Radiological Protection Aspects of the Generic Design Assessment of Potential New Nuclear Reactors in the UK

Grant Ingham and Susan McCready-Shea

Office for Nuclear Regulation, Redgrave Court, Merton Road, Bootle, Merseyside, L20 7HS,United Kingdom

Abstract

The Office for Nuclear Regulation is undertaking the Generic Design Assessment (GDA) of two nuclear pressurised water reactor (PWR) designs as part of a phased regulatory process to prepare for potential new nuclear build. Radiological protection is one of the technical areas that we are examining in detail, and this paper presents our approach to the radiological protection assessment of the EDF and AREVA UK EPR™ and Westinghouse AP1000® reactor designs.

We present the process that we have followed, the challenges involved with assessing reactor designs prior to the site specific phase, and the outcomes of our work. We examine the claims, supporting arguments and detailed evidence provided in the Requesting Parties' safety documentation. Topics covered include the minimisation of radiation sources, the adequacy of radiation shielding, the effectiveness of measures to control radioactive contamination, and the adequacy of measures intended to restrict the exposure of workers during accidents.

Overall, we concluded that predicted doses to members of the public are very low and the approach to optimising radiation exposures of workers when carrying out high dose work activities was adequate. We summarise the key Assessment Findings, which are matters where the lack of detailed information has limited the extent of our assessment and will require further assessment during the site specific phase as the additional details become available as the design progresses. We also describe the GDA Issues, which are matters of particular significance and will require resolution before ONR would agree to the commencement of nuclear island safety related construction of either reactor design in the UK. There are two GDA Issues: the substantiation of bulk shielding and the radiological zoning scheme for the EPR design; and criticality control of the spent fuel pool for the AP1000® design.

We concluded that both designs ensure that engineered features would restrict exposures to workers to ionising radiation so far as is reasonably practicable during normal operation and accident conditions. The reports describing our assessment and our conclusions were published in December 2011.

Key Words

Assessment
New build
Nuclear
Reactor
Regulator

Introduction

In response to growing interest in nuclear power, and in anticipation of possible applications for new build in the UK, the nuclear regulators developed a revised assessment process for new nuclear power stations [1]. The nuclear regulators are the Office for Nuclear Regulation (ONR, formerly part of and now an agency of the Health and Safety Executive, HSE) and the Environment Agency. ONR has regulatory authority in England, Scotland and Wales, and the Agency in England and Wales. Generic Design Assessment (GDA) constituted the first of this two phase process, with the site-specific phase (focussing on licensing/permitting of specific reactors) being referred to as Phase 2.

GDA was divided into four steps, with the progression through each step requiring an increasingly detailed assessment of the safety cases for each reactor design. Four reactor designs were originally submitted for assessment, but by Step 3, when the radiological protection assessment commenced, only two pressurised water reactor (PWR) designs remained: EDF and AREVA's UK EPR™, and Westinghouse's AP1000® reactor.

Step 3 technical reports on radiological protection aspects for both designs were published [2,3] in November 2009 and these focussed on high level claims and arguments. The assessment progressed to Step 4, where the principal focus was on the detailed evidence presented in the safety case submissions of the Requesting Parties (EDF and AREVA, and Westinghouse) which underpinned their claims and arguments. The final Step 4 radiological protection technical assessment reports, which detailed the outcomes of the GDA assessments, were published in December 2011 [4,5]. Publication of the Step 4 reports represented the end of our planned assessment.

Methodology

Scope

The objective of the Step 4 assessment was to review the safety aspects of the proposed reactor designs in more detail by examining the evidence supporting arguments and claims made in the Requesting Parties' safety documentation, and by building on the assessment already carried out for Step 3, in order to make a judgement on the adequacy of the radiological protection aspects of the safety cases and supporting documentation.

The assessments covered aspects of routine radiological protection associated with the generic design, with the emphasis on assessing whether occupational and public exposures to ionising radiations are as low as reasonably practicable (ALARP). In the UK, ALARP is synonymous with as far as reasonably achievable (ALARA) and with so far as is reasonably practicable (SFAIRP). The assessments principally considered radiological protection matters associated with the normal operation of the reactors, although they also considered exposures to intervention personnel and other persons on site during accident conditions. The exposure of persons off site during accidents was considered in the Level 3 Probabilistic Safety Analysis (PSA) assessments for the designs [6,7].

Both assessments covered the same topics which were defined at the commencement of Step 4. These are detailed in Table 1:

Assessment areas relevant to normal operation
• Radiation sources. • Designated areas (radiological classification of areas / radiological zoning). • Shielding. • Contaminated Areas. • Ventilation. • Radiological instrumentation. • Decontamination. • Optimisation for work activities (including fuel route). • Waste handling and decommissioning. • Public exposure from direct shine (direct radiation originating from within the site boundary).
Assessment areas relevant to accident conditions
• Criticality control in the spent fuel pool. • Persons on-site. • Intervention personnel.

Table 1. Step 4 Assessment Topics.

Approach

The criteria used to determine the adequacy of the Requesting Parties' safety cases were obtained from relevant UK legislation and both national and international standards. The principal piece of legislation used for the assessments was the Ionising Radiations Regulations 1999 [8]. In addition the HSE's Safety Assessment Principles (SAPs) [9] and a range of Technical Assessment Guides (TAGs) describe ONR's expectations with regard to safety cases and include specific guidance relevant to radiological protection. One of the foremost principles described in legislation and standards that was used as the basis for ONR's assessments was the hierarchy of control measures. ONR's expectation was that, first and foremost, in any work with ionising radiation, the Requesting Parties should demonstrate that their facilities utilise engineered means to control doses received by workers and other persons. Only after these had been applied could consideration be given to the use of supporting systems of work and administrative controls.

ONR acknowledged that there are matters relevant to radiological protection that could not be adequately assessed during GDA, as they are directly related to the operating regimes selected by future licensees. As a result, the assessment was primarily focused on the radiological risks associated with physical design features associated with the reactor designs, rather than the specific working practices, because these practices will be subject to change based on licensee operating preferences. However, both Requesting Parties submitted examples of specific working practices for some tasks to demonstrate that the magnitude of doses incurred by personnel align with relevant legislation and standards and are ALARP. These examples also supported the demonstration of the effectiveness of design features, which had been incorporated within the designs in order to restrict exposure to ionising radiations.

There was a significant quantity of safety documentation provided by the Requesting Parties and, as a result, it would not have been possible or necessary to assess the safety case in its entirety. ONR utilised a sampling approach to limit the areas scrutinised [9]. The majority of samples were drawn from areas of high safety relevance since weaknesses in these areas are potentially very serious, but a few were also taken from lower significance areas to identify topics of possible omission by the Requesting Parties.

ONR's radiological protection assessors liaised with experts within its own organisation, in addition to experts from other organisations. Regular interactions took place with:

- ONR assessors working in other assessment areas. The main areas that closely impacted on the assessments included Reactor Chemistry, Fault Studies, PSA, Mechanical Engineering, Radioactive Waste and Decommissioning, Control and Instrumentation, and Civil Engineering.
- Inspectors undertaking assessments on behalf of the Environment Agency. The radiological protection assessors regularly attended joint meetings with the Agency on topics associated with radioactive waste and decommissioning.
- Non-UK regulators. Radiological protection assessors held meetings with regulators from other countries that had been, or were in the process of, performing their own assessments of the reactor designs.

In addition, ONR also engaged Technical Support Contractors (TSCs) in order to provide additional resource or specialist technical support for specific tasks, which included radiological shielding and criticality control of fuel in the spent fuel pool (SFP). Whilst the TSCs undertook detailed literature and technical reviews, these reviews were under close direction and supervision by ONR and the regulatory judgments on the adequacy, or otherwise, of the radiological protection aspects of the designs were made exclusively by ONR.

Regular meetings were held with the Requesting Parties, both in the UK and abroad. From a radiological protection perspective both Requesting Parties worked effectively with ONR and were generally forthcoming with information when requested. The majority of supporting evidence for the assessment was provided as a result of raising Technical Queries (TQs). When a potential matter of concern was identified, a Regulatory Observation (RO) was raised with associated actions which ONR required the Requesting Parties to address within an agreed timescale. Where matters were of such significant concern that they would prevent ONR from issuing a Design Acceptance Confirmation (DAC) at the end of GDA, ONR could raise a Regulatory Issue. However, no Regulatory Issues were raised in the radiological protection assessment area during Step 4.

When the assessment reports were being drafted in early 2011, any ongoing matters of concern were captured using two mechanisms. The first, Assessment Findings, were matters where the lack of detailed information limited the extent of ONR's assessment. These will require further analysis by future licensees during the site specific phase as the additional details become available as the design progresses. The second mechanism, GDA Issues, were matters of particular significance and will require resolution before ONR would agree to the commencement of nuclear island safety related construction of the reactor design in the UK. ONR's GDA Issues and the Requesting Parties' Resolution Plans were published on ONR's website in July 2011 and the GDA Issues and Assessment Findings were also summarised in Appendices of the Step 4 technical reports. ONR communicated and agreed all Assessment Findings and GDA Issues with the Requesting Parties before the reports were issued in order to allow them to prepare for their resolution.

Results of Assessment

Key aspects of ONR's radiological protection assessment of the two reactor designs are summarised below.

AP1000®
ONR was broadly satisfied with the claims, arguments and evidence laid down within Westinghouse's safety case and supporting documentation for radiological protection. ONR considered that from a radiological protection view point, the AP1000® design is suitable for construction in the UK. However, this conclusion is subject to satisfactory progression and resolution of a GDA Issue, which is discussed later.

Normal Operation – Radiation Sources:
The management of radiation sources associated with the operation of a nuclear reactor is a fundamental aspect of radiological protection at nuclear power stations. Since it is not normally practicable to eliminate certain sources of ionising radiation, the emphasis must be on reducing the magnitude of the radiation sources in order to reduce radiation levels and correspondingly minimise the exposure of personnel and the public to ionising radiation. Many measures, which can be taken to reduce radioactive sources associated with an AP1000® reactor, are related to the operating regime which is selected for the plant and so depend on the decisions taken by future licensees. However, there are aspects that are related to the physical design itself and these were the subject of ONR's assessment.

ONR's assessment focussed on Westinghouse's arrangements for deriving and managing radiation source term data for the AP1000® plant, and evidence of efforts to reduce the source term SFAIRP. ONR considered that the methods used to derive radiation source terms (such as specialist computer codes) was appropriate and that source terms had been consistently applied across assessment areas. With regard to reducing source terms, Westinghouse provided evidence of its strategy to minimise these source terms as part of the generic design and ONR was broadly satisfied with the measures which it outlined. However, in order to

reduce potential operator exposures, the radiological protection assessment concluded that there may be scope for further reductions in the source term at the procurement stage. An assessment finding was raised on this matter that requires a future licensee to demonstrate that the content of cobalt and other elements within primary circuit materials which may become activated and contribute significantly to operator radiation exposure has been reduced SFAIRP. The report is expected to take into account improvements that Westinghouse identified, in addition to new materials which may have become available following the GDA process.

Normal Operation – Designated Areas:
Westinghouse created a sufficiently detailed radiological profile of the facility, identifying and applying a radiological zoning scheme to the AP1000® design and then assessed whether the external radiation criteria were met. It expended significant effort in quantifying the external radiation hazard associated with the AP1000® and, as a result, provided confidence that Westinghouse understands the hazards associated with the AP1000® design.

Although calculated using conservative assumptions, there were areas within the containment where dose rates were predicted to be extremely high. These have generally been identified by Westinghouse and recommendations have been put forward to decrease the dose rates further, by reducing the source term or incorporating localised shielding. Although these dose rates were of concern, the improvements that were highlighted were associated with the detailed design and the procurement of components rather than being symptomatic of flaws with the bulk shielding design. As a result, these matters were captured as assessment findings rather than GDA Issues.

In addition to the related Assessment Finding on source terms, two additional Assessment Findings were raised on this topic:

- Due to concerns over the magnitude of dose rates associated with certain areas of the Containment whilst at power, an Assessment Finding was raised requiring a future licensee to identify, and provide a justification for all reasonably foreseeable work activities that are likely to require entry to the Containment whilst at power.
- In some cases, it was difficult to relate the radiation zoning of each area to the type of work activities which would be undertaken in that area and so it was not clear whether all reasonably practicable measures had been incorporated into the design in order to minimise external radiation levels. Consequently, the associated Assessment Finding required a future licensee to provide a report that identifies external dose rates for all controlled areas during normal operation, taking into account any changes to the radiation source term and shielding design which have been made since GDA. In addition, the licensee will be expected to submit an ALARP justification for areas to which access is required and where the dose rate exceeds 150 micro-sieverts per hour (during normal operation) to demonstrate that dose rates have been reduced SFAIRP.

It should be noted that the concerns over enhanced dose rates within containment are related to the minimisation of worker doses alone; the shielding associated with the civil structure of the Containment ensures that the external radiation risk to the public from these sources under normal operations would be negligible.

Westinghouse outlined a scheme for zoning for airborne and surface contamination which had been primarily used for ventilation design, rather than operational radiological protection programmes. It also provided some indication of the potential contamination profile of the facility during outages.

ONR was satisfied that Westinghouse had identified and quantified the radiological hazards associated with its plant and had identified areas for improvement in order to restrict workers

doses SFAIRP, including reducing the source term or incorporating localised shielding. ONR understands that a future licensee is likely to adopt its own scheme for area designation, but from the perspective of assessing the generic design of the AP1000®, Westinghouse's zoning scheme was adequate and had been appropriately applied.

Normal Operation – Shielding:
The utilisation of effective shielding is a key control measure for restricting the exposure of personnel and the public. It is a passive engineering measure and so is at the top of the hierarchy of control measures. As a result, ONR considered shielding design to be a principal aspect of its assessment.

The shielding assessment was undertaken to assess the AP1000® shielding provisions identified in the submission, to review the arguments presented in the safety case, and to assess whether the evidence presented substantiated those arguments for shielding. The objectives of the shielding assessment were as follows:

- To be satisfied that the AP1000® shielding design fulfilled the requirements outlined in the SAPs and TAGs.
- To be satisfied that relevant good practice had been applied to the shielding provisions to help to demonstrate that external dose rates and dose accrual by workers and members of the public were ALARP.

Westinghouses's submission demonstrated that the shielding design was being developed through a logical and iterative design process using acceptable methods, shielding codes and adequately conservative assumptions. The documentation demonstrated that the shielding was generally adequate to reduce dose rates to within the classification of areas criteria. Where this was not the case, Westinghouse provided reasonable responses either justifying the breach of criteria or recommending further analysis. As a result, ONR identified no reason why the shielding design of the AP1000® would not be capable of reducing external dose rates SFAIRP.

Normal Operation – Optimisation for Work Activities:
In addition to assessing Westinghouse's general strategy for reducing worker doses SFAIRP, ONR sampled several specific work activities in order identify whether all reasonably practicable measures had been adopted to restrict exposures. These included:

- Refuelling
- Steam Generator inspections and maintenance
- Maintaining the Chemical and Volume Control System
- Inspection and maintenance of Automatic Depressurisation System (ADS) valves
- Radioactive Waste Processing
- SFP

The collective annual dose which was presented for the AP1000® (239 person-mSv) was in the order of that reported by the best-performing PWRs which are currently operating throughout the world, including the 'Konvoi' reactors which ONR considered to represent relevant good practice with regard to worker doses [10].

ONR considered that Westinghouse had applied the hierarchy of control measures, incorporating engineering controls and other safety features which had been derived from operational experience and could be expected to successfully reduce worker doses. In particular, Westinghouse had demonstrated that features that facilitate the use of robotic and remote technologies had been incorporated into the design. Furthermore, there was evidence that design improvements have been targeted at activities which have the highest worker doses, such as engineering controls which enable exposure times associated with refuelling to be decreased.

ONR considered, based on the evidence presented, that Westinghouse had reduced the exposure of workers at an AP1000® reactor SFAIRP. Nevertheless, there are some areas for improvement and Westinghouse has generally been forthcoming at identifying these during its own dose assessments. Those considered to be significant were captured as Assessment Findings.

One topic of particular interest in this assessment area was the design of health physics and solid radioactive waste facilities, primarily because ONR considered that insufficient space had been allocated to them and this could challenge the radiological safety of personnel working within them. This was considered to be a significant matter, and Westinghouse outlined a potential strategy for multi-unit sites which involved using centralised facilities for health physics and solid radioactive waste management activities. Since these facilities can be located outside the nuclear island, ONR considered that it should be possible for them to be constructed without the physical restrictions on space that are apparent in the submission. Consequently, this matter could be addressed during the site specific phase, and therefore was captured as an Assessment Finding.

Normal Operation – Contaminated Areas:
Westinghouse's submission outlined sources of potential internal radiation hazard and described the control measures that could be adopted to prevent the spread of contamination. ONR considered that Westinghouse had demonstrated that it had incorporated engineering controls into the AP1000® design which will minimise the generation of contamination and also the potential for it spreading. It also identified measures further down the hierarchy of contamination control measures which could be utilised by future licensees. However, Westinghouse has not provided sufficient information in order to provide assurance that 'defence in depth' for contamination control has been applied throughout the AP1000® design. As a result, ONR judged that a human factors assessment of Westinghouse's arrangements should be used to substantiate its effectiveness. Administrative controls will contribute to any contamination control arrangements, and it is acknowledged that these be determined by the licensee at the site specific phase. Consequently, this matter was captured as an Assessment Finding.

Normal Operation – Public Exposure:
The assessment of public exposure to ionising radiation included the following matters:

- Liaison with the Environment Agency on optimisation of doses to the public from direct radiation originating within the site boundary (ONR has the lead).
- Liaison with the Environment Agency on optimisation of doses to the public from authorised discharges (the Environment Agency has the lead).

The total annual predicted dose to a member of the public from direct radiation and representative discharges was below 20 micro-sieverts [3], and so ONR considered that Westinghouse had demonstrated that public exposure from direct radiation under normal conditions had been reduced SFAIRP.

Accident Conditions – Persons On-Site:
This assessment topic covered the adequacy of measures included in the AP1000® design that are intended to restrict the exposure of persons on-site to ionising radiation. Several Assessment Findings were raised in this topic area associated with developing the safety case to take into account a future licensee's specific arrangements for responding to accidents. However, the majority of regulatory effort in this topic area was associated with a matter that ONR considered to be of significant concern: the control of criticality in the SFP.

Westinghouse's submission utilised burnup credit as a control for placing irradiated fuel in the SFP. This approach involves taking credit for the irradiation history of spent fuel, so that

it is considered to be less reactive than un-irradiated fuel in order to maximise the number of fuel assemblies accommodated in a given space, while minimising the risk of a criticality excursion and ensuring adequate cooling. While the application of burnup credit appears to be an established practice in the USA, there has not historically been the same pressure on storage facility capacity in the UK to take credit for burnup and so the approach has therefore not developed to the same extent. Modelling of burnup can be complex, making burnup credit arguments quite complicated in criticality safety cases and lending weight to the UK practice of simply regarding burnup as an additional, unquantified safety factor. As a result, ONR indicated to Westinghouse that the approach was unlikely to be acceptable for GDA because:

- Burnup credit methodology has not to date been employed in the UK;
- Only limited experimental validation work was apparently available to Westinghouse's designers to support the burnup credit analysis;
- There was a high degree of reliance on administrative/software control to prevent the misplacing of fuel assemblies.

As a result, ONR raised a RO on the matter, and Westinghouse's response indicated that their preferred option was to utilise an arrangement where one out of every four spent fuel storage locations was blocked out. This approach did not explicitly rely on burnup credit, but placed reliance on the presence of soluble boron in the SFP in order to ensure sub-criticality under non-accident conditions. ONR concluded that a new design should not have to rely on soluble poisons to ensure sub-criticality, but rather that it should be possible to control criticality through geometrical and fixed poisons alone, which ONR considers to be relevant good practice.

After several interactions with Westinghouse it became apparent that it would not be possible to resolve the matter before the Step 4 assessment report was finalised. As a result, the matter became a GDA Issue that required Westinghouse to provide a safety case, with supporting evidence, which demonstrates that criticality control of the SFP is assured for all foreseeable operating conditions through geometrical control and fixed poisons alone. After several meetings between ONR and Westinghouse, the Requesting Party has submitted a Resolution Plan for the GDA Issue (published in July 2011).

<u>UK EPR™</u>

ONR was broadly satisfied with the claims, arguments and evidence laid down within EDF and AREVA's safety case and supporting documentation for radiological protection. ONR considered that from a radiological protection view point, the UK EPR™ design is suitable for construction in the UK. However, this conclusion is subject to satisfactory progression and resolution of a GDA Issue, which are discussed later.

Normal Operation – Radiation Sources:
ONR and the Environment Agency considered that the information supplied by EDF and AREVA satisfied the regulatory expectations regarding derivation of the source term, identification of assessments where the source term was used, use of the source term consistently across assessment areas, and use of the source term in specific assessment areas. ONR also considered the information regarding reductions in the levels of cobalt, silver and antimony from the source term in the UK EPR™, and concluded that the reductions incorporated in the design compared with previous plants appeared ALARP and therefore further reductions of these elements from materials associated with the primary coolant were not necessary. Nevertheless, the restriction of exposure through material selection is partly dependent on procurement procedures. In addition, new materials may be developed before a UK EPR™ is constructed, in which case it would be appropriate for a further review of

materials to be undertaken before future procurement. ONR captured this requirement in an Assessment Finding.

Normal Operation – Designated Areas and Shielding:
Typically within the UK, the initial dose rate criteria for all rooms of a facility are outlined in a designation of areas (often referred to as a radiological classification of areas) document. Shielding assessments are then carried out to ensure that the shielding provisions reduce dose rates in the room to within the criteria outlined in the designation of areas. Where initial dose rate predictions do not meet the criteria, shielding provisions may be revised to further reduce dose rates to within the criteria. Alternatively in cases where changes to the shielding are not practicable, the radiation zoning classification may be increased to reflect the potential for high dose rates, along with further restrictions on occupancy applied to ensure dose accrual remains acceptable. Shielding summary documents are usually produced to confirm that conservative dose rate predictions meet the radiological zoning criteria for each room of the facility. This should also include reference to the detailed shielding assessment from which the results have been extracted.

Given the above methodology, the GDA assessment had initially intended to perform a high level review of shielding provisions and dose rate profile across the nuclear island for all modes of operation. ONR requested documentation outlining the current radiological zoning for the UK EPR™, along with a shielding summary showing that the theoretical dose rates calculated in shielding assessments met the radiological zoning criteria. Since Flamanville-3 (FA-3) was the reference design for the UK EPR™, the information from this site would have sufficed.

EDF and AREVA were unable to provide this information / documentation for the FA-3 EPR or UK EPR™ within the timescale of Step 4 of the GDA assessment because it took a period of time for ONR and EDF and AREVA to come to a common understanding on the evidence required. In the absence of a reference radiological zoning scheme and any shielding summary documentation for the UK EPR™, ONR's assessment was unable to determine whether the general shielding design and dose rate profile throughout the UK EPR™ were acceptable when compared to UK design guidance and practices.

Radiological zoning for restriction of exposure to ionising radiation of workers is fundamental to the basic design of the nuclear island of the UK EPR™. In addition, bulk shielding is inextricably linked with civil engineering aspects of the UK EPR™ design, and bulk shielding assessments need to be completed before nuclear island construction commences. Therefore, in ONR's opinion, suitable and sufficient detailed work should be completed within GDA to demonstrate that the bulk shielding provided by nuclear island construction concrete is adequate.

The associated GDA Issue Action required EDF and AREVA to provide an overview document that supplements the claims and arguments presented in the safety submission with additional information on the radiological zoning classification scheme for the nuclear island, including dose rate criteria and predictions for all modes of plant operation, for occupied areas.

Although the radiological zoning and shielding summary data were not available for assessment during GDA, ONR considered that the documentation that was provided outlined good shielding practices and an appropriate scheme for designating areas with regard to radiological hazard from external radiation. The design basis data, calculation methods and computational codes used were adequate and were applied conservatively, which gave confidence that shielding provisions and predicted dose rates would also be conservative with regard to dose uptake from external radiation. The samples of EDF and AREVA's shielding

assessments demonstrated how it had consistently used good shielding practices and appropriate calculation methods in the design and optimisation of shielding provisions.

The evidence provided confidence that shielding assessments for the UK EPR™ have been conducted using recognised shielding practices in a conservative manner comparable to methods typically used in the UK.

Normal Operations – Contaminated Areas:
ONR's assessment considered sources and minimisation of surface and airborne contamination, application of the hierarchy of control measures to contamination control, and monitoring of workplaces and people. ONR assessed examples of contamination control and concluded that the hot maintenance workshop was suitably located and had sufficient space for temporary workshops, and the air transfer system was an effective and dose-saving way of transporting samples around the plant.

ONR also considered that it was not clear how rooms and equipment were linked together to form a logical path for entering and exiting the controlled area in order to minimise the spread of contamination. In light of the responsibility of future licensees for health physics facilities and arrangements to ensure that they are suitable and sufficient for controlling exposures of workers and for minimising the spread of contamination, ONR raised an Assessment Finding on access to controlled areas and health physics facilities. This required a report to demonstrate that the layout of health physics facilities for entering and exiting the controlled area are suitable and sufficient to minimise the spread of contamination, including the ability of the facilities to accommodate additional workloads, for example, for intervention personnel during accident conditions.

Normal Operation – Optimisation for Work Activities:
From the evidence provided, ONR considered that the calculated average annual collective dose of 345person-mSv for the UK EPR™ is consistent with the operational average annual collective dose of advanced PWRs. Experience shows that calculated doses are almost always conservative when compared with operational doses. In this case, the calculated average annual collective dose for the UK EPR™ was within the range of the operational average dose for operational advanced PWRs between 1997 and 2007 [10]. Although this was at the upper end of the range, this was not entirely unexpected since the collective dose for the UK EPR™ was a planning estimate, whereas the collective doses for the operational advanced PWRs were from operational data which are almost always lower than the preceding calculated doses. Therefore, ONR concluded that the calculated average annual collective dose of 345person-mSv is acceptable, and the future operational average annual collective dose of the UK EPR™ is expected to be lower than this value.

EDF and AREVA's approach to optimisation to work optimisation was to identify the collective dose from the best-performing French nuclear power plants (NPPs), identify work activities that together were responsible for 50% of that collective dose, and optimise those doses to predict dose estimates. ONR considered this systematic approach to be appropriate, and sampled two of the tasks from the list of seven high dose work activities that represented 50% of the total collective dose: Steam Generator (SG) inspections and maintenance, and fitting and removing insulation.

ONR considered that the dose estimates for these work tasks was acceptable. The final dose estimate for SG inspections and maintenance was based on conservative calculations, but future operational doses for such work activities are expected to be lower. Three Assessment Findings were raised following the assessment of these samples. The first concerned the use of robotics for SG inspections and maintenance. EDF and AREVA had assumed that no robotics would be used but had demonstrated that there were opportunities for dose reductions by using robotics for such activities as SG tube plugging and testing and non-destructive

testing. Therefore, ONR raised an Assessment Finding that requires a future licensee to provide an ALARP justification for the use (or not) of robotics in SG maintenance and testing based on optimisation studies. The second and third Assessment Findings concerned fitting and removing insulation, which require a future licensee to provide an ALARP justification for fitting and removing insulations in cramped areas, and also for fitting and removing insulation where partial insulation removal is required for inspection and maintenance.

In addition to the two work task samples described above, ONR also assessed the Requesting Parties submission regarding waste handling and decommissioning. ONR concluded that the approach taken by EDF and AREVA to radioactive waste handling, including during decommissioning, was suitable and sufficient in that the Requesting Party had undertaken a thorough review of waste handling to try to identify improvements that might result in dose savings. These improvements resulted in reductions in exposure times, ambient dose rates and source terms, all of which yielded dose savings. There was no reason to suppose that the estimated annual collective dose saving of 25% (compared with the current French fleet of nuclear power stations) would not be achieved.

Normal Operation - Public Exposure:
The total predicted dose to a member of the public from representative discharges and direct radiation was below 30 micro-sieverts per year, with the contribution from direct shine being less than 5 micro-sieverts per year. ONR accepted this dose as being very low and considered that the bulk shielding arrangements for the UK EPR™ design is adequate for protecting the public from direct radiation.

Accident Conditions – Persons On-Site:
ONR assessed the Requesting Party's submission with regard to criticality accidents. The design of the UK EPR™ SFP maintains sub-criticality of spent fuel by geometrical controls and fixed poisons alone. ONR concluded that the claims, arguments and evidence laid down within the safety submissions for criticality safety were adequate. ONR identified three Assessment Findings: assuring the presence of borated stainless steel in SFP storage racks at the construction stage in accordance with design intent; monitoring the potential degradation of borated stainless steel in the SFP during the plant's lifetime; and controlling and verifying the enrichment and continued presence of boron in the SFP.

The scope of ONR's assessment of other accident conditions included impacts on-site of accidents, escape routes and plant accessibility, and the protection of persons on-site and intervention personnel. Potential doses to workers on the site during accidents were not analysed in detail by EDF and AREVA, and this was not unreasonable at this stage. ONR identified an Assessment Finding to develop the safety case to demonstrate that the on site-specific radiological consequences analyses for accidents (including hazards) take account of UK methodology assumptions and take into account a future licensee's specific arrangements for responding to accidents.

The placement of escape routes through low radiation zoned areas was appropriate. Dose rates in the Main Control Room would not be insignificant immediately post accident if the ventilation system failed, and so ONR identified an Assessment Finding to provide an ALARP justification for occupancy of the Main Control Room immediately post accident if the ventilation system has failed.

Although accessing valves for closure (in locations with higher radiation zoned areas) via low radiation zoned areas was appropriate in terms of dose management, further analysis was necessary regarding access requirements for other components and equipment. Consequently, ONR identified an Assessment Finding to provide a safety case to identify access requirements to specific components and pieces of equipment that will require maintenance or

repair during the post-accident phase, and identifying potential doses to workers carrying out those maintenance / repair activities and demonstrating that they are ALARP.

Conclusions

ONR made the following conclusions following the radiological protection assessment of the UK EPR™ and AP1000® reactor designs:

- The plants and their operations have been designed to ensure that engineered features would restrict ionising radiation exposures to workers SFAIRP during normal operation.
- The plants and their operations have been designed to ensure that engineered features would restrict ionising radiation exposures to workers SFAIRP during accident conditions.
- The approach to optimising radiation exposures of workers when carrying out high-dose work activities is adequate.
- Predicted doses to members of the public are very low.

There are two GDA Issues: the substantiation of bulk shielding and the radiological zoning scheme for the EPR design; and criticality control of the spent fuel pool for the AP1000® design. These will require resolution before ONR would agree to the commencement of nuclear island safety related construction of either reactor design in the UK.

References

1. *Nuclear power station generic design assessment – guidance to requesting parties.* Version 3, HSE, August 2008
2. *Step 3 Radiological Protection Assessment of the EDF and AREVA UK EPR™.* HSE-ND Assessment Report AR 09/030. November 2009.
3. *Step 3 Radiological and Level 3 PSA Assessment of the Westinghouse AP1000®.* HSE-ND Assessment Report AR 09/020, November 2009.
4. *Step 4 Radiological Protection Assessment of the EDF and AREVA UK EPR™ Reactor.* ONR Assessment Report ONR-GDA-AR-11-025, November 2011.
5. *Step 4 Radiological Protection Assessment of the Westinghouse AP1000® Reactor.* ONR Assessment Report ONR-GDA-AR-11-009, November 2011.
6. *Step 4 Probabilistic Safety Analysis Assessment of the EDF and AREVA UK EPR™ Reactor*. ONR Assessment Report ONR-GDA-AR-11-019 Revision 0.
7. *Step 4 Probabilistic Safety Analysis Assessment of the Westinghouse AP1000® Reactor*. ONR Assessment Report ONR-GDA-AR-11-003, Revision 0.
8. *Ionising Radiations Regulations 1999*. Statutory Instrument No. 3232. 1999.
9. *Safety Assessment Principles for Nuclear Facilities.* 2006 Edition Revision 1. HSE. January 2008. www.hse.gov.uk/nuclear/saps/saps2006.pdf
10. *Occupational Radiological Protection Principles and Criteria for designing New Nuclear Power Plants.* NEA No. 6975. Nuclear Energy Agency: Organisation for Economic Co-operation and Development. 2010.