 work and moves into assessment of the reasoning (safety arguments) supporting the safety claims. For security, the focus is on the arrangements for developing the conceptual security plan.
- GDA Step 4 is the detailed assessment phase where we analyse the evidence provided to support the safety claims and arguments. At the end of Step 4, the regulators determine whether sufficient evidence has been submitted by the RP to issue a Design Acceptance Confirmation (DAC) by ONR, and a Statement of Design Acceptability (SoDA) by the Environment Agency.

Completion of GDA alone does not enable a reactor design to be constructed on a site within Great Britain, and the link between GDA, nuclear site licensing and eventual regulation of the construction phase is clearly described on our website[5]. The process enables assessment of the design at the earliest opportunity, to provide clarity of required design and safety case changes resulting from regulatory requirements. This in turn reduces regulatory uncertainty and helps to inform investment decisions taken by eventual operators.

This report is the GDA Step 3 summary report for the Hitachi-GE UK ABWR design. Following completion of GDA Step 2 in August 2014, we published a series of reports summarising our work and concluded that there are no fundamental safety shortfalls that would prevent the UK ABWR from being constructed in Great Britain.

This report on Step 3 of GDA covers the period from September 2014 to October 2015. The specific objectives of the ONR's work during this period were to:

- improve our knowledge of the design;
- assess the safety arguments underpinning the fundamental safety claims assessed in Step 2 of GDA;
- assess security proposals for the UK ABWR;
- identify significant issues and whether any design changes or safety case changes may be required;
- identify major issues that may prevent the issue of a DAC/SoDA; and
- significantly reduce regulatory uncertainty.

This report is essentially an interim statement on the progress of

4 The construct of 'claims, arguments and evidence' is explained in our Step 2 Summary Report.

5 ONR website – new build http://www.onr.org.uk/civil-nuclear-reactors/index.htm

our assessment since starting in 2013. Throughout Step 3 we have published all of our Regulatory Observations (RO) which are matters that we consider are potentially significant regulatory shortfalls, requiring action and in some cases new work. We have also raised and published two Regulatory Issues (RI), which are serious regulatory shortfalls that are significant enough to prevent ONR issuing a DAC, and require action and new work for them to be addressed. The published ROs and RIs provide significant detail on our assessment findings in each of the associated technical topic areas, and Hitachi-GE have published their resolution plans describing how they will address the issues.

Following the initial round of GDAs (2007-2013), we undertook a lessons learned exercise that we published on our website[6]. This exercise recommended that all ROs should be published as they are raised (which was not the case in the earlier GDAs). In doing this, stakeholders receive information on our regulatory assessment throughout the step, rather than waiting until the end. The exercise further noted that this would remove the requirement to publish detailed technical assessment reports at the end of Step 3, as the information is already in the public domain.

We have continued to publish quarterly progress reports[7] which contain metrics highlighting our opinions on Hitachi-GE's delivery performance and submission quality.

Regulatory expectations

UK legislation requires that risks to health and safety be reduced so far as is reasonably practicable (SFAIRP), and ONR makes decisions based on compliance with the law. For any nuclear reactor proposed for construction, we require that risks arising from the radiological hazard be reduced SFAIRP. This is our overriding requirement. Basically, this means that we expect a very robust design that provides protection against potential accidents arising from equipment failures, internal and external hazards and human interactions. We expect a comprehensive safety analysis that demonstrates that the hazards and failure mechanisms are well understood and that the reactor design can tolerate these with sufficient safety margins. In simple terms, we expect analyses that show that reactor can be safety shutdown; that the shutdown reactor can be cooled and that radioactivity can be contained. We also expect evidence that multiple redundant, and in certain cases, diverse safety systems are provided, such that if one fails there is another one available to fulfil the function.

6 Lessons Learned Report http://www.onr.org.uk/new-reactors/reports/onr-gda-sr-13-001.pdf

7 Quarterly progress reports http://www.onr.org.uk/new-reactors/quarterly-updates.htm

The principles used by ONR to assess the adequacy of analyses are the Safety Assessment Principles[8] (SAPs), which were revised and updated in 2014 to reflect learning from the 2011 Fukushima Dai-ichi accident. Underpinning the SAPs there are detailed Technical Assessment Guides (TAGs)[9], which provide guidance to inspectors on interpreting the SAPs. All of this documentation is published on our website.

The regulatory expectations for security and environmental analyses and documentation are provided in separate guidance[10 11].

For Step 3 our assessment has analysed the safety arguments underpinning the high level 'claims'; which are the overarching statements about reactor safety made by Hitachi-GE. We adopt a sampling approach to assessment and this is documented in the Step 3 assessment plans for the individual topic areas. In each topic area, our assessment covers a representative sample, which may include aspects of the RP's submission related to novel technology, areas of higher risk or where our understanding is less developed.

Use of Technical Support Contractors

It is usual in GDA for ONR to engage specialist contractors to provide technical support; this may be to supplement our capacity in recognition of the sheer volume of work involved, or to provide specialist expertise that we do not retain in-house (such as particular computer models or niche technical experience). For Step 3, we have let 24 contracts to 13 different organisations with a total value of almost £3 million. The detail of these has been provided throughout Step 3 in our quarterly progress reports. What is important to note is that the information and assessment provided by contractors is used to inform ONR decisions and judgements, and all regulatory decisions and judgements are taken by ONR.

8 Safety Assessment Principles http://www.onr.org.uk/saps/saps2014.pdf

9 Technical Assessment Guides http://www.onr.org.uk/operational/tech_asst_guides/index.htm

10 http://www.onr.org.uk/ocns/ocnsdesign.pdf

11 https://www.gov.uk/government/publications/assessment-of-candidate-nuclear-power-plant-designs

Main Features of the design and safety systems

Image courtesy of Hitachi-GE Nuclear Energy Ltd

Shimane RCCV liner installation

Hitachi-GE provides information and description of the ABWR design on their website[12], and we provided a high level overview.

Basic Description

The development of the ABWR began in 1978, and was first adopted in the construction of the Kashiwazaki-Kariwa Nuclear Power Station Unit 6 and Unit 7, which commenced commercial operation in 1996 and 1997. At full power, a single ABWR reactor produces around 1350MWe of electricity.

The ABWR uses demineralised water as a coolant and neutron moderator. Heat is produced by nuclear fission in the reactor core, and this causes the coolant to boil, producing steam. The steam is directly used to drive a turbine, after which the steam is cooled in a

12 Hitachi GE website http://www.hitachi-hgne-uk-abwr.co.uk/reactor.html

condenser and converted back to water. This water is then returned to the reactor core, completing the loop. The coolant is maintained at high pressure, so that it boils in the core at about 285°C. This is fundamentally different from other reactor types which do not use this direct cycle of steam to drive the turbine generators.

The basic layout of an ABWR comprises a reactor building, control building and turbine building, the configuration of which is site dependant, however they are located immediately adjacent to each other.

The major part of the reactor building is the Reinforced Concrete Containment Vessel (RCCV), which contains the Reactor Pressure Vessel (RPV). The RCCV is a steel lined reinforced concrete structure, cylindrical in nature, 36m tall, 29m in diameter and with 2m thick walls, with a steel bolted head. It has two principal functions: to contain pressure and prevent leakage. The reinforced concrete manages the functions of pressure containment and shielding, and the liner handles the function of leakage prevention.

The RCCV is divided into a drywell and a suppression chamber by the diaphragm floor and the RPV pedestal. The suppression chamber contains the suppression pool and an air space. Vapour, which could be generated by a Loss of Coolant Accident (LOCA), flows from the drywell space through horizontal vent pipes embedded into the RPV pedestal to the suppression pool, where the steam is condensed.

The RPV is a cylindrical steel vessel that contains the core and reactor internals. The RPV consists of a removable hemispherical top head, cylindrical shells, a bottom head, and some nozzles. The RPV is installed vertically on the pedestal inside the RCCV. The RPV is around 21 metres in height, 7.4 metres in diameter and with a steel wall thickness of around 17 centimetres. The RPV functions as the pressure retaining barrier to retain the coolant, and as the barrier to isolate radioactive material generated in the core from getting outside the RPV. The vessel contains the core, steam separator, steam dryer, reactor internal pumps and the control rod arrangements.

The reactor core is assembled in an upright cylindrical disposition containing 872 fuel assemblies. A fuel assembly has a square array of fuel rods and a hollow pipe (water rod), where water coolant flows. Fuel assemblies are placed inside zircaloy channel boxes, the function of which includes forming the coolant flow path and guiding the insertion and withdrawal of control rods between fuel assemblies. Each fuel rod is made out of a Zircaloy-2 cladding tube containing Uranium Dioxide (UO2) pellets with less than 5wt% Uranium-235 enrichment; both ends of a fuel rod have plugs welded on; its plenum is filled with helium gas. At the end of a fuel cycle, the spent fuel will contain radioactive fission products which remain confined inside the cladding.

The control rods are cruciform and are inserted between every 4 fuel assemblies. They perform the twin functions of power distribution shaping and reactivity control. The control rods enter the vessel through the bottom dome and are inserted under either electric or hydraulic power.

Safety systems

During normal operation, steam generated in the reactor is transferred to the turbine facility via four main steam pipes. In order to prevent overpressure of the reactor following a transient in operation or an accident, steam inside the reactor is discharged into the suppression pool by the relief valve function or the safety valve function of the Safety Relief Valves (SRVs). Main steam isolation valves are arranged in pairs (at either side of the containment wall) to isolate the reactor in case of fuel failure, Main Steam Line Break Accident (MSLBA) or LOCAs.

The ABWR also has a standby liquid control system which acts as a second line of criticality control. If required it can inject borated water directly into the RPV, which will bring the core to a sub-critical state and maintain it as it cools.

The ABWR safety systems include three independent divisions of Emergency Core Cooling Systems (ECCS). Each division of the ECCS has one high pressure and one low pressure make-up system. The pumps for these systems are either electrically (motor) or steam (turbine) driven. The choice of which system to use is dependent on the accident transient. The volume of the RCCV is maintained in an inerted state by the use of a nitrogen atmosphere, which reduces the likelihood of combustion if a leak of hydrogen occurs. In the event of a loss of off-site electrical power, the ABWR has independent emergency diesel generators to provide power to the essential safety systems.

Fuel is inserted and removed from the RPV using the fuelling machine which is located on the operating floor. Spent fuel is placed in the spent fuel pool immediately after removal from the RPV and kept there until it has cooled sufficiently to allow placement into fuel casks for long term storage.

Overseas regulators' assessment

Our strategy for working with overseas regulators is described in published documentation[13].

Our international activity during Step 3 has included our participation in, and chairing of, the ABWR Working Group (ABWR WG) within the Multinational Design Evaluation Programme (MDEP). This has enabled the sharing of technical information and technical assessment findings and opinions with the nuclear regulatory authorities of the United States (Nuclear Regulatory Commission, US NRC), Japan (Nuclear Regulation Authority, NRA), Sweden (Swedish Radiation Safety Authority, SSM) and Finland (Radiation and Nuclear Safety Authority, STUK). Since the beginning of Step 3 three meetings of the ABWR WG have been held (September 2014, April 2015 and October 2015), during which significant progress has been made in the understanding of the different ABWR designs and their variety of technical solutions to address safety. This is being used by the ABWR WG to inform its detailed technical work. The MDEP ABWR WG is making substantial progress with the development of an ABWR common position paper addressing issues related to the Fukushima Dai-ichi accident. This paper provides the context of the events at Fukushima Dai-ichi, a discussion about how the various ABWR designs address those aspects, and a statement of the common position for the following areas: "evolutionary improvement in safety", "external hazards", "reliability of safety functions", "accidents with core melt", "emergency preparedness in design", "spent fuel pools", and "safety analysis".

Two technical expert sub-groups (TESG) within MDEP's ABWR WG have been established during this period to promote in-depth information exchange in the areas of ABWR control and instrumentation (C&I) and severe accidents (SA). The TESG meetings held so far have provided useful insights on C&I topics such as:

- diversity of RPV level measurement;
- back-up building instrumentation; and
- man-machine interfaces

13 Guidance to Requesting Parties http://www.onr.org.uk/new-reactors/ngn03.pdf

SA topics such as:

- ex-vessel core management;
- suppression pool pH control; and
- hydrogen management.

Joint topics such as:

- SA instrumentation requirements.

ONR will use insights obtained from this work to inform our assessment of the adequacy of the UK ABWR C&I and SA features during Step 4 of GDA.

In addition to the MDEP work, during this period we have had bilateral technical discussions with the Swedish regulator (SSM) and the Japanese regulator (NRA). With SSM we discussed the general approach to operational chemistry selection and implementation for Nordic Boiling Water Reactors (BWR), some aspects of BWR 'accident chemistry' (specifically, suppression pH control and iodine behaviour during accidents), the RPV bottom drain line and materials selection for key systems, etc. With NRA we also discussed aspects of BWR 'accident chemistry' and iodine behaviour, as well as filtered containment venting, hydrogen control systems and fuel performance. Important outcomes from these meetings have supported ONR's assessment during Step 3 in the areas of reactor chemistry, radiation protection, structural integrity and severe accidents.

We have continued engagement with the US NRC during Step 3; mainly to share information on ABWR assessment developments in both countries. Plans are also in place for discussions on seismic margins analysis with US NRC's specialists.

Our participation in the MDEP ABWR WG and its TESGs and our bilateral exchanges with key international stakeholders with experience of regulating BWR and ABWR designs is providing knowledge and insight that we are using in the delivery of the UK ABWR GDA.

Public involvement

ONR's mission includes *"….holding the industry to account on behalf of the public"*, and we place great importance on being open and transparent about our work and the regulatory decisions that we make. We believe that this will help to improve and maintain public trust in the work that we do. ONR publishes all of its reports, statements and guidance on the joint regulators' GDA website, which includes an electronic news bulletin specifically for those interested in new nuclear reactors.

ONR requires Hitachi-GE to publish technical information on their reactor design, including safety case documentation, and to host a public comments process, which enables members of the public to view and comment on the design and safety case information. During Step 3, 17 comments were posted on the Hitachi-GE website and responses provided.

For Step 3 we worked to increase awareness of our work amongst communities and stakeholders, increase interest in our websites and the Hitachi-GE public comments process. We also wanted to explain why the GDA processes is important, why we are involved in nuclear new build and highlight the opportunities for people to get involved.

During Step 3 we have:

- Completed the Sciencewise public dialogue project which involved surveying and engaging with the public on how we can improve communications around GDA and increase awareness of the nuclear regulators.
- Published four quarterly reports, two website news stories and six e-bulletins.
- Published three articles in ONR's external publications.

We published a report on public engagement and communications in September 2015[14] and we are now considering the recommendations as part of our on-going communications work. The principle outcome is that the Sciencewise project has provided a better understanding of the needs of the public; how they want to be involved and what we can do to help build trust in the regulators. We have already made improvements to our e-bulletin as a result of the project outcomes and we are using feedback from the project to inform our future public engagement and the environmental regulators' consultation approaches and materials.

14 http://www.sciencewise-erc.org.uk/cms/assets/Uploads/GDA-dialogue-report-August-2015-FINAL.pdf

Step 3 Assessment summary

Image courtesy of Hitachi-GE Nuclear Energy Ltd

Large module installation

Overview

Step 3 has been a period of intense activity, with significant progress being made. For the duration of Step 3 we have:

- attended 374 meetings;
- issued 427 Regulatory Queries (RQ);
- raised 50 ROs; and
- raised two RIs.

In line with our lessons learned following the first GDAs, this pattern signifies a comparative increase in the issue of ROs and RIs compared to the first GDAs. During Step 3 the UK EPR received one RO and the AP1000 33, and neither technology received an RI. However we recognised in our lessons learned the benefit of identification and earlier issuing of ROs and RIs to provide clarity on regulatory concerns. Therefore we regard this increase as positive as it reinforces one of the benefits of GDA; clear and early identification of regulatory issues and challenges requiring resolution. Early identification of these issues provides every opportunity for Hitachi-GE to address them during Step 4.

During Step 3 Hitachi-GE provided a further 812 submissions, building on the 325 supplied within Step 2. These have been submitted in accordance with the programme agreed with the regulators throughout Step 3.

Our global view is that the UK ABWR design and safety case has progressed and matured throughout Step 3, and Hitachi-GE has developed its knowledge and understanding of UK regulation. At the end of Step 3 our judgement is that sufficient progress has been made in all of the technical areas to justify progression of the project to Step 4 of GDA.

There have been some notable technical challenges in Step 3, which have resulted in the issue of two RIs in the areas of reactor chemistry[15] and probabilistic safety assessment (PSA)[16]. However, Hitachi-GE has been able to provide sufficient material within Step 3 to allow progress to Step 4, and should the quality of delivery and programme continue, we expect that these issues will be resolved within the Step 4 timescale.

Throughout Step 3, which included some challenging discussions around the RIs, Hitachi-GE has responded constructively, and they have been determined to understand and meet regulatory expectations. Our interactions at all levels are generally positive and we have been greatly encouraged by Hitachi-GE's increased use of technical support contractors to provide specialist expertise and to support their learning of UK regulation. However, the scope of work to be delivered in Step 4 is significant and will require Hitachi-GE to be much more proactive and systematic in identifying and resolving issues themselves, ahead of intervention by ONR.

There are a number of technical challenges that remain, some of which are significant, and we anticipate that further design changes may be required to meet UK regulatory expectations. However if Hitachi-GE continue in the spirit with which they have approached Step 3, it is possible that they can achieve their ambition of completing GDA in December 2017.

Principal achievements of Step 3

Hitachi-GE has achieved a great deal in Step 3. In addition to agreeing to the design changes described later in this report, of particular note is:

- The significant work on developing their safety case expertise - this has involved the production of a safety case development manual and associated training of a large number of technical staff.
- The establishment of the joint Hitachi-GE/Horizon Nuclear Power Safety Case Office - this will facilitate the development of a holistic, integrated, complete, and visible generic safety case that is well understood by Horizon Nuclear Power following completion of GDA.

15 RI-ABWR 0001 http://www.onr.org.uk/new-reactors/uk-abwr/reports/ri-abwr-0001.pdf

16 RI-ABWR 0002 http://www.onr.org.uk/new-reactors/uk-abwr/reports/ri-abwr-0002.pdf

- The enhanced collaborative working with Horizon Nuclear Power to facilitate optimised GDA scope, safety case visibility and knowledge transfer.
- The increase in resource committed to GDA - Hitachi-GE has increased resource across the project in the majority of technical areas and at leadership and project management levels. This has improved their ability to deliver and maintain their programme. The Hitachi-GE team now consists of approximately 330 staff, with engineers in Japan supported by UK Subject Matter Experts (SMEs), and Technical Support Contractors sourced from the UK. This includes a Step 3 increase of approximately 119 individuals; 43 above initial expectations.
- The increase in UK safety case/regulatory expertise - Over the period of Step 3, Hitachi-GE has secured the services of world-class experts, which has enabled them to respond to challenging technical issues and improve the quality of their submissions.
- The submission of an updated Level 1 internal events at power PSA, in response to RI-ABWR-02. As a result of this work the risk profile has changed significantly. The revised PSA shows that the contribution to the core damage frequency (CDF) associated with internal initiating events during operation at power that arises from loss of offsite power (LOOP) has decreased. On the other hand, the contribution to the CDF from events that require manual shutdown (including loss of support systems) has increased. The revised PSA has further highlighted the importance of the Reactor Cooling and Reactor Building Service Water Systems. These insights coming from the revised PSA will inform our assessment during Step 4.

Principal design/operational changes resulting from UK regulatory requirements.

The following are changes to the extant ABWR design and operating regime that have resulted from UK regulatory requirements during Step 3. Further information on each of these issues is available in the published ROs:

- *Inclusion of an aircraft impact protection shell* – Required to protect against accidents and other threats.
- *Operating chemistry regime* – The Japanese ABWRs were all designed, built and operated using normal water chemistry. For the UK ABWR, following a rigorous ALARP (as low as reasonably practicable) assessment, Hitachi-GE has chosen to implement an operating chemistry regime based upon the addition of hydrogen with noble metals and depleted Zinc. While there is extensive operating experience of this regime globally, this will be the first time that any BWR will operate with this chemistry regime from the beginning of life. This decision will also impact on other aspects of the detailed plant design, such as material choices.

- *Changes proposed to the suppression pool pH control* – Required to mitigate potential radiological consequences during accidents, and multiple material changes to reflect the operating chemistry regime and analysis of relevant good practice.
- *Removal of the emergency diesel generators from the reactor building* – To reduce the fire risk. The position of the emergency diesel generators is a decision for Step 4.
- *Major design changes across the C&I systems*:
  - Redesign of the Class 1 Safety System Logic and Control System (SSLC) by the introduction of a field programmable gate array technology.
  - Development of the Class 2 Hardwired Backup Safety Systems using analogue devices to provide a second line of protection for frequent faults.
  - Elimination of direct communication from lower class safety systems to higher class safety systems.
  - Removal of non-safety Category A Class 1 functions from the SSLC and their reassignment to a Class 2 Safety Auxiliary Control System independent from the protection system, so that the protection system no longer carries out control loop functions.
  - Introduction of a Class 1 operator interface to the protection system
  - Physical separation of the protection system equipment divisions by the introduction of physical barriers. This has led to a corresponding increase in the footprint of the control building to accommodate the walls and additional cabinets.
- *Architecture of the electrical distribution system* – Modification to achieve diversity between the standby electrical systems by operating at different voltage levels and the addition of diverse generators in the back-up building, plus provisions for station black-out through an additional generator and mobile sources of power.
- *Greater redundancy/segregation to the spent fuel pool cooling system* – To meet the requirements of the UK safety case and categorisation/classification scheme.
- *Increased capacity to residual heat removal heat exchanger* – To provide UK standard minimum number+2 safety injection/shutdown capability.
- *Improvements to the design of the low pressure safety injection* – To allow injection into either feedwater lines (rather than one), to provide UK standard minimum number+2 capability.
- *Hydrogen management in accident conditions* – Design changes have been proposed resulting from Hitachi-GE's assessment work following the Fukushima accident to provide passive autocatalytic re-combiners instead of the flammability control system which depends on electricity and auxiliary cooling water to operate. This will be explored in Step 4.

Principal technical challenges to be resolved during Step 4

Step 4 is the period of detailed technical assessment and therefore it is expected that there will technical issues to be resolved throughout the step. Some of these are already known to ONR and Hitachi-GE, and others will come to light as a result of our assessment. In addition to the challenges highlighted here, there remains a significant volume of work to be undertaken across the topic areas. This requires continued focus and sustained high quality, on-time delivery by Hitachi-GE.

This section highlights a number of key areas that will present a significant challenge to Hitachi-GE in Step 4.

- Removal of spent fuel from the reactor building - During Step 3 Hitachi-GE did not demonstrate that deterministic and probabilistic criteria will be met.
- Developing the safety case for the fuel route, radioactive waste and decommissioning - There are a number of challenges across these topics that aggregate, and we require further information to provide confidence that these will not undermine the safety case in these areas.
- Compliance with UK Grid Code Limits - Analysis and determination of design changes required to demonstrate that the reactor can operate within Grid Code limits.
- Safety case for containment venting - A number of significant claims have been identified on the requirement for containment venting for rare, but within design basis events and severe accidents;
    - where venting is used to prevent fuel damage and fault escalation
    - where key safety systems are assumed to have failed and containment venting is part of the mitigation measures
- In Step 4, Hitachi-GE will need to demonstrate the effectiveness, reliability and safety of containment venting in a range of scenarios;
- Delivery of a full scope PSA - This is a significant piece of work that could result in late design changes being required.
- Decision on materials selection for the plant - Resulting from the operating chemistry regime.

Summary of ONR findings

Summaries of progress in each topic area are provided below. They are taken from the individual topic reports and are therefore not necessarily consistent in their format. The detail of our main assessment findings is within the published ROs and RIs.

1 Engineering disciplines

Structural Integrity
Through Step 3, Hitachi-GE has developed a structure for the presentation of the main safety arguments that is consistent with UK expectations.

We have assessed the basis of the safety case of the highest integrity pressure boundary components. These include the RPV, the main steam lines and main steam isolation valves. Lower classification components have been considered on a sampling basis. We have also sampled aspects of pipe-whip, inspection qualification, categorisation and classification, materials selection, and assessed the submissions for the metallic components within the containment building. In the areas sampled, Hitachi-GE is progressing towards a demonstration of structural integrity that is consistent with UK expectations and a proportionate approach towards ensuring nuclear safety.

We are broadly satisfied with the structure and arguments presented within Hitachi-GE's submissions in the structural integrity topic area.

For Step 4 we will assess the adequacy of the reinforced concrete containment vessel, whether the manufacture of the main vessels is ALARP, whether materials selection processes and procedures are adequate, and whether adequate non-destructive inspection can be applied.

Civil Engineering / External Hazards
We have assessed the hierarchy of documents that present the UK ABWR civil engineering and external hazards aspects of the safety case. We are satisfied that a logical hierarchy exists and that the structure, clarity and quality of this system of documents meet the requirements of Step 3. We consider that Hitachi-GE has made significant progress with Revision B of the pre-construction safety report (PCSR) during Step 3, and that the clear identification of the system functional requirements has improved the quality of the safety case.

We consider that the UK ABWR generic layout has been clearly defined and that sufficient detail of nuclear safety related Structures Systems and Components (SSCs) and balance of plant items has been provided for the project to proceed to Step 4.

We have examined the basis of safety case for each of the civil engineering SSCs and we are content that these are adequate for Step 3, and that the design bases for the civil engineering SSCs have been clearly defined.

We have sampled the design reports for the civil engineering SSCs and judge that the design basis has been correctly and adequately defined. This is adequate for Step 3.

We have examined the seismic analysis reports for each of the civil engineering SSCs and are content that appropriate seismic analysis methodologies have been applied. This is adequate for Step 3.

We have carried out a high level review of the external hazards submissions and judge that Hitachi-GE has adequately identified and evaluated generic UK external hazards and the review, grouping, screening, categorisation and combination of these.

During Step 3, Hitachi-GE has made progress in defining the design requirements of the aircraft impact protection shell and its influence on the reactor building design. We will consider other design modifications, such as the relocation of the emergency diesel generators, in detail during Step 4.

We are broadly satisfied with the arguments laid down within Hitachi-GE's submissions in the civil engineering and external hazards topic areas. At the start of Step 4, we will look again at the major safety submissions that have been significantly revised during the course of Step 3, and there are a number of areas that we will need to assess for the first time.

Internal Hazards
Hitachi-GE has provided greater clarity on the internal hazards safety case being developed. Hitachi-GE continues to develop its safety case in response to a number of ROs, and has commenced design modifications requiring multi-discipline input.

The Step 3 assessment has identified several areas that require follow up in Step 4. Hitachi-GE has provided assurance that the Step 3 claims and arguments will be reviewed and updated at Step 4 as appropriate, on completion of the consequences analysis for all areas.

Mechanical Engineering
Hitachi-GE provided a PCSR and a full suite of basis of safety case documents for assessment during Step 3. These documents and their supporting references have a structure to appropriately set out the safety claims, arguments and evidence in the area of mechanical engineering.

This Step 3 assessment has made some progress in the area of mechanical engineering. However, for a number of specific SSCs, progress has been limited. This is due to the development schedule of some of Hitachi-GE's basis of safety case documents, which Hitachi-

GE expects to develop in Step 4. Hitachi-GE's submission was limited in setting out the SSCs design bases claims and arguments at a component level and their strategy is to set them out within the design justification reports. For GDA this is to be limited to the long lead procurement items.

There has also been limited progress with the Step 2 mechanical engineering ROs, although we do now have adequate resolution plans. There has been better progress with the mechanical engineering aspects of the cross-cutting ROs and we are encouraged by Hitachi-GE's use of UK consultants to develop the safety case for mechanical engineering.

We are broadly satisfied with the claims and arguments laid down within Hitachi-GE's submissions in the mechanical engineering topic area.

Security

We have assessed Hitachi-GE's methodology for identifying Vital Areas (VAs) and the application of UK design basis threats to selected candidate VAs, and concluded that the methodology is appropriate to be applied in Step 4. Hitachi-GE will continue with VA identification work using UK contractors to apply sensitive threat information not available to non-UK nationals. Hitachi-GE has also provided a sufficient level of information on other SSCs, including computer based systems important to safety, to be able to assess where security measures are required.

We are broadly satisfied with Hitachi-GE's development of the conceptual security arrangements. At the start of Step 4, we will assess the application of Hitachi-GE's VA identification methodology; particularly the application of UK design basis threats against candidate VAs. Once identified, we will then assess the conceptual security arrangements that provide protection to those areas and provide defence in depth.

Overall Hitachi-GE has made good progress in determining an acceptable VA identification methodology and in providing a high level concept of security operations. Importantly, they have demonstrated their ability to develop security arrangements, which is a relatively new concept to them in this area.

2 Safety Analysis Disciplines

Fault Studies

We have looked in detail at the initiating events included within the design basis, and (through a sampling approach) Hitachi-GE's modelling of fault sequences. During Step 3, Hitachi-GE has provided greater clarity on the means by which the UK ABWR safety case will demonstrate diversity for the frequent faults (notably through the back-up building) and cope with prolonged loss of off-site power events. Hitachi-GE continues to develop its safety case for pipe breaks in the main steam tunnel and its fault schedule has continued to evolve.

We are broadly satisfied with the arguments laid down within Hitachi-GE's submissions in the fault studies topic area. At the start of Step 4, we will look again at the major safety submissions which have been significantly revised during Step 3, and there are a number of areas that we will need to consider for the first time. The requirement for containment venting, the effectiveness and safety of the proposed containment venting methods, and the possible alternatives to containment venting will be a major area for detailed assessment.

Severe Accidents

We have looked holistically at Hitachi-GE's severe accidents safety case for the UK ABWR, and through a sampling approach we have assessed in detail Hitachi-GE's severe accident analysis. Our key findings are:

Hitachi-GE is able to present a set of coherent safety arguments to form a severe accidents safety case for the UK ABWR reactor at power. This severe accidents safety case is supported by severe accident analysis, performed with internationally recognised analysis tools. However;

- Hitachi-GE still has to further demonstrate that the design of the UK ABWR severe accidents measures are in line with relevant good practice for new reactors, and show that the risk from a severe accident has been reduced to ALARP.
- Hitachi-GE has to demonstrate that they have considered all operating modes and all relevant facilities (including the spent fuel pool) in order to demonstrate a complete severe accidents safety case.
- Hitachi-GE will have to demonstrate that they have both minimised the requirement for containment venting following a severe accident, as well as demonstrating that the design of the containment vent filter will reduce any release to the environment to ALARP.

We are broadly satisfied with the arguments laid down within Hitachi-GE's submissions for the UK ABWR in the severe accidents topic area. At the start of Step 4 we will look again at the major safety submissions as well as the areas not considered within Step 3 (e.g. spent fuel pool severe accident analysis). The requirement for containment venting, the effectiveness and safety of the proposed containment venting methods, and the possible alternatives to containment venting will also be major areas for detailed assessment in Step 4.

Fuel and Core

- The design limits specified for fuel have been determined, taking into account anticipated faults and operational transients, and these broadly meet regulatory expectations. In particular, those that have been developed for interim dry fuel storage appear to be logically consistent and credible. The work relating to stress levels for hydrogen-assisted cracking was innovative and merits commendation.

- In a number of areas, the safety case was found to be insufficiently detailed, but this has been rectified by the provision of topic reports, and the current situation is generally satisfactory with a number of detailed issues for further consideration in Step 4.
- The methods of analysis employed are a mixture of old established codes and newer more comprehensive models.
- In the area of fuel pin modelling, the PRIME code met our expectations and although we need to examine the evidence in more detail during Step 4, it is unlikely that there will be significant weaknesses.
- In the area of core physics, we had some concerns about the adequacy of the methods employed. These have been largely addressed, but the extent of information presented is limited. We will review the position in the context of the results of independent confirmatory calculations. This is potentially significant to the analysis of safety margins for criticality and thermal performance.
- In the thermal analysis area, we are content with the principles of the analysis methods and in Step 4, we will examine their application in more detail.
- In a number of areas, we will consider the way in which analysis is used to define suitable operational rules to control the plant risk.
- To conclude, we are broadly satisfied with the arguments laid down within the Requesting Party's submissions in the area of fuel design.

Control and Instrumentation (C & I)
Our assessment has focused on the arguments that support the safety category A and safety classification 1 and 2 systems. In addition we have followed up on a number of regulatory concerns raised in the Step 2 C & I Assessment Report, and assessed the overall ability of Hitachi-GE to articulate the safety case in the UK regulatory environment.

We have assessed the principle arguments that support the safety claims made in Step 2 of GDA. The majority of the arguments are not fully developed and are not fully reasoned. However there is sufficient information within Hitachi-GE's C & I safety case for us to conclude that they are adequate for Step 3 of GDA. Furthermore, there is now a clear link from the UK ABWR fault schedule through to the specific claims on the C & I equipment that either prevents or mitigates faults.

Hitachi-GE committed during Step 2 to improve the diversity of the primary protection system by redesigning it to use field programmable gate array technology, which will be the first time it has been used for a primary reactor protection system in the UK. This change has been recognised by both ONR and Hitachi-GE as a significant potential risk to the completion of GDA and hence to the issue of a DAC at the end of Step 4. We have reviewed the progress Hitachi-GE is making in developing the design and the processes it is using and we are satisfied that Hitachi-GE is making adequate progress.

Due to the unique and complex nature of field programmable gate array technology designs, we have commissioned a specialist Technical Support Contractor to perform an in-depth technical assessment of the design. This assessment will be complete during the early stages of Step 4 and will be used to inform the Step 4 assessment activities.

Electrical Engineering

During Step 3 we have looked in detail at the presentation of safety claims on the electrical system to support plant safety functions. In order to support these claims, Hitachi-GE has established detailed claims derived from safety functional requirements, and has developed the architecture of the electrical distribution system to provide appropriate levels of diversity. During Step 3 Hitachi-GE has adequately developed the basis of safety case structure and arguments to support the safety claims. During Step 4 Hitachi-GE will develop the detailed arguments and supporting evidence for these claims.

We are broadly satisfied with the arguments laid down within Hitachi-GE's submissions in the electrical engineering topic area. During Step 4 Hitachi-GE will conduct detailed electrical system studies to demonstrate the resilience of the electrical system to a range of potential disturbances. We will assess the results of these studies including conducting confirmatory studies using a specialist Technical Support Contractor.

Human Factors

- The PCSR broadly meets UK regulatory expectations in the area of human factors. Hitachi-GE's safety case claims that the UK ABWR will be designed in accordance with modern standards; particularly the design of the working environment, equipment and interfaces to optimise the human performance of tasks related to nuclear safety.
- The UK ABWR has a comprehensive human factors integration programme that meets UK regulatory expectations, and the submissions provided during GDA Step 3 provide assurance that the processes are functioning correctly in delivering informed human factors expertise to the design and safety case development.
- Following regulatory challenge during GDA Step 2, Hitachi-GE has developed a wide ranging, consistent and systematic approach to the use of task analysis in design and safety case activities for the UK ABWR.

- In response to RO-ABWR-0005, Hitachi-GE has established a significant human factors capability (about 50 human factors specialists) to support development of the UK ABWR, including specialists with extensive UK experience.
- The approach to Human Reliability Assessment (HRA) appears acceptable, and the identification of human based safety claims is suitable in covering the complete human contribution to safety. However, a more detailed analysis and justification is currently lacking (to an extent that should be available at Step 3).
- The human contribution to overall risk is currently unknown due to the lack of a full scope PSA for the UK ABWR. The absence of a full scope UK ABWR PSA (and its supporting analyses) also presents a risk to completion of the human factors assessment, as the PSA supports the identification and understanding of risk-significance operator actions across the plant and plant states.

Probabilistic Safety Analysis
PSA has proved to be a particularly challenging topic for Hitachi-GE to progress in Step 3. We have looked in detail at the PSA methodologies and identification of initiating events and (through a sampling approach) looked at Hitachi-GE's internal events at power PSA.

Our assessment identified significant shortfalls and gaps against regulatory expectations which were captured in RI-ABWR-0002 and associated ROs and RQs. We are currently undertaking assessment of one of the major safety submissions which has been significantly revised during the course of Step 3 (the updated internal events Level 1 PSA at power) to confirm that these shortfalls have been addressed. Our initial judgement is that Hitachi-GE's improved PSA arrangements and PSA capability has set up the basis to develop and deliver the PSA information that we require for a meaningful assessment during Step 4.

We are broadly satisfied that the commitment provided by Hitachi-GE in response to RI-ABWR-0002 will address the shortfalls identified in the arguments laid down within Hitachi-GE's submissions in the PSA topic area. However due to the volume of work required, PSA is a high risk topic area with respect to completing GDA of the UK ABWR design within Hitachi-GE's timescales. Continued delivery of the agreed resolution plan for RI-ABWR-0002 will be key to sustained progress.

At the start of Step 4, we will look again at the major safety submissions that have been significantly revised during the course of Step 3, and there are a number of key submissions expected early in Step 4 which we will assess for the first time.

3 Science disciplines

Conventional Fire
We have looked at the fire safety strategy (through a sampling approach) for several areas of the UK ABWR which challenge UK expectations for fire safe design. During Step 3, Hitachi-GE has provided worked examples demonstrating the means by which the equivalent level of safety to prescriptive guidance will be achieved, by utilising a fire engineering approach employing alternative control measures. Hitachi-GE continues to develop its fire safety strategies.

Conventional Safety
During Step 3 we have assessed Hitachi-GE's selected conventional health and safety topic area submissions. Hitachi-GE has demonstrated understanding of the UK regulatory framework, and a largely appropriate risk hierarchy of control. Worked topic examples have shown consideration of Construction (Design and Management) Regulations 2015 designer duties in the elimination, so far as is reasonably practicable, of foreseeable risks across the lifespan of the reactor. Hitachi-GE continues to develop its conventional health and safety design strategies, incorporating a number of relevant cross-cutting topics.

Radiological Protection
We have assessed the arguments presented by Hitachi-GE in the following areas:

- shielding design;
- radiological zoning;
- dose assessment for workers from all sources; and
- dose assessment for workers and the public from the hazard of direct shine, along with post-accident accessibility.

During Step 3, Hitachi-GE has provided greater clarity on how radiation and contamination are controlled, such that doses to workers and members of the public are reduced to ALARP. There are still however a number of areas to be followed up as a comprehensive assessment is not possible until the final source terms are available, [refer to RI-ABWR-001] to develop the final models and exposure assessments. In general Hitachi-GE has made significant progress in the later months of Step 3 and it is anticipated that this will continue.

In Step 4 there are a number of areas that we will need to assess for the first time, including the design and operation of the heating, ventilation and air conditioning system, the design for exclusion of workers from high dose rate areas and the means of achieving this intent. We will also revisit a number of areas that we anticipate will develop in maturity including; shielding design and the design of through-shielding wall penetrations, worker and public exposure assessments and arrangements to manage radiation protection during maintenance. There are also a number of cross cutting issues to consider, including; spent fuel management, waste and decommissioning and the inclusion of a bottom drain line.

Radioactive Waste Management, Spent Fuel Management and Decommissioning

We have assessed the systems that deal with solid, liquid and gaseous radioactive waste, and examined how Hitachi-GE has developed its understanding of ALARP. We have also looked at non-reactor faults (e.g. faults within radioactive waste systems) where UK expectations differ from those in Japan. In addition we have assessed Hitachi-GE's approach to chemical engineering design as this has the potential to impact (by prompting design changes) across a range of topic areas. Furthermore we have examined Hitachi-GE's understanding of the risks, including likelihood and consequences for safely removing spent fuel from the reactor building, and judge this is a key area that requires follow-up. Finally, we have assessed Hitachi-GE's proposed design and approach to support the decommissioning of the plant at the end of life.

We are broadly satisfied with the arguments laid down in Hitachi-GE's submissions in the radioactive waste, spent fuel management and decommissioning topic areas. At the start of Step 4, we will look again at the major safety submissions that have been significantly revised during the course of Step 3, and there are a number of areas that we will need to assess for the first time. The requirement for liquid and solid radioactive waste treatment facilities will be an area of major consideration, as will examining Hitachi-GE's approach to safe removal of spent fuel from the reactor building, where there are currently significant uncertainties. The design for decommissioning will also be considered in greater detail.

Reactor Chemistry

Reactor chemistry has proved to be a particularly challenging topic for Hitachi-GE to progress; which resulted in re-scope of the assessment planned for Step 3. As a result we assessed:

- The definition and justification of the radiological source terms (the nature and amount of radioactivity) for the UK ABWR during normal operations.
- The generation, accumulation, management and mitigation of radiolysis gas during normal operations and the justification for this in the UK ABWR safety case.
- The justification for the material choices for the UK ABWR.
- The justification of the claims regarding pH control in the suppression pool during accidents.

- The chemistry related aspects of the design basis and severe accident analysis for the UK ABWR.
- Hitachi-GE's strategy and plan for producing the reactor chemistry aspects of the UK ABWR safety case.
- Hitachi-GE's ALARP demonstration of the chosen operating chemistry for the UK ABWR primary cooling system.

Throughout Step 3 we have made our regulatory expectations clear in these areas by producing separately, or jointly with other technical disciplines, one Regulatory Issue (RI-ABWR-0001) and six Regulatory Observations (RO-ABWR-0019; -0022; -0034; -0035; -0043 and -0044).

For Step 3 we consider Hitachi-GE has submitted the minimum amount of information required for Step 3. We are broadly satisfied with the arguments laid down within Hitachi-GE's submissions and our view is that they are just fit-for-purpose for Step 3 of GDA. Due to this we recognise that reactor chemistry is a high risk topic area with respect to completing GDA of the UK ABWR design within Hitachi-GE's timescales.

At the start of Step 4 we will assess Hitachi-GE's submissions against RI-ABWR-0001, which will be a major area of assessment; the outcome of which will affect numerous topic areas. We will also continue to re-visit the majority of the ROs raised during Step 3 and the Step 3 priorities, as Hitachi-GE continues to further develop the safety case for UK ABWR in these areas.

Management for Safety and Quality Assurance (MSQA)
Our assessment focused on the implementation of MSQA arrangements during Step 3 and the preparation of the MSQA arrangements to be submitted by Hitachi-GE in Step 4.

We are broadly satisfied that the MSQA arrangements for the GDA have been developed and implemented by Hitachi-GE. The arrangements generally meet the expectations in the Guidance to Requesting Parties[17], Interface Arrangements and the Environment Agency's Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs[18]

Some shortfalls associated with training, commitment capture, and identification of assumptions and requirements in the safety case have been identified during the assessment. Two ROs and an RQ were raised to clarify and resolve the shortfalls. These RQs/ROs will be resolved as part of routine regulatory business during Step 4.

17 Guidance to Requesting Parties http://www.onr.org.uk/new-reactors/ngn03.pdf

18 Process and Information Document https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/296440/LIT_7998_3e266c.pdf

Conclusions

Image courtesy of Hitachi-GE Nuclear Energy Ltd

Shimane RPV insertion

This is an interim progress statement on ONR's work on the GDA of the UK ABWR. Together with the published ROs, RIs and quarterly reports, it summarises our assessment to date.

Hitachi-GE has made significant progress throughout the Step 3 assessment period, both technically in terms of progressing the UK ABWR design to meet UK regulatory expectations, and also organisationally in terms of building their capability and capacity. We have raised some significant technical challenges, and PSA and reactor chemistry are highlighted as key areas of focus. However, we believe that Hitachi-GE will be able to address them throughout Step 4 and achieve a DAC on the timescales they have declared. The volume of work required is substantial, and Hitachi-GE will have to maintain pace and deliver high quality submissions on time throughout Step 4. We expect that further design and safety case changes will be required as a result of our Step 4 assessment and we will continue to ensure that Hitachi-GE's solutions reduce risks to ALARP.

At the end of Step 3 we judge that Hitachi-GE have made sufficient progress to continue into Step 4 of GDA.

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