Environment Agency

Generic design assessment

AP1000® nuclear power plant design by Westinghouse Electric Company LLC

Final assessment report

Best available techniques to prevent or minimise creation of radioactive wastes

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Environment Agency
Horizon house, Deanery Road
Bristol BS1 5AH
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

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Protective status	This document contains no sensitive nuclear information or commercially confidential information.
Process and Information Document[1]	The following sections of Table 1 in our Process and Information document are relevant to this assessment: 1.2 General information relating to the facility 1.5 An analysis should be provided that includes an evaluation of options considered and shows that the Best Available Techniques will be used to minimise the production and discharge or disposal of waste. 2.1 A description of how radioactive wastes will arise, be managed and disposed of throughout the facility's lifecycle.
Radioactive Substances Regulation Environmental Principles[2]	The following principles are relevant to this assessment: Principle RSMDP3 – Use of BAT to minimise waste: Principle RSMDP4 – Processes for Identifying BAT:. Principle RSMDP7 – BAT to Minimise Environmental Risk and Impact: Principle RSMDP8 – Segregation of Wastes: Principle RSMDP9 – Characterisation.
Report author	Original report – Tooley, E. J. Revision to Final report – Green, R.

1. Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs, Environment Agency, Jan 2007.

   http://publications.environment-agency.gov.uk/pdf/GEHO0107BLTN-e-e.pdf

2. Regulatory Guidance Series, No RSR 1: Radioactive Substances Regulation - Environmental Principles (REPs), 2010.

   http://publications.environment-agency.gov.uk/pdf/GEHO0709BQSB-e-e.pdf

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Summary

1 This report presents the findings of our assessment of whether the best available techniques to prevent or minimise the creation of radioactive waste are used by the AP1000®, based on information submitted by Westinghouse in their Environment Report (ER) and supporting documents.

2 We concluded that overall the AP1000 nuclear power plant utilises the best available techniques (BAT) to prevent and minimise production of gaseous and aqueous radioactive waste during routine operations and maintenance and from anticipated operational events.

3 This report also covers the containment of radioactive liquids within the AP1000. We concluded that the AP1000 uses BAT to contain liquids and prevent contamination of groundwater in normal operation. The techniques used should also minimise contamination under fault conditions.

4 As part of our assessment we identified the following assessment findings:

a) Future operators shall, at the detailed design phase, provide a BAT assessment to demonstrate whether boron recycling represents BAT for their location. (AP1000-AF02)

b) Future operators shall, before the commissioning phase, provide their proposals for how they intend to implement zinc injection. The proposals shall be supported by an assessment of the impact of zinc injection on waste and crud composition. (AP1000-AF03)

c) Future operators shall, before the construction phase, provide a BAT assessment to demonstrate that the design and capacity of secondary containment proposed for the monitor tanks is adequate for their location. (AP1000-AF04)

5 Our findings on the wider environmental impacts and waste management arrangements for the AP1000 reactor may be found in our Decision Document (Environment Agency, 2011a).

1 Introduction

6 We originally published this report in June 2010 to support our GDA consultation on the AP1000 design. The consultation was on our preliminary conclusions. It began on 28 June 2010 and closed on 18 October 2010. (Consultation Document: Environment Agency, 2010a)

7 We received additional information from Westinghouse after June 2010 and also undertook additional assessment in response to consultation responses. This report is an update of our original report covering assessment undertaken between June 2010 and the end of March 2011 when Westinghouse published an update of their submission. Where any paragraph has been added or substantially revised it is in a blue font.

8 We do not specifically deal with consultation responses in this report, they are covered in detail in the Decision Document (Environment Agency, 2011a). However, where a response prompted additional assessment by us this is referenced, the key to GDA reference numbers is in Annex 7 of the Decision Document. The conclusions in this report have been made after consideration of all relevant responses to our consultation.

9 We require new nuclear power plant to be designed to use the best available techniques (BAT) to prevent the unnecessary creation of radioactive wastes. Where wastes are created we expect BAT to be used to minimise the generation of those wastes.

10 We set out in our Process and Information Document (P&ID, see Environment Agency, 2007) the requirements for a Requesting Party (RP) to provide information that:

a) shows BAT will be used to minimise the production of waste (reference 1.5); and

b) describes sources of radioactivity and matters which affect wastes arising (reference 2.1).

11 Statutory Guidance (DECC, 2009) to us in 2009 reinforced the requirement to use BAT, paragraph 23:

"*In relation to any designs for new nuclear power stations, the Environment Agency should ensure that BAT is applied so that the design is capable of meeting high environmental standards. This requirement should be applied at an early stage so that the most modern or best available technology can be incorporated into the design of the stations, where this would ensure improved standards. The application of BAT should ensure that radioactive wastes and discharges from any new nuclear power stations in England and Wales are minimised and do not exceed those of comparable stations across the world*."

12 In our Radioactive Substances Regulation Environmental Principles (REPs, see Environment Agency, 2010b), principle RSMDP3 (Use of BAT to minimise waste) refers to this topic:

"*The best available techniques should be used to ensure that production of radioactive waste is prevented and where that is not practicable minimised with regard to activity and quantity.*"

13 In particular, a consideration under principle RSMDP3 is relevant:

"*Processes creating radioactive materials should be chosen and optimised so as to prevent and where that is not practicable minimise the production of radioactive waste at source over the complete lifecycle of the facility*."

14 The methodology for identifying BAT is given in principle RSMDP4 and the application of BAT is described in principle RSMDP6. We also published in 2010 our guidance '*RSR: Principles of optimisation in the management and disposal of radioactive waste*' (Environment Agency, 2010d). The guidance initially says:

'BAT are the means an operator uses in the operation of a facility to deliver an optimised outcome, ie to reduce exposures to ALARA' [ALARA: as low as reasonably achievable, economic and social factors being taken into consideration, applied to radiological risks to people].

15 BAT replaces, and is expected to provide the same level of environment protection as, the previously used concepts of best practicable environmental option (BPEO) and best practicable means (BPM). BAT includes an '*economic feasibility*' element. [Clarification prompted by comments of several respondents to our consultation]

16 We keep BAT under consideration and review permits regularly to see if improvements are needed to reflect developments and improvements, for example in plant, techniques or operator practice. Our permits include conditions requiring the use of BAT and BAT requires that operators continually assess whether more can be done to reduce discharges. [Clarification prompted by comments of several respondents to our consultation]

17 This assessment considers the design of AP1000 with respect to the creation of radioactive material which may become waste, the foreseeable levels of radioactivity in radioactive waste and techniques that have been included in the design to minimise the creation of radioactive waste. The assessment considers the information provided by Westinghouse Electric Company LLC (Westinghouse, WEC) for its AP1000 design and the assessment aims to establish whether the design fulfils the requirements of UK Statute, policy and guidance on radioactive waste. The assessment also identifies key issues that should be taken forward into any discharge permit that may be issued in the form of relevant limitations and conditions along with any areas where insufficient information has been provided in GDA which results in an assessment finding being set out at this stage of our considerations.

18 This assessment does not cover radioactive waste arising from decommissioning at the end of the reactor lifecycle.

2 Assessment

19 This assessment considers the sources of radioactive materials in the AP 1000 that will eventually become waste and the techniques employed to minimise their creation. We expect new nuclear power plants to be designed to use BAT to prevent the unnecessary creation of radioactive wastes. Where wastes are created we expect BAT to be used to minimise the generation of those wastes. (Statutory Guidance (DECC, 2009) and our REPS (Environment Agency 2010b, see, RSMDP3)).

20 The assessment has also considered the AP1000 design in the light of UK Statute, policy and guidance.

21 The key legislative areas that have been taken into account are:

a) Environmental Permitting Regulations 2010 (EPR 10) which is aimed at the control of radioactive substances (including waste).

b) Statutory guidance to the Environment Agency concerning the Regulation of Radioactive Discharges into the Environment (DECC, 2009) which sets out the principles that:

  i) regulatory justification of practices by the Government;

  ii) optimisation of protection on the basis that radiological doses and risks to workers and members of the public from a source of exposure should be kept as low as reasonably achievable (the ALARA principle);

  iii) application of limits and conditions to control discharges from justified activities;

  iv) sustainable development;

  v) the use of Best Available Techniques (BAT);

  vi) the precautionary principle;

  vii) the polluter pays principle;

  viii) the preferred use of 'concentrate and contain' in the management of radioactive waste over 'dilute and disperse' in cases where there would be a definite benefit in reducing environmental pollution, provided that BAT is being applied and worker dose is taken into account.

c) Cm 2919 Review of radioactive waste management policy which sets out the principles that:

  i) radioactive waste is not created for which there are no current or foreseeable techniques for management;

  ii) that radioactive waste is not unnecessarily created;

  iii) that such wastes as are created are safely and appropriately managed and treated; and

  iv) that those wastes are safely disposed of at appropriate times and in appropriate ways.

22 Bearing in mind the legislative framework and the REPs, this assessment aims to establish the acceptability of the AP1000 design with respect to creation of radioactive waste.

23 Westinghouse provided its submission to GDA in August 2007. We carried out our initial assessment and concluded we needed additional information. We raised a Regulatory Issue on Westinghouse in February 2008 setting out the further information that we needed. In particular we believed P&ID reference 1.5 had not been addressed by the submission and required "*a formal BAT assessment for each significant waste stream*".

24 Westinghouse completely revised its submission during 2008 and provided an updated Environment Report with supporting documents.

25 We assessed information contained in the Environment Report but found that while much improved from the original submission it still lacked the detail we require to demonstrate BAT is used. We raised a Regulatory Observation (RO), RO-AP1000-034 on Westinghouse in June 2009 that had actions to provide:

a) a comprehensive Integrated Waste Strategy;

b) a demonstration that BAT will be used to prevent or minimise the creation and disposal of wastes

c) a demonstration that a Radioactive Waste Management Case can be developed to show the long term safety and environmental performance of the management of higher activity waste from their generation to their conditioning into the form in which they will be suitable for storage and eventual disposal.

26 We raised 43 Technical Queries (TQs) on Westinghouse during our assessment. One was relevant to this report.

a) TQ-AP1000-145 – Reactor coolant – zinc injection. 1 June 2009.

27 We also liaised with the Office for Nuclear Regulation[1] (ONR) on matters of joint interest and used their Step 3 and Step 4 reports to inform our assessment.

28 Westinghouse responded to all the ROs and TQs. They reviewed and updated the Environment Report in March-April 2010 to include all the relevant information provided by the ROs and TQs. This version of the ER was referenced by our Consultation Document and publically available on the AP1000 website.

29 Additional information on some topics was submitted by Westinghouse after March 2010. Westinghouse reviewed and updated the ER to include all submitted information in March 2011. This report only uses and refers to the information contained in the updated Environment Report (UKP-GW-GL-790 (Rev 4))(ER) and its supporting documents in particular the AP1000 BAT Assessment (UKP-GW-GL-026 (Rev 2))(AP1000 BAT), publically available on the AP1000 website (www.ukap1000application.com).

2.1 Assessment methodology

30 The basis of our assessment was to:

a) Consider the submission made by Westinghouse in particular the Environment Report and its supporting documents;

b) hold technical meetings with Westinghouse to clarify our understanding of the information presented and explain any concerns we had with that information;

c) raise Regulatory Observations and Technical Queries where we believed information provided by Westinghouse insufficient;

d) assess the techniques proposed by Westinghouse to prevent or minimise the creation of radioactive waste using our internal guidance and regulatory experience and decide if they represent BAT;

e) liaise with ONR on matters of joint interest;

f) decide on any GDA Issues;

g) identify assessment findings to carry forward from GDA.

[1] The Office for Nuclear Regulation (ONR) was created on 1st April 2011 as an Agency of the Health and Safety Executive (HSE). It was formed from HSE's Nuclear Directorate and has the same role. In this report we therefore generally use the term "ONR", except where we refer back to documents or actions that originated when it was still HSE's Nuclear Directorate.

2.2 Assessment objectives

31 Key areas of the submission made under the GDA arrangements by Westinghouse for the AP1000 design that have been considered are:

a) Are all the sources of aqueous and gaseous radioactive waste identified?

b) Have the significant radionuclides present in waste been identified? These are those which contribute significantly to the amount of activity in waste disposals or to the potential doses to members of the public (see our Considerations document (Environment Agency, 2009 as superseded by Defra, 2010 and Environment Agency 2010c).

c) Have options for preventing and minimising the creation of significant radionuclides that will be present in waste been presented?

d) Do the options chosen for the AP1000 use Best Available Techniques to minimise the creation of radioactive waste?

2.3 Westinghouse documentation

32 We referred to the following documents to produce this report:

Document reference	Title	Version number
UKP-GW-GL-790	UK AP1000 Environment Report	4
UKP-GW-GL-026	AP1000 Nuclear Power Plant BAT Assessment	2
UKP-GW-GL-028	Proposed Annual Limits for Radioactive Discharge	2
EPS-GW-GL-700	AP1000 European Design Control Document	1
APP-WLS-M3C-049	Monthly Radiation Emissions from Radioactive Nuclides - AP1000 Calculation Note	2
APP-WLS-M3C-040	Expected Radioactive Effluents Associated with Advanced Plant Design - AP1000 Calculation Note	0

33 We use short references in this report, for example:

a) ER sub-chapter 6.2 section 1.2.1 = ERsc6.2s1.2.1.

2.4 AP1000 design and sources of radioactivity

34 The origins of radioactive materials within the UK AP1000 are primarily (ERs3):

a) fission products created in the fuel that may pass through the fuel cladding by diffusion or through leaks and enter the coolant;

b) dissolved or suspended corrosion products or other non-radioactive materials in the coolant that can be activated by neutrons as the coolant passes through the reactor core.

35 Westinghouse has provided information in its AP1000 BAT Assessment on the amount of certain radionuclides they would expect to generate during AP1000 operations for the following radionuclides or groups of radionuclides:

a) Tritium

b) Carbon-14

c) Nitrogen-16

d) Strontium-90

e) Iodine-131

f) Caesium-137

g) Plutonium -241

h) Noble gases

i) Other beta emitting particulate radionuclides which are produced by the activation of non-radioactive material. This group includes cobalt-58, cobalt-60, iron-55 and nickel-63.

36 We consider that, in line with our Considerations Document (Environment Agency, 2009 as superseded by Defra, 2010 and Environment Agency 2010c), Westinghouse has identified those radionuclides which either:

a) Contribute significantly to the amount of activity (Bq) in waste disposals;

b) Contribute significantly to potential dose to members of the public;

c) Indicate plant performance, for example where the levels of a radionuclide might increase in the event of a deviation from normal plant operation.

37 For each radionuclide Westinghouse have considered the options for preventing or minimising their creation at source and have scored the options against the following attributes:

a) Proven technology

b) Available technology

c) Effective technology

d) Ease of use

e) Cost

f) Impact in terms of doses to the public

g) Impact in terms of operator dose

h) Environmental impact

i) The ability to generate suitable waste forms

j) Secondary and decommissioning waste

3 BAT options assessment

38 The outcomes of the Westinghouse BAT options assessment are summarised below for each significant radionuclide:

3.1 Tritium

39 Tritium is one of the most abundant radionuclides present in the coolant and contributes significantly to activity in waste disposals. It is created by (AP1000 BAT Form 1):

a) unavoidable ternary fission of the uranium fuel. In ternary fission the uranium nucleus splits into 3 fragments which occurs in around 1 in 400 cases and one such fragment may be tritium which is able to diffuse through the fuel clad and into the coolant in the absence of fuel defects. The tritium formed is initially contained within the fuel cladding but may diffuse into the coolant. The rate of tritium released into the coolant is dependent on reactor power. Westinghouse claim that the zirconium fuel cladding (ZIRLO) used in the AP1000 is more effective at reducing diffusion than other cladding materials. Westinghouse use a 10% in-core tritium release to the coolant as the design basis which results in the production of 63 TBq of tritium per 18 month cycle. Westinghouse use a 2% release of tritium to the coolant as the best estimate of tritium production which results in the production of 13 TBq of tritium per 18 month cycle.

b) activation of the boron which is used as a burnable absorber either in discrete burnable absorber rods or as integral fuel burnable rods. The tritium will be produced within the cladding and may diffuse into the coolant. Westinghouse predict the production of tritium by this route to be 10 TBq per 18 month cycle (design basis) or 2 TBq per 18 month cycle(best estimate).

c) activation of boron-10 which is present as boric acid in the coolant. Boron is used to control the reactivity of the reactor. Westinghouse claim the use of two techniques for minimising production of tritium in the AP1000:

    i) the use of grey rod clusters for load following minimises the amount of coolant boron needed for reactor control and the need for changes to boron concentration (ERs3.2.8);

    ii) the use of burnable poisons (a boride coating or incorporation of gadolinium oxide within some fuel pellets) reduces the amount of boron required.

    Westinghouse predict tritium production by this route to be 27 TBq per 18 month cycle.

d) activation of lithium-6 and lithium-7 present in the lithium hydroxide which is used for chemistry control of the coolant to offset the corrosive effect of boric acid. Westinghouse claim that the use of lithium hydroxide enriched to 99.9% of lithium-7 in the AP1000 minimises production of tritium (lithium-6 produces greater quantities of tritium than lithium-7). Westinghouse predict tritium production by this route to be 6 TBq per 18 month cycle.

e) activation of deuterium in the reactor coolant (deuterium is an isotope of hydrogen which is naturally present in water at 0.015%). We accept that the production of tritium from deuterium is unavoidable and there are no available techniques to minimise its production Westinghouse predict tritium production by this route to be 0.15 TBq per 18 month cycle.

40 The term poison used for nuclear reactors means that a material, such as boron or gadolinium oxide, absorbs neutrons reducing or ‘poisoning’ the rate of nuclear reaction. This is normally undesirable but introducing some poison in a new fuel load reduces its initial reactivity and reduces the need for high levels of boron to control reactivity in the early part of a power cycle. The poison is consumed or ‘burned’ as the

power cycle continues so that it has little effect towards the end of a cycle when fuel reactivity is lower. The poison is completely contained within fuel pins and should not be discharged to the environment to cause any health impact. [Explanation prompted by respondent GDA159]

41 An individual respondent (GDA89) thought the consultation document was unclear on the potential use of enriched boric acid to reduce tritium production. We reviewed information in the ER and revised our assessment as follows:

42 Westinghouse have considered use of boric acid enriched with boron-10 in place of natural boric acid (ERs3.4.4.2). As boron-10 is the effective moderator the quantity of enriched boric acid could be reduced by a factor of three compared to natural boric acid. This would not affect tritium production from boron-10 as the same amount of boron-10 is involved regardless of acid type. However reducing the amount of boric acid would enable addition of lithium hydroxide (that balances the pH) to be reduced with consequent reduction in production of tritium from lithium-7. Westinghouse claim the increased cost of enriched boric acid (200 times cost of natural acid) is unjustified as:

a) the quantity of boron-10 needed in the AP1000 has been reduced by use of grey rods for mechanical reactor control and other methods;

b) only small quantities of lithium hydroxide are needed as it is a strong base and boric acid is a weak acid, also 99.9 percent lithium-7 hydroxide will be used, giving low potential for tritium production.

43 The production of tritium from lithium-7 predicted above was 6 TBq out of a total of 110 TBq for the design basis 18-month cycle. On that basis we conclude that potential for reduction of tritium by use of enriched boron-10 is limited and accept the Westinghouse argument for not using the enriched acid.

44 Westinghouse considered the use of boron recycle to minimise production of tritium in the AP1000 in the BAT options appraisal (AP1000 BAT section 4.3.3.1.2). The AP1000 design does not include boron recycle and any boron present in effluents will be discharged to the sea.

45 Westinghouse claims that boron recycling requires a significant amount of additional equipment and because recycling can only occur in the next fuel cycle, borated water would need to be stored for long periods. The operation, maintenance and storage of borated water is likely to increase occupational radiation exposure and Westinghouse does not consider this to be ALARP.

46 Westinghouse claims that the AP1000 design minimises production of aqueous radioactive waste. In particular, using mechanical rather than chemical controls reduces the quantity of boron needed to control reactivity.

47 Apart from the discharge of radioactivity, there is, to protect the marine environment, an Environmental Quality Standard relating to the concentration of boron in seawater. Westinghouse claims the AP1000 discharge of boron would have a negligible effect on receiving waters. Westinghouse concludes that boron discharge rather than boron recycle is BAT. (ERs3.4.4.3)

48 We accept that in terms of chemical boron discharge there is little benefit to the use of boron recycle. However, a boron recycle system would enable coolant to be recycled and reduce the overall aqueous waste volume entering the Liquid radioactive waste system (WLS). Future operators will need to show how they will treat aqueous wastes that are not compatible with the ion exchange system in the WLS. Evaporation is a technique that will need to be considered. Lower aqueous waste volumes might be a factor in potential use of an evaporator as it would reduce the quantity of evaporator bottoms needing disposal. The reduction in waste volume from use of boron recycle will be a factor to consider in assessment of the use of evaporation required by assessment finding AP1000-AF05 (see our report EAGDAR AP1000-05 where the topic is covered in detail in section 2.5.1 (Environment Agency, 2011c)).

49 We accept the current Westinghouse justification for not using boron recycle. However there are location specific circumstances where boron recycle may have application to reduce volume of discharge and both its radioactive and non-radioactive wastes concentrations. If boron recycle were employed then the case for use of enriched boric acid may change. We have therefore included an assessment finding:

a) Future operators shall, at the detailed design phase, provide a BAT assessment to demonstrate whether boron recycling represents BAT for their location. (AP1000-AF02)

50 Westinghouse have provided information on the predicted source terms for tritium used as a design basis where it is assumed that 10% of the in-core tritium is released to the coolant and best estimates of realistic source terms where it is assumed that 2% of the in-core tritium is released to the coolant.

Source of tritium	**Design basis release to coolant (TBq per 18 month cycle)**	**Best estimate release to coolant (TBq per 18 month cycle)**
Ternary fission in core	62.9	13.098
Burnable absorbers	10.323	2.072
Soluble boron in coolant	27.158	27.158
Soluble lithium in coolant	6.216	6.216
Deuterium in coolant	0.148	0.148
Total	**109.335**	**48.692**

51 Tritium is produced by activation of boron-10, hydrogen-2, lithium-6 and lithium-7:

a) B-10 + n → 2(He-4) + H-3

b) H-2 + n → H-3

c) Li-6 + n_{th} → H-3 + He

d) Li-7 + n → He-4 + H-3 + n

52 Westinghouse estimate the source terms for tritium to be 37,000 Bq g^{-1} in reactor coolant and 37 Bq g^{-1} in steam generator steam.

53 Westinghouse have identified the following options for the prevention or minimisation of tritium in the AP 1000 design (AP1000 BAT Form 1):

a) Use of Lithium-7 hydroxide - The use of lithium-7 hydroxide for pH control rather than lithium-6 reduces the production of tritium since the neutron absorption cross-section of lithium-7 is five orders of magnitude smaller than that of lithium-6.

b) Zirconium cladding - The use of zirconium cladding for fuel can reduce the diffusion of tritium produced in the fuel through the cladding tube wall and thus into the primary coolant.

c) Use of enriched boron - the use of enriched boron (B-10) can reduce the total amount of boron required for chemical shim purposes.

d) Use of gray rods – Gray rods are moveable control rods with which contain a low density neutron absorber to provide reactivity control. The use of grey rods to aid load following can significantly reduce the amount of coolant borne boron needed for reactivity control and subsequent changes in boron concentration.

e) Boron recycling - Boron recycle systems can reduce the amount of boron used and hence the amount tritium discharged to the environment.

54 Westinghouse have scored the options and the use of zirconium cladding and grey rods scored highest, with the use if lithium-7 hydroxide scoring one point lower. The use of enriched boron scored five points lower than the top scoring options with boron recycling scoring lowest. Westinghouse concludes that the following techniques are BAT to minimise tritium production in the AP1000:

a) using lithium-7 rather than lithium-6;

b) using zirconium fuel cladding;

c) using grey rods.

55 Westinghouse predicts the total production of tritium from an AP1000 to be 109.3 TBq per 18 month cycle (design basis) or 48.7 TBq per 18 month cycle (best estimate).

56 Our assessment concluded that Westinghouse has demonstrated that BAT is used to minimise the production of tritium in the AP1000 at this time. Our assessment identified the following assessment finding:

a) Future operators shall, at the detailed design phase, provide a BAT assessment to demonstrate whether boron recycling represents BAT for their location. (AP1000-AF02)

57 The Health Protection Agency (GDA89) recommended that a BAT assessment on boron recycling should consider the production of tritiated methane as well as tritium gas and tritiated water. We accept this and will ensure tritiated methane is covered in any assessment.

3.2 Carbon-14

58 Carbon-14 contributes significantly to both activity disposals and potential dose. It is created by the following mechanisms (AP1000 BAT Form 2):

a) Neutron activation of oxygen-17 (O-17 (n, α) → C-14) which is a naturally occurring stable isotope of oxygen in the coolant. Westinghouse claim they minimise the production of carbon-14 by eliminating free oxygen in the coolant. Westinghouse predict the amount of carbon-14 produced from oxygen-17 to be 552 GBq y^{-1}.

b) Neutron activation of nitrogen-14 (N-14 (n,p) → C-14) dissolved in the coolant. The AP1000 uses lithium hydroxide to control coolant pH as opposed to hydrazine which contains nitrogen and is used in some other designs. Using lithium hydroxide instead of hydrazine reduces the amount of nitrogen in the coolant and the amount of carbon-14 produced by this mechanism. Westinghouse have considered the use of argon as the cover gas for the coolant water supply tanks to minimise the dissolution of nitrogen. This would make the systems more complex and costly and Westinghouse do not consider the use of argon cover gas to be BAT for the AP1000. Assuming 15 ppm of nitrogen in the coolant Westinghouse predict the production of carbon-14 from nitrogen-14 to be 110 GBq y^{-1}.

c) The neutron activation of nitrogen-14 (N-14 (n,p) → C-14) in fuel. Nitrogen-14 in the fuel is minimised during the fabrication process during which the fuel rods are pressurised with helium which expels nitrogen from the fuel.

d) Carbon-14 is produced by the neutron activation of oxygen-17 (O-17 (n, α) → C-14) and nitrogen-14 (N-14 (n,p) → C-14) in stainless steel structural materials, however Westinghouse claim that the carbon-14 produced by these routes will remain in these materials.

59 Westinghouse claim that airborne release of C-14 from PWRs is predominantly hydrocarbons (75 – 95%), mainly methane, with only a small fraction in the form of CO_2.

60 Based on a nitrogen concentration of 15ppm in the primary coolant Westinghouse estimate the total rate of production of carbon-14 in the AP1000 to be:

Source of carbon-14	Design basis estimate (GBq y^{-1})
From oxygen-17	552
From nitrogen-14	110
Total	662

61 Westinghouse have considered the following techniques to prevent or minimise the production of carbon-14 at source:

a) Oxygen scavenging - Oxygen control of the demineralised water can be achieved by catalytic oxygen reduction units which reduce oxygen levels and by the addition of an oxygen scavenger during plant start up from cold shutdown.

b) Control of nitrogen impurities in the fuel rods - fuel rods can be pre-pressurised with helium to minimize compressive clad stresses and prevent clad flattening under reactor coolant operating pressures. The use of helium pressurisation expels nitrogen from the fuel rod.

c) Use of argon in place of nitrogen as cover gas.

d) pH control using lithium hydroxide - pH control of the primary coolant can be achieved by using lithium hydroxide instead of hydrazine (NH_2-NH_2) which prevents formation of C-14 from nitrogen.

e) Electro-deionisation – the use of secondary demineralization can increase the removal of dissolved carbon dioxide gas.

62 Westinghouse have scored each option against the attributes listed in the BAT form of the BAT report including attributes such as proven technology and impact (operator dose, public dose), and the equal highest scoring options are oxygen scavenging and pH control, closely followed by control of nitrogen impurities in the fuel and electro-deionisation. Westinghouse claim that all these four measures are included in the AP1000 design.

63 Assuming 15 ppm nitrogen in the coolant Westinghouse predict the total production of carbon-14 to be 662 GBq y^{-1}.

64 Our assessment concluded that Westinghouse has demonstrated that BAT is used to minimise the production of carbon-14 in the AP1000.

3.3 Nitrogen-16

65 Nitrigen-16 is formed by the activation of oxygen-16 in the primary coolant. There is no practicable way to reduce its formation. However, its short half-life of 7.13 seconds means that discharges to the environment will be insignificant. (AP1000 BAT Form 3).

66 The production of nitrogen-16 is prevented or minimised by:

a) Hydrazine addition – hydrazine can be injected to control the oxygen concentration in the primary circuit.

b) Oxygen elimination – the injection of hydrogen at power can minimise radiolysis in the core.

67 Westinghouse has scored both options equally against the attributes selected for its assessment. Westinghouse claims that both these measures are included in the AP1000 design.

68 We consider that the minimisation of the production of nitrogen-16 at source is primarily a matter for the ONR as the short half life of nitrogen-16 results in the key impact being in terms of operator dose.

69 We do not consider nitrogen-16 further in our assessment.

3.4 Strontium-90

70 Strontium-90 is a fission product normally contained within the fuel cladding. If there are any fuel defects strontium-90 can enter into the primary coolant.

71 Westinghouse estimate the design basis activity of strontium-90 in reactor coolant to be 1.813 Bq g^{-1} based upon assuming 0.25% fuel defects. Westinghouse estimate the realistic source term in the AP1000 to be 0.37 Bq g^{-1} in reactor coolant and 2.59E-07 Bq g^{-1} in steam generator steam. (AP1000 BAT Form 4)

72 Westinghouse have not carried out an options assessment for the prevention or minimisation of strontium-90 at source but they do claim that minimisation of fuel defects is key to minimising strontium-90 production. (AP1000 BAT Form 4)

73 We consider that the production of strontium-90 is unavoidable however we recognise that techniques to minimise fuel defects which are used to minimise the production of other radionuclides will also minimise the production of strontium-90.

74 We consider that Westinghouse has demonstrated that BAT is used to minimise the production of strontium-90 in the AP1000.

3.5 Iodine radionuclides

75 Iodine radionuclides are formed in the fuel by fission and can be released into the coolant as a result of defects in the fuel. In addition fission of uranium found on fuel and other surfaces (tramp uranium) can undergo fission and iodine radionuclides can be released into the coolant. The presence of iodine radionuclides in gaseous discharges is another indicator of fuel defects.

76 Westinghouse predict that design basis iodine-131 activity in reactor coolant will be 7.10E-01 μCi g^{-1} (26.3 kBq g^{-1}). Westinghouse predict the realistic source terms for iodine-131 to be 0.04 μCi g^{-1} (1.48kBq g^{-1}) in coolant and 2.7e-08 μCi g^{-1} (<1Bq g^{-1}) in steam generator steam. (BAT Assessment form 5)

77 We accept there are no techniques to prevent the production of iodine radionuclides within the fuel pins.

78 The majority of iodine radionuclides produced will form compounds and remain in the liquid phase of effluents from the CVS. A small fraction will remain as elemental iodine and will be degassed in the CVS and passed to the WGS. Any leaks from the primary coolant system could also result in iodine radionuclides being found in the containment atmosphere.

79 Westinghouse conclude that that the following techniques are BAT to minimise iodine-131 (and other iodine radionuclides) production in the AP1000:

a) Minimisation of fuel defects in operation – reactor operating regimes are used which minimise the likelihood of damage to the fuel and leaking fuel pins are located during refuelling and removed.

b) Control of uranium contamination on external surfaces of fuel (tramp uranium) in fuel manufacture and fabrication.

80 Westinghouse have scored each option against the attributes listed in the BAT form of the BAT report including attributes such as proven technology and impact (operator dose, public dose), and the highest scoring option is the minimisation of fuel defects in operation followed by the control of uranium contamination on external surfaces of fuel

(tramp uranium) in fuel manufacture and fabrication. Westinghouse claim that both these measures are included in the AP1000 design.

81 Our assessment concluded that Westinghouse has demonstrated that BAT is used to minimise the production of iodine-131 (and other iodine radionuclides) in the AP1000.

3.6 Caesium 134 and caesium-137

82 Caesium-134 and caesium-137 are fission products normally contained within the fuel cladding. If there are any fuel defects caesium radionuclides can enter the primary coolant. Fission of uranium contamination in the reactor (tramp uranium) can also be a source of caesium-134 and caesium-137. Caesium is highly soluble and, if present in the coolant, will eventually be treated in the WLS. The detection of caesium radionuclides in liquid radioactive waste disposals provides a useful indication of fuel integrity.

83 Westinghouse conclude that the following techniques are BAT to minimise caesium-137 production in the AP1000 (AP1000 BAT Form 6):

a) Minimisation of fuel defects in operation – reactor operating regimes are used which minimise the likelihood of damage to the fuel and leaking fuel pins are located during refuelling and removed.

b) Control of uranium contamination on external surfaces of fuel (tramp uranium) in fuel manufacture and fabrication.

84 Our assessment concluded that Westinghouse has demonstrated that BAT is used to minimise the production of caesium-137 in the AP1000.

3.7 Noble gases (argon-41, krypton-85m, krypton-85, xenon-133m and xenon-133)

85 Noble gas radionuclides such as krypton-85, krypton-85m, xenon-133 and xenon -133m are fission products and are produced by fission of the uranium in the fuel. They are normally contained within the fuel cladding. However if there are any fuel defects these gases can enter into the reactor coolant. The presence of noble gases in discharges is an indicator of fuel defects. If fuel defects become significant then noble gases will contribute significantly to activity in gaseous waste disposals. (AP1000 BAT Form 8).

86 Even though there may be no defective fuel pins, natural uranium contamination of core construction materials and the fuel cladding, as well as enriched uranium contamination of external cladding surfaces during manufacture can also be a source of fission products in the coolant during power operations. However, Westinghouse claim this is insignificant in modern fuel manufacturing. Noble gas radionuclides dissolved in the coolant will be removed by degassing in the CVS and pass through the WGS and be discharged to the air.

87 Westinghouse claim that fuel leak rate in existing AP1000 plants is much less than the AP1000 design basis value of 0.25% which was used during aqueous and gaseous radioactive waste system design and that current fuel design has been improved, both in terms of the integrity of fuel rods and the robustness of the fuel assembly with respect to vibration of the rods within the assembly. (ER s3.2.4).

88 Westinghouse say that the AP1000 GDA design basis is using Westinghouse fuel type 17RFA. Westinghouse say on fuel integrity: *'Since the implementation of the Westinghouse 17x17 RFA in 1998 the overall leakage rate of this design, incorporating all the Westinghouse debris protection features, is 0. The overall leakage rate, on a rod basis, of the basic RFA fuel product including designs that do not use all the debris protection features is less than 10^{-5}'* (ERs3.2.4)

89 Westinghouse have provided information on the sources of noble gases (argon-41, krypton-85m, krypton-85, xenon-133m and xenon -133) in the AP1000.

90 Westinghouse predict the noble gases source terms in reactor coolant to be:

Radionuclide	**Design basis source term activity in reactor coolant (Bq g^{-1})**	**Realistic source term activity in reactor coolant (Bq g^{-1})**
Argon-41	not detectable	not detectable
Krypton-85m	31,080	7,770
Krypton-85	111,000	51,800
Xenon-133m	62,900	40,700
Xenon-133	4,440,000	3,441

91 Westinghouse have considered the one technique to prevent or minimise the production of noble gases at source:

a) Minimisation of fuel defects in operation – reactor operating regimes can be used which minimise the likelihood of damage to the fuel and leaking fuel pins can be located during refuelling and removed.

92 Westinghouse have scored the single option against the attributes listed in the BAT form of the BAT report including attributes such as proven technology and impact (operator dose, public dose), and claim that measures to minimise fuel defects are included in the AP1000 design.

93 Westinghouse conclude that the minimisation of fuel defects in operation, the use of reactor operating regimes which minimise the likelihood of damage to the fuel, and the location and removal of leaking fuel pins during refuelling, is BAT to minimise noble gas production in the AP1000.

94 We recognise however that the use of reactor operating regimes which minimise the likelihood of damage to the fuel and the location and removal of leaking fuel pins during refuelling will be a matter for future operators of the AP1000 and we will continue to seek assurances that hand over between Westinghouse and future operators will address this matter. This topic is covered within section 6.6 of our Decision Document '*Expectations for the operator's management system*' and the associated assessment report (Environment Agency, 2011b).

95 Our assessment concluded that the average fuel failure rate quoted by Westinghouse is indicative of use of BAT to minimise the release of noble gases from the fuel in the AP1000. Fuel integrity will be reflected in the disposal limits we set for noble gases. Our conclusion is based on the use of Westinghouse type 17RFA fuel assemblies in the AP1000**.**

96 Argon-41 is produced by the activation of natural argon-40 in air surrounding the reactor in the containment area. Westinghouse predict that 1,300 GBq y^{-1} of argon-41 will be produced in the AP1000. Argon-41 is collected by the ventilation system and discharged through the main vent without treatment.

97 We conclude that, taking into account that the production of argon-41 is unavoidable, its short half life (109 minutes) and low radiological impact, it is not proportionate to assess BAT in detail for argon-41. Discharges of argon-41 will be monitored and measured with other noble gases at the main plant stack and the turbine building stack.

3.8 Beta emitting particulates

98 Westinghouse have provided information on the sources of beta emitting particulates activity (cobalt-58, cobalt-60, iron-55 and nickel-63) in the AP1000:

a) **Cobalt-58** is formed by the activation of nickel-58, a stable isotope of nickel, which is a major constituent of the AP1000 steam generator tubes and the stainless steel used to fabricate the core and the reactor pressure vessel components. Westinghouse claim they minimise the potential for the production of cobalt-58 by:

   i) specifying metals that resist the corrosive effect of the coolant thus reducing corrosion products available to be activated;

   ii) only using nickel-based alloys where component reliability may be compromised by the use of other materials, e.g. the steam generator tubes;

   iii) pre-passivation of the steam generator to develop a single, chromium-rich layer which reduces corrosion product release.

b) **Cobalt-60** is formed by the activation of cobalt-59 in the reactor steel. Cobalt is also found in the hard-wearing alloy, Stellite™ which may be used on hardfacing components. Westinghouse claim they have minimised the amount of cobalt-60 produced in the AP1000 by minimising the amount of cobalt bearing materials used in the design using the following techniques:

   i) using low or zero cobalt alloys for hardfacing materials in contact with coolant unless necessary for reliability considerations;

   ii) limiting cobalt content of components in contact with coolant;

   iii) specifying low cobalt content (0.015 %) tubing for the steam generator.

c) **Iron-55** is formed by the activation of the stable isotope iron-54 found the reactor steel. Minimisation of use is not practicable. Control of corrosion by the choice of appropriate materials and the general measures described below will minimise production of corrosion products that may be activated.

d) **Nickel-63** is formed by the activation of the stable isotope nickel-63 found in nickel alloys, in particular the steam generator tubes. Minimisation of the production of nickel-63 is achieved by the same techniques as for cobalt-60.

99 Westinghouse predict the beta emitting particulates source terms in reactor coolant to be:

Radionuclide	Design basis source activity ($Bq\ g^{-1}$)	Realistic source activity ($Bq\ g^{-1}$)
Cobalt-58	70.3	144.3
Cobalt-60	8.14	16.28
Iron-55	18.5	37
Nickel-63	No information provided	No information provided

100 The production of beta emitting particulates is generally by release into the primary coolant by corrosion, wear or thermal shock of stable isotopes in the materials of the reactor and subsequent activation of those isotopes as they pass through the reactor core.

101 Options for the prevention or minimisation of the production of beta emitting particulates include:

a) Materials selection and QA - control of the choice of materials in contact with the primary coolant can lead to a reduction in the production of corrosion products including Co-58, Co-60, Fe-55 and Ni-63. Quality assurance and quality control systems during manufacture and construction can contribute to low corrosion rates.

b) Maintenance of an elevated pH - a constant elevated pH value can be maintained in the primary coolant by optimised regulation of the lithium concentration. This chemical is chosen for its compatibility with the materials and water chemistry of borated water / stainless steel / nickel-chromium-iron systems.

c) Hydrazine addition - during plant startup from cold shutdown hydrazine can be introduced as an oxygen scavenging agent.

d) Oxygen elimination - during power operations, dissolved hydrogen can be added to the reactor coolant system to eliminate free oxygen produced by radiolysis in the core and to prevent ammonia formation. This can reduce the oxygen content and limits radiolysis.

e) Zinc injection into the primary system - injection of zinc causes:

i) Corrosion films to become thinner but more stable, reducing ongoing corrosion of reactor vessel materials.

ii) Divalent cations to be displaced, released into the coolant, and blocked from redeposition.

iii) A reduction in the risk of a crud induced power shift (CIPS).

f) Piping design - the piping in pipe chases can be designed with consideration for corrosion and operating environment. Pipe bends can be used instead of elbows where practicable to reduce potential crud traps. Welds can be made smooth to prevent crud traps from forming.

102 Westinghouse have scored all the options against the attributes listed in the BAT form of the BAT report including attributes such as proven technology and impact (operator dose), and piping design scored the highest by only one point. All other options scored equally. Westinghouse claim that all these measures are included in the AP1000 design.

103 We raised a Technical Query (TQ-AP1000-145) on 1 June 2009 requiring Westinghouse to confirm if the zinc injection was carried out using depleted zinc. Zinc-64 is transformed into zinc-65 by neutron capture. Zinc-65 has a half-life of 244.26 days and emits gamma radiation with an energy of 2.27 MeV. Zinc-64 has a natural abundance of 48.6%, but in depleted zinc it is reduced below 1%. The use of depleted zinc therefore reduces corrosion which minimises aqueous liquid radioactive waste discharges whilst reducing occupational exposure compared to the use of natural zinc.

104 Westinghouse responded on 17 June 2009 confirming that depleted zinc will be used for the AP1000.

105 In response to an RO raised by ONR, Westinghouse provided additional information on zinc injection after our consultation. Document LTR-AP1000-10-490 dated 29 July 2010 provided information on the benefits of zinc injection in reducing corrosion. The information was supported by data from operating plant. Westinghouse state that zinc injection is now used on more than 59 PWRs worldwide. We assessed this information and reviewed ONR's more detailed assessment on this topic (ONR assessment report AP1000 - AR 11/008) and concluded that zinc injection benefits in reduction of discharges (see our detailed assessment in Annex 1 of this report). This conclusion is subject to the use of depleted zinc acetate (zinc acetate with less than 1 % Zinc-64). However, there is some uncertainty regarding the effect of zinc injection on the composition of some wastes and crud. We therefore have identified an assessment finding:

Future operators shall, before the commissioning phase, provide their proposals for how they intend to implement zinc injection. The proposals shall be supported by an assessment of the impact of zinc injection on waste and crud composition. (AP1000-AF03)

106 Westinghouse claim that a fundamental design goal of AP1000 has been to limit source terms through implementation of such advances as improved fuel, improved operational chemistry, and overall simplification (which limits leakage pathways).

107 Westinghouse claim that fission gases will normally be retained within the reactor coolant, and all planned coolant releases will be routed to the liquid radioactive waste system where the gaseous component is stripped and routed to the gaseous radioactive waste system. Westinghouse claim that releases from the heating, ventilation and air conditioning (HVAC) filters only arise as a result of incidental leakage from the reactor coolant system. They claim that a major design emphasis of AP1000 has been to minimise this incidental leakage, through such measures as:

a) Use of canned motor reactor coolant pumps, which are hermetically sealed.

b) Simplification of the loop configuration and connecting piping, which reduces the number of potential release pathways.

c) Implementation of a full-flow letdown degasifier, which eliminates the need to store gas-laden liquids in tanks within the WLS.

108 Our assessment concluded that Westinghouse has demonstrated that BAT is used to minimise the production of activation products in the AP1000.

3.9 Radioactive actinides

109 Radioactive actinides are formed in the fuel and can enter the coolant as a result of fuel leaks. They are also formed in any trace surface contamination of the fuel pins by fuel (tramp uranium), although the amount of tramp uranium is insignificant (see ERs3.2.3). They may enter the coolant and may be significant in terms of the impact of disposals as the majority are alpha emitters.

110 No information has been provided on the amount of alpha emitting radioactive actinides expected to be produced by the AP1000 however ER Table 3.4-6 lists the following actinides as having a negligible annual discharge to the sea: uranium-234, uranium-235, uranium-238, neptunium-237, plutonium-238, plutonium -239, plutonium -240, plutonium -242, americium-241, americium-243, curium-242 and curium-244.

111 Information has been provided about plutonium -241 which is a beta emitting actinide. The amount of plutonium-241 expected to be produced has not been given, however information has been provided about the average amount of plutonium-241 in liquid discharges which is predicted to be 0.00008 GBq y^{-1}.

112 We accept that the production of Pu-241 is an inevitable consequence of uranium fission reactions and cannot be prevented in the fuel. Westinghouse claim that the following techniques used in the AP1000 are BAT to minimise the quantity of Pu-241 potentially present in the coolant:

a) improved cladding material and quality control in manufacture has greatly reduced the incidence of fuel pin failures (see also noble gases above);

b) control of uranium contamination in the manufacture of fuel pins;

c) minimising plant shutdowns;

d) ultrasonic fuel cleaning.

113 We recognise however that minimising plant shutdowns will be a matter for future operators of the AP1000 and we will continue to seek assurances that hand over between Westinghouse and future operators will address this matter. This topic is

covered within section 6.6 of our Decision Document '*Expectations for the operator's management system*' and the associated assessment report (Environment Agency, 2011b)

114 Our assessment concluded that Westinghouse has demonstrated that BAT is used to minimise the production of plutonium-241 in the AP1000, and we accept that other actinides do not contribute significantly to annual discharges to the sea.

4 Overall measures to minimise production of radioactive waste

115 Informed by its options assessment, Westinghouse claims there are a number of measures in the design of the AP1000 which are BAT to prevent or minimise the production of radioactive waste at source (ERs3.1) these include:

4.1 Fuel rod and cladding design

116 The AP1000 fuel rods consist of cylindrical, ceramic pellets of slightly enriched uranium dioxide (UO_2). These pellets are contained in cold-worked and stress-relieved ZIRLO clad tubing, which is plugged and seal-welded at the ends to encapsulate the fuel. ZIRLO is an advanced zirconium-based alloy which has a high corrosion resistance to coolant, fuel, and fission products, and high strength and ductility at operating temperatures. Westinghouse claim that the selection of ZIRLO cladding materials minimises the formation of defects that can result in radioactive releases to the reactor coolant.

117 Westinghouse say that the AP1000 GDA design basis is using Westinghouse fuel type 17RFA. Westinghouse say on fuel integrity: *'Since the implementation of the Westinghouse 17x17 RFA in 1998 the overall leakage rate of this design, incorporating all the Westinghouse debris protection features, is 0. The overall leakage rate, on a rod basis, of the basic RFA fuel product including designs that do not use all the debris protection features is less than 10^{-5}.*

4.2 Materials selection

118 To reduce activation of cobalt to Co-60 a qualified low or zero cobalt alloy equivalent to Stellite-6 is primarily used for hard-facing material in contact with reactor coolant. The use of cobalt base alloy is minimized. Low or zero cobalt alloys used for hard-facing or other applications where cobalt alloys have been previously used are qualified using wear and corrosion tests.

119 However based on significant engineering experience cobalt-based alloys are used to a limited extent in the control rod drive mechanisms.

120 Westinghouse claim that cobalt-based alloys have limited use in the AP1000 design.

4.3 Minimisation of leakage pathways

121 Westinghouse claim that the AP1000 is designed with fewer valves and components than predecessor plants which will result in fewer leakage pathways and lower overall input to the liquid radioactive waste systems. Westinghouse claim that releases from the heating, ventilation and air conditioning (HVAC) systems only arise as a result of incidental leakage from the reactor coolant system. They claim that a major design emphasis of AP1000 has been to minimise this incidental leakage, through such measures as:

a) Use of canned motor reactor coolant pumps, which are hermetically sealed.

b) Simplification of the loop configuration and connecting piping, which reduces the number of potential release pathways.

c) Implementation of a full-flow letdown degasifier, which eliminates the need to store gas-laden liquids in tanks within the WLS.

4.4 Control of reactor coolant water chemistry

122 The reactor coolant system (RCS) contains boric acid for long-term reactivity control of the core. The following chemicals are added to the borated coolant:

a) Lithium hydroxide (Li7OH) is used to control the pH of the reactor coolant system and is chosen for its compatibility with borated water chemistry and the stainless steel and zirconium materials. The use of Li7OH, where the Li-7 isotope has been enriched, as opposed to Li6OH also removes an important formation mechanism for tritium. Westinghouse claim that the effective control of pH reduces the formation of radioactive corrosion products that may be released in liquid effluent.

b) Hydrazine is introduced as an oxygen scavenger during plant startup from cold shutdown. Westinghouse claims that the removal of dissolved oxygen reduces corrosion product formation.

c) Dissolved hydrogen. Westinghouse claims this eliminates free oxygen produced by radiolysis in the core and prevents ammonia formation.

d) Zinc acetate is added from the start of operations to minimise corrosion. Westinghouse claims this reduces radioactive cobalt and activated nickel concentrations.

123 The RCS water chemistry is routinely analyzed to ensure that the chemistry is correct and that corrosion product particulates are below specified limits.

4.5 Grey rods and burnable absorber rods

124 Core reactivity is controlled by means of a chemical poison (boric acid) dissolved in the coolant, rod cluster control assemblies, grey rod cluster assemblies and burnable absorbers.

125 Grey rods are moveable control rods with which contain a low density neutron absorber to provide reactivity control. The grey rod cluster assemblies are used in load follow manoeuvring and provide a mechanical shim reactivity mechanism which eliminates the need for chemical shim control provided by changes to the concentration of soluble boron.

126 Discrete burnable absorber rods or integral fuel burnable absorber rods or both may be used to provide partial control of the excess reactivity available during the fuel cycle. In doing so, the burnable absorber rods reduce the requirement for soluble boron in the moderator at the beginning of the fuel cycle.

127 Westinghouse claim that the reactor controls provided by grey rods and burnable absorber rods reduces the requirement for varying the boron concentrations in the reactor coolant system and thus the volume of reactor coolant that is withdrawn by the CVS and treated in the liquid radioactive waste system is reduced.

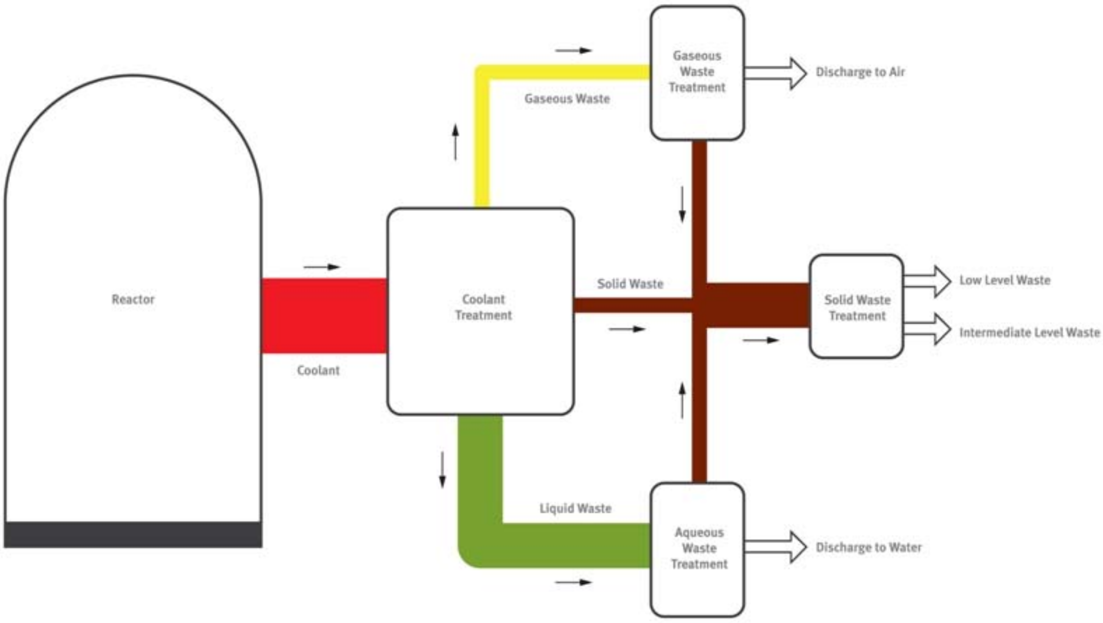
4.6 Recycling steam generator blow down

128 Steam generator blowdown fluid is recycled and normally returned to the condensate system.

5 Processing of radioactive materials in the AP1000 reactor

129 This section describes how radioactive materials are processed and handled in the AP1000. We expect the options chosen for a new nuclear power plant to minimise the overall impact of their discharges on people and the environment. (Statutory Guidance (DECC, 2009a) and our REPS (Environment Agency, 2010c) RSMDP7)

130 The majority of radioactive materials that will form waste are initially contained within the reactor coolant. Therefore, the options used to treat coolant are important factors that determine the form of radioactive waste and its ultimate disposal to solid, liquid and gaseous waste routes. The diagram below is used for illustrative purposes.



Conceptual waste flow diagram for a PWR

131 Gaseous radioactivity from radiologically controlled areas within the AP1000 is removed by ventilation systems to reduce occupational exposure. The ventilation systems discharge into the main plant vent.

5.1 Primary circuit – the reactor coolant system (RCS)

132 The reactor coolant system (RCS) includes the reactor, two steam generators, four coolant pumps and a pressuriser. The coolant is essentially water with boric acid added for long-term reactivity control of the reactor and lithium hydroxide to offset the corrosive effect of the acid. The RCS chemistry is controlled by sending a portion of the coolant to the chemical and volume control system (CVS).

133 The CVS (ER s3.2.7) is used to:

a) reduce boron concentration by let-down of coolant to the WLS and replacement with demineralised water;

b) manage lithium hydroxide to control pH of coolant;

c) manage hydrazine at plant start-up to scavenge oxygen;

d) manage hydrogen during power operations to eliminate free oxygen. Hydrogen added to control radiolysis product production and limit corrosion of fuel cladding / alloys by reactive species;

e) manage zinc acetate to minimise corrosion;

f) manage boric acid addition to the RCS.

134 The CVS also purifies the coolant to maintain low system radioactivity. The returning coolant flow is passed through a mixed bed demineraliser to remove dissolved corrosion products. The mixed bed also acts as a filter to remove particulate corrosion products. The bed is sized to provide demineralisation for one cycle of operation but a second demineraliser is provided in case the operational bed becomes exhausted. A cation bed demineraliser is available to use in the event of fuel leaks and mainly removes caesium isotopes. Filters are installed downstream of the demineralisers for final removal of particulates and resin fines. The filter elements and spent demineraliser resins need to be replaced at intervals and become significant (possibly ILW) solid radioactive waste. We consider using filters and demineralisers in this system in the AP1000 as BAT, with the benefit of reducing the radioactivity of liquid waste outweighing the generation of solid waste. (ER s3.2.10)

135 Iodine radionuclides will also be absorbed in the CVS mixed bed demineraliser. Noble gas removal is not normally necessary when fuel defects are within normally anticipated ranges. If noble gas removal is needed, the CVS can operate together with the WLS degasifier, see below. (ERs3.2.10).

136 The operation of the CVS is important to optimise the impact of radioactive disposals. We need assurance that Westinghouse will work with future operators to inform their use of BAT. We have included this topic within section 6.6 of this document under 'Expectations for the operator's management system' where we have examined the arrangements for transfer of knowledge about the AP1000 design from Westinghouse to future operators. The other issue AP1000 OI-02 that we included in our Consultation Document has therefore been closed out.

5.2 Secondary circuit

137 The secondary circuit contains boiler quality water that is made into steam in the steam generators. The steam drives turbines that generate electricity. The steam is condensed after passing through the turbines and the condensate water normally reused. In the event of any tube leaks in the SGs, the secondary circuit water could be contaminated with radioactivity, in particular with tritium. Radiation monitors are installed to detect contamination so that operators can take the necessary action. (ER s3.3.3)

138 Air in-leakage and non-condensable gases removed from the condenser after the turbine in the secondary circuit do not normally contain radioactivity (as noted above) and are discharged without treatment through the condenser air removal system to the turbine building vent. Any condensate not reused (the blowdown) will be collected in the Waste Water Retention Basin (WWRB). The contents of the WWRB are monitored before discharge, if any radioactivity is detected then the contents can be treated in the Liquid radioactive waste system.

5.3 Ventilation systems

139 We require BAT to be used in the design of ventilation systems. Systems should include appropriate treatment systems to remove and collect airborne radioactive substances before they are discharged to the air. (Our REPS ENDP16)

140 The containment air filtration system (VFS) serves the reactor containment building, the fuel handling area and some other controlled areas. Radioactive materials can be present in the ventilation air from trace leaks of coolant or from activation of argon normally present in air to argon-41. The VFS is normally only operated periodically to reduce detected airborne activity or to maintain containment pressure. (ERs3.3.2.2)

141 The VFS comprises two 100 per cent capacity systems, each with an inlet electric heater, a high efficiency particulate air (HEPA) filter bank, a charcoal iodine adsorber, a post-filter and an exhaust fan. Gaseous radiation monitoring equipment is located

downstream of the VFS with an alarm to warn of abnormal releases.

142 The containment venting system includes a filtration system which provides the following functions:

a) intermittent flow of outdoor air to purge the containment atmosphere of airborne radioactivity during normal plant operation, and a continuous flow during hot or cold plant shutdown conditions to provide an acceptable level of airborne radioactivity before people enter.

b) intermittent venting of air into and out of the containment to maintain the containment pressure within its design pressure range during normal plant operation.

c) directs the exhaust air from the containment atmosphere to the plant vent for monitoring, and provides filtration to limit the release of airborne radioactivity at the site boundary within acceptable levels.

d) monitoring of gaseous, particulate and iodine concentration levels discharged to the environment through the plant vent.

143 The two exhaust air filtration units are located within the radiologically controlled area of the annex building. Each exhaust air filtration unit can handle 100 per cent of the system capacity. Each unit consists of an electric heater, an upstream high efficiency particulate air (HEPA) filter bank, a charcoal adsorber with a downstream post-filter bank, and an exhaust fan.

144 A radiation monitor is located downstream of the exhaust air filtration units in the common ductwork to provide an alarm if abnormal gaseous releases are detected.

145 During normal plant operation, the containment air filtration system is operated from time to time to purge the containment atmosphere as determined by the main control room operator to reduce airborne radioactivity or to maintain the containment pressure within its normal operating range.

146 The filtered exhaust air from the containment is discharged to the atmosphere through the plant vent by the exhaust fan. Radioactivity indication and alarms are provided to inform the main control room operators of the concentration of gaseous radioactivity in the containment air filtration system exhaust duct and gaseous, particulate and iodine concentrations in the plant vent.

147 Westinghouse provides a specification for its choice of HEPA filter elements in the ER Table 3.3-2. It claims these HEPA filters are BAT as they balance increased pressure drop (with increased energy use) and larger filter volume requiring disposal as LLW against performance. We accept this claim at present but will require performance data to confirm this at site-specific permitting. (ERs3.3.9.2)

148 The filtered exhaust air from the VFS is discharged to air through the main plant vent. The vent is monitored for radioactive discharges.

149 The Regulators jointly raised a Regulatory Observation (RO-AP1000-43) on Westinghouse regarding nuclear ventilation, in particular the radiologically controlled area ventilation system (VAS). We noted our concerns in the Consultation Document as a potential GDA Issue. Subsequently Westinghouse proposed some design changes for the AP1000 to comply with UK good practice described in "A*n Aid to the Design of Ventilation of Radioactive Areas*" (Nuclear Industry Safety Directors Forum, 2009), these are shown in the latest version (Revision 4) of the Environment Report (ERs3.3.2).

150 The VAS serves the fuel handling and other areas of the AP1000. The VAS consists of two separate sub-systems, the fuel handling area ventilation subsystem, and the auxiliary / annex building. In normal circumstances radioactivity is not expected to be collected by the VAS and, as described in our Consultation Document, it is discharged without treatment into the main plant vent unless radiation monitors divert it to the

Containment ventilation System, VFS, on detection of radioactivity. Changes have been made to the VAS and other nuclear ventilations systems, VHS and VRS:

a) Health Physics and Hot Machine Shop Ventilation System (VHS): the VHS fans will shut down on a High radiation signal and exhaust through the VFS, the airflow from the served spaces will then be reduced, but the exhaust will thus be HEPA filtered.

b) VHS: High efficiency filters in or at the individual machine tools and glove box exhausts will be replaced with HEPA filters.

c) Radwaste Building HVAC System (VRS): HEPA filtration will be added to the VRS exhaust from the radwaste building.

d) Radiologically controlled area ventilation system (VAS): Auxiliary building area radiation monitors will be added to the controls that isolate VAS and actuate VFS filtration.

e) VAS: HEPA filtration is added to the VAS subsystem serving the fuel handling area. This negates the potential for release through the VAS in case of equipment failure; there is a potential for corrosion product crud accumulated on spent fuel assemblies to become airborne.

151 We sought evidence that the design change proposals (DCPs) for ventilation were subject to Westinghouse due process for approval, and that the DCPs are robust in implementation in GDA. Westinghouse provided evidence in response to TQ-AP1000-1201 on the approved DCPs for ventilation:

a) APP-GW-GEE-2083 covers c) above;

b) APP-GW-GEE-2084 covers a), b) and d) above;

c) APP-GW-GEE-2085 covers e) above.

152 Our assessment concluded that with the implementation of the design changes outlined above the AP1000 uses BAT to minimise gaseous radioactive waste discharges from the VAS, VHS and VRS. The potential GDA Issue AP1000-I2 shown in the Consultation Document has been closed out.

153 The turbine building ventilation system (VTS) comprises roof exhaust ventilators which help to control the temperature of the building. The turbine building air is not normally contaminated with radioactivity and is exhausted without treatment directly to the air via the turbine building stack. The only potential for contamination of the turbine building air arises if there is a steam generator tube leak, which allows radioactivity from the primary circuit to enter the secondary circuit. In this event, operators will take action to deal with this. (ERs3.3.2.5)

154 Extract air from building equipment in the radwaste building is directed to the main plant vent after passing through HEPA filters. (ERs3.3.2.6)

155 The ventilation air from the ILW store passes through two HEPA filters in series before being discharged through a separate ILW store ventilation stack. (ER3.3.2.7)

156 Our assessment concluded that the nuclear ventilation systems on the AP1000 are BAT to minimise the discharge of radioactivity to air.

6 Containment of radioactive liquids in the AP1000

157 Radioactive liquids will be produced in the AP1000, we expect these liquids to be contained within the facility to prevent contamination of land or groundwater under normal conditions. Under fault conditions we expect BAT to be used to minimise the probability of contamination occurring and the extent of contamination. (Our REPS (Environment Agency 2010b), RSMDP10 and CLDP1)

158 Under the Environmental Permitting Regulations 2010 (EPR 10), a permit is required for the deliberate discharge of certain substances, including radioactive substances, to groundwater, with the aim of preventing or limiting pollution of groundwater.

159 Westinghouse claims that there is no likelihood of direct or indirect discharges of radioactive substances to groundwater. In that case, an AP1000 should not need to be permitted by us for a discharge to groundwater under EPR 10.

160 Westinghouse claims that the AP1000 has '*emphasised best practices with respect to prevention of contamination of land and groundwater*'. Westinghouse describes techniques that should prevent contamination (ERs2.9.5), in particular:

a) simplicity of design reduces lengths of piping and numbers of components reducing potential for leaks;

b) nuclear island is built as a single structure without joints in the concrete and is waterproofed. This prevents leakage from any equipment reaching the environment;

c) use of embedded pipes minimised;

d) use of coolant pumps without mechanical seals;

e) spent fuel pool constructed of ½ inch stainless steel plate joined by full penetration welds. The welds are fitted with leak detection systems. The pool is, as far as possible, within a building so leaks would be contained within the building;

f) all tanks containing radioactive liquid are within buildings that act as bunds preventing any leaks reaching the environment.

161 We confirm that, in principle, such techniques can be BAT. We will need to confirm for specific sites that:

a) the civil engineering design proposed for buildings will achieve the secondary containment claimed for tanks within those buildings;

b) the engineering design of the base of the spent fuel pool or of any tank within buildings should allow for external inspection of the base and walls as far as practicable;

c) the secondary containment shall ensure that any leakage past the primary containment is contained within the building;

d) primary and secondary containments must have independent leak detection and monitoring systems to provide redundancy. Systems for collection/retention of any leakage shall also be provided.

162 We note that ONR have raised a GDA Issue (GI-AP1000-CE-05) concerning secondary containment and leak detection for potential spent fuel pool leaks. The response to that Issue will assist our specific site assessment.

163 In the USA, Regulation 10 CFR 20.1406 requires applicants for licenses to operate nuclear power plant to show how they minimise contamination of the environment. The US NRC issued Regulatory Guide 4.21 in June 2008 to use when reviewing facilities regarding the spread of contamination. Westinghouse claims that AP1000 fully complies with this guidance. The US NRC published review findings in May 2010 and confirmed that the AP1000 '*addressed the minimization of waste generation in 10 CFR 20.1406*' (NRC ADAMS accession number ML0926503740).We accept this guide

as an example of good practice and that the NRC finding supports our conclusion below.

164 Westinghouse states that liquid radioactive waste is collected in five tank systems (ER s3.4.2) and provides design and secondary containment information on these tanks (ER Table 3.4-2):

a) reactor coolant drain tank, 3.4 m^3, within containment shell;

b) effluent hold-up tanks, 2 x 106 m^3, secondary containment within auxiliary building;

c) waste hold-up tanks, 2 x 57 m^3, secondary containment within auxiliary building;

d) chemical waste tank, 34 m^3, secondary containment within auxiliary building;

e) monitor tanks, 6 x 57 m^3, secondary containment will be provided to UK regulatory requirements during site-specific design, we have made this an assessment finding, see below.

165 Westinghouse states that the site of an AP1000 should have a network of boreholes for sampling groundwater established during construction. A conceptual site model should be developed for each specific site and this will help location of boreholes. The network will remain in place during operation and be used to monitor groundwater quality and detect any contaminants that inadvertently reach the water table. We expect operators to contact us at the early stages of site-specific designs so that we can advise on the appropriate location and construction of boreholes.

166 Our assessment concluded that the AP1000 uses BAT to contain liquids and prevent contamination of groundwater in normal operation. The techniques used should also minimise contamination under fault conditions. However,

a) Future operators shall, before the construction phase, provide a BAT assessment to demonstrate that the design and capacity of secondary containment proposed for the monitor tanks is adequate for their location. (AP1000-AF04)

7 Public comments

167 The public involvement process remained open during our assessment see http://www.hse.gov.uk/newreactors/publicinvolvement.htm

168 We did not receive any public comments by this route during this assessment relating to the creation of radioactive waste.

169 The conclusions in this report have been made after consideration of all relevant responses to our consultation.

8 Conclusion

170 Our conclusion remains unchanged since our consultation.

171 We conclude that overall the AP1000 utilises the best available techniques (BAT):

a) to prevent and minimise production of gaseous and aqueous radioactive waste during routine operations and maintenance and from anticipated operational events;

b) to contain liquids and prevent contamination of groundwater in normal operation. The techniques used should also minimise contamination under fault conditions.

172 As part of our assessment we identified the following assessment findings:

a) Future operators shall, at the detailed design phase, provide a BAT assessment to demonstrate whether boron recycling represents BAT for their location. (AP1000-AF02)

b) Future operators shall, before the commissioning phase, provide their proposals for how they intend to implement zinc injection. The proposals shall be supported by an assessment of the impact of zinc injection on waste and crud composition. (AP1000-AF03)

c) Future operators shall, before the construction phase, provide a BAT assessment to demonstrate that the design and capacity of secondary containment proposed for the monitor tanks is adequate for their location. (AP1000-AF04)

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While every effort has been made to ensure the accuracy of the references listed in this report, their future availability cannot be guaranteed.

Abbreviations

ALARA	As low as reasonably achievable
ALARP	As Low As Reasonably Practicable
BAT	Best available techniques
CVS	Chemical and Volume control system
CWS	Circulating water system
DCD	Design Control Document
EPR 10	Environmental Permitting (England and Wales) Regulations 2010
EPRI	Electrical Power Research Institute – an independent USA organisation
ER	Environment Report
GDA	Generic design assessment
HSE	Health and Safety Executive
IAEA	International Atomic Energy Agency
JPO	Joint Programme Office
ONR	Office for Nuclear Regulation, an Agency of the HSE (formerly HSE's Nuclear Directorate)
P&ID	Process and information document
PCSR	Pre-Construction Safety Report
PWR	Pressurised water reactor
QA	Quality Assurance
RCS	Reactor coolant system
REPs	Radioactive substances environmental principles
RGN	Regulatory Guidance Note
RGS	Regulatory Guidance Series
RO	Regulatory Observation
SODA	Statement of Design Acceptability
TQ	Technical Query
US NRC	United States Nuclear Regulatory Commission
WEC	Westinghouse Electric Company LLC
WGS	Gaseous radioactive waste system
WLS	Liquid radioactive waste system

Annex 1 – Zinc injection

Background

173 Zinc (as zinc acetate) has been used in more than 59 PWRs over the last 20 years without problems and has given benefits:

a) Minimises risk of Primary Water Stress Corrosion Cracking in susceptible materials;

b) Reduces ongoing corrosion in the primary circuit;

c) Lower corrosion release:

i) Reduces risk of Crud Induced Power Shift;

ii) Reduces risk of Crud Induced Localised Corrosion of fuel;

iii) Minimises plant dose rates.

174 Zinc injected at 10 ± 5 ppb into reactor coolant acts by being incorporated into the oxide film established between metal (stainless steel or nickel-based alloy) and coolant. The films become more stable inhibiting corrosion and reducing incorporation of radioactive corrosion products such as Co-60/Co-58.

175 Both RPs (Westinghouse and EDF and AREVA) now include zinc injection as part of their basic design. They have both provided reports explaining the theory of zinc injection supported by reviews of the use of zinc injection in currently operating plant. They both conclude that use of zinc injection from the start of a new plant will give significant benefit in reduced corrosion.

176 A significant benefit would appear to be that use of zinc reduces incorporation of radionuclides (in particular Co-60/Co-58) onto the internal surfaces of reactor coolant system. This will reduce occupational dose rates.

177 Natural zinc contains 48.6% Zn-64 which can be activated in neutron flux to Zn-65 (1.1 MeV gamma emitter with a 243.8 day half-life). Depleted zinc acetate is available with <1% Zn-64. Depleted Zn should be used to maintain dose rates ALARP.

178 In terms of Best Available Techniques (BAT) to minimise radioactive waste there appear to be several benefits:

a) Reduced corrosion should give reduced level of corrosion products available for activation. This in turn should:

i) Reduce activity levels in filters and ion exchange resins for disposal;

ii) Reduce final discharge activity levels.

iii) Reduce activity on inner surfaces of reactor system components, this should facilitate disposal of any parts replaced for maintenance and all parts at decommissioning.

179 There appear to be no disbenefits in terms of radioactive waste, but there is some uncertainty (or perhaps just a lack of collated information) regarding the effect of zinc injection on the composition of some wastes and crud.

180 Zinc is a Dangerous Substance for discharge to water with an Environmental Quality Standard of 40 µg/l. However the quantity of zinc used in injection to PWRs is tiny – of the order of 5 g/day. Some of this will be used by incorporation into the oxide film, some will be adsorbed by ion exchange resin. Even if all zinc is assumed to be discharged the quantity will be < 2 kg/year. The discharge concentration of this within cooling water is <0.001 µg/l – insignificant against the EQS.

181 We believe, based on a review of information provided by both RPs and our limited review of available information, that the use of depleted zinc (<1% Zn-64) injection for corrosion control is BAT for new PWRs to minimise at source the production of corrosion products that may become activated to create radioactive waste. Zinc

injection should commence during pre-core conditioning of the reactor system to achieve maximum benefit and to minimise the incorporation of radionuclides into the oxide layer.

Westinghouse information

182 In response to ROA 56.A1 (provide justification for addition of Zn) Westinghouse have provided note LTR-AP1000-10-490 dated 29 Jul 10. The note is useful as a reference guide to use of zinc as well as a ROA response. A summary of the note follows:

183 Zinc injection has been used in PWRs for 20 years. Zinc ions interact with the oxide films on both stainless steel and nickel-based alloys inhibiting and reducing the release of corrosion products (e.g. Ni and Co) into the coolant. Zinc also serves to block redeposition of circulating corrosion products.

184 Westinghouse say that zinc will be injected into the AP1000 RCS starting during pre-core hot functional testing. The RCS surfaces will begin to develop protective oxide films (chromium-rich oxide with zinc incorporated at the metal / oxide surface). The film will reduce corrosion products reaching the coolant which can deposit on fuel and become activated. This will maximise fuel performance and minimise plant dose rate.

185 Westinghouse recommend a target operating zinc concentration of 10 ppb (± 5). This is based on operational experience to date and will reduce corrosion rates and corrosion products released into the coolant. The target is well below the solubility limit for zinc.

186 An additional benefit shown in operating plants is the mitigation of Primary Water Stress Corrosion Cracking in susceptible materials.

187 A concern with use of zinc is deposition of zinc oxide or silicate within crud on the core. This could decrease heat transfer and potentially increase cladding corrosion. Westinghouse claim research has shown higher cladding temperatures only at zinc levels of 60 ppb, temperature increase at 40 ppb was insignificant, therefore at 10 ppb there are no concerns.

188 Control of silica (SiO_2) in the RCS will also be important to minimise formation of zinc silicate.

189 Westinghouse say that most operational plants have seen increases in radio-cobalt concentrations in the coolant following zinc injection. This appears to indicate successful incorporation of zinc into oxide films displacing historic deposits of radio-cobalt and preventing redeposition of activated corrosion products. Cobalt should be removed by the coolant purification system.

190 Westinghouse say some plants also see increases in shutdown releases following zinc injection. Westinghouse claim that the AP1000 CVS purification will cope with this.

191 Westinghouse claim laboratory work shows corrosion reduction by a factor of 3 or more for 20 ppb of zinc over 3.5 months. Also Tomari 3 (working plant using zinc injection) shows 70% reduction in corrosion as compared to sister plants.

192 Westinghouse claim use of zinc addition reduces corrosion rates of primary system materials that then reduces nickel and iron corrosion products in coolant to reduce material available to deposit as crud.

193 Westinghouse note that zinc injection is just one technique of crud minimisation and core design, pH optimisation and ultrasonic fuel cleaning are others.

194 Westinghouse say zinc addition has been used in more than 59 PWRs worldwide beginning in 1994. Westinghouse monitor fuel and state:

a) No increase in cladding corrosion or cladding oxide thickness resulting from use of Zn;

b) No undesirable effect on fuel crud deposits;

c) While zinc has been incorporated in fuel crud deposits no densification or reduction in porosity seen;

d) Zinc addition at 4-50 ppb has no deleterious effects on PWR fuel.

195 Westinghouse claim zinc addition has given dose rate reductions of 50% or more on mature plants. This is relevant as the same oxide film conditioning will happen on new plants.

196 Westinghouse say data from EPRI Zinc Users Group Jun 2010 shows dose rates reducing as zinc addition progresses following near Co-60 decay curve. This indicates no further incorporation of radioisotopes into the oxide film and that the measured dose is given by existing Co-60 in the film.

197 Westinghouse claim that while zinc will be removed by ion exchange, calculations show that resin capacity is adequate and zinc addition will not impact waste generation rates or frequency resin bed changes.

198 Zinc is added in the form of zinc acetate which contains carbon. It is believed some carbon will be converted to methane or carbon dioxide. Some carbon has been detected in fuel crud deposits. Westinghouse claim that the low levels of zinc injection – say 5 g Zn/day – and that the carbon is mainly in the form of C-12 with low neutron capture cross section means there will be no significant increase in C-14 production from use of zinc injection.

199 Natural zinc contains 48.6% Zn-64 which can be activated in neutron flux to Zn-65 (1.1 MeV gamma emitter with a 243.8 day half-life).
Depleted zinc acetate is available with <1% Zn-64.
Westinghouse say that depleted zinc should be used to maintain dose rates ALARP.

200 Westinghouse conclude that zinc injection should be used from beginning of plant life. Justification:

a) Minimises risk of Primary Water Stress Corrosion Cracking in susceptible materials;

b) Reduces ongoing corrosion in the primary circuit;

c) Lower corrosion release: Reduces risk of Crud Induced Power Shift;

d) Reduces risk of Crud Induced Localised Corrosion

e) Minimises plant dose rates.

f) Use of depleted Zn recommended to minimise dose rates SFAIRP.

201 Zinc addition is covered in section 2.6.6 of the UK AP1000 Environment Report:

'*Nucleate boiling, especially in high duty cores can result in build up of boron and boron-lithium compounds in the RCS that has the potential to cause water stress corrosion cracking, crud-induced power shift and the release of active corrosion products into the WLS. To reduce these effects, the AP1000 NPP incorporates a zinc addition subsystem as part of the CVS to produce and maintain a zinc oxide film on primary piping and components. This zinc addition has also been found to significantly reduce occupational radiation exposure by as much as 50 percent when incorporated as early as hot functional testing.*

Zinc concentrations ranging from 10 parts per billion (ppb) (+/- 5ppb) are dosed into the RCS. Higher injection rates are typically used when zinc addition is first initiated in order to more quickly saturate RCS surfaces with zinc and achieve a residual zinc concentration in the coolant. Typical zinc uptake rates up to 95% occur in the first few months of zinc injection. On average these reduce to 20% - 90% of the injection rate over a given operational cycle. It is expected that up to around 5 kg of zinc will be injected during the first zinc cycle to maintain a target concentration of 10 ppb, assuming a CVS purification flowrate of 100 gpm. This zinc usage will decrease over *time, potentially to 2-3 kg per cycle*'.

Conclusion

202 Our assessment concludes that the use of zinc injection into the coolant:

a) Minimises corrosion of reactor system components. This should reduce the level of corrosion products in the coolant available to be activated to create radioactive waste. This complies with the first consideration of REP RSMDP3 to minimise production of radioactive waste at source.

b) Minimises the uptake of radioactive material into the inner surfaces of reactor system components. This should facilitate the disposal of those components whether replaced for maintenance or during decommissioning.

c) Minimises risk of primary water stress corrosion cracking in reactor system components. This should reduce the number of components needing to be replaced during life of plant and hence needing disposal.

d) Minimises crud formation which should in turn reduce pin failures (Crud Induced Localised Corrosion / Crud Induced Power Shift). Fewer pin failures should reduce discharges of fission products and the disposal problems associated with failed pins.

203 Westinghouse have presented information that the above benefits do not seem to be associated with any radiochemical disbenefits but we find there is some uncertainty (or perhaps just a lack of collated information) regarding the effect of zinc injection on the composition of some wastes and crud.

204 There is considerable benefit to use zinc injection as early as possible in the life of new plant. This is to prevent incorporation of radioactive material into the oxide layers as they are formed. Use of zinc should be considered within the pre-core commissioning and conditioning of the reactor system.

205 There would be a concern if natural zinc were used as this would lead to increased radioactivity by the activation of Zn-64 to Zn-65. However this is readily resolved by using depleted zinc (<1 % Zn-64) in place of natural zinc. Depleted zinc acetate appears to be available at reasonable cost.

206 There is also a considerable benefit to safety as the use of zinc injection minimises radioactivity retained on inner surfaces of reactor system components and this minimises plant dose rates.

207 Zinc is a Dangerous Substance for discharge to water with an Environmental Quality Standard of 40 µg/l. However the quantity of zinc used in injection to the AP1000 PWRs is tiny – of the order of 5 g/day. Some of this will be used by incorporation into the oxide film, some will be adsorbed by ion exchange resin. Even if all zinc is assumed to be discharged the quantity will be < 2 kg/year. The discharge concentration of this within cooling water is <0.001 µg/l – insignificant against the EQS.

208 We conclude that the use of depleted zinc (<1% Zn-64) injection for corrosion control is BAT for the AP1000 to minimise at source the production of corrosion products that may become activated to create radioactive waste. Zinc injection should commence during pre-core conditioning of the reactor system to achieve maximum benefit and to minimise the incorporation of radionuclides into the oxide layer. However there is some uncertainty regarding the effect of zinc injection on the composition of some wastes and crud. We therefore have identified an assessment finding:

Future operators shall, before the commissioning phase, provide their proposals for how they intend to implement zinc injection. The proposals shall be supported by an assessment of the impact of zinc injection on waste and crud composition. (AP1000-AF03)

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