Generic design assessment

AP1000® nuclear power plant design by Westinghouse Electric Company LLC

Final assessment report

Gaseous radioactive waste disposal and limits

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Generic design assessment

AP1000® nuclear power plant design by Westinghouse Electric Company LLC

Final assessment report: Discharges of gaseous radioactive waste

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 including: 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. 2.2 Design basis estimates for monthly discharges of gaseous and liquid radioactive 2.3 Proposed annual limits with derivation for radioactive gaseous and liquid discharges
Radioactive Substances Regulation Environmental Principles[2]	The following principles are relevant to this assessment: RSMDP3 – Use of BAT to minimise waste: RSMDP4 – Processes for Identifying BAT: RSMDP7 – BAT to Minimise Environmental Risk and Impact: RSMDP8 – Segregation of Wastes: RSMDP9 – Characterisation: RSMDP12 – Limits and Levels on Discharges: ENDP15 – Mechanical Containment Systems for Liquids And Gases:
Report author	Original report – Tooley, E. J. Review and 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 the assessment of information relating to gaseous radioactive wastes from the Westinghouse Electric Company's AP1000® reactor design submitted to the Environment Agency under the UK Generic Design Assessment (GDA) process.

2 Our conclusion remains unchanged since our consultation.

3 We conclude that overall the AP1000 utilises the best available techniques (BAT) to minimise discharges of gaseous radioactive waste:

a) during routine operations and maintenance;

b) from anticipated operational events.

4 We conclude that the gaseous discharges from the AP1000 should not exceed those of comparable power stations across the world. The proposed discharge of carbon-14 in gaseous waste is slightly higher than the range for other European PWRs but this may be accounted for by the increased availability expected of the AP1000.

5 We conclude that any operational, single AP1000 unit should comply with the limits and levels set out below for the disposal of gaseous radioactive waste to air. The limits and levels will be the starting point for any site-specific permit, but will be reviewed as part of the site permitting process based on any additional information provided by a future AP1000 operator. The limits would also be reviewed periodically thereafter, as data becomes available from operational AP1000 reactors.

Radionuclides or group of radionuclides	Annual limit (GBq)	Proposed Quarterly notification level (GBq)
Tritium	3,000	600
Carbon-14	1,000	210
Iodine-131	0.3	0.03
Noble gases excluding Argon-41	13,000	1,300
All other radionuclides (excepting tritium, carbon-14, iodine radionuclides and noble gases)	0.03	0.003

6 We conclude that the AP1000 stack provides adequate dispersion under GDA generic site conditions. However dispersion is very location specific and will need to be demonstrated as adequate by modelling for each specific site.

7 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

8 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.

9 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.

10 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.

11 In addition to using BAT to prevent and, where that is not practicable, minimise the creation of radioactive waste (as discussed in our report EAGDAR AP1000-03, see Environment Agency, 2011b), we also expect new nuclear power plant to use BAT to minimise the impact of discharges of radioactive waste to the environment.

12 This report assesses the gaseous radioactive waste created and whether the AP1000 uses BAT to minimise the impact of its discharge. We compare discharges with other comparable stations across the world and propose disposal limits and notification levels for those discharges.

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

a) shows BAT will be used to minimise the discharge and disposal of gaseous radioactive wastes (reference 1.5);

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

c) gives design basis estimates for monthly discharges of gaseous radioactive waste (reference 2.2); and

d) gives their proposed annual limits with derivation for gaseous radioactive waste (reference 2.3).

1.1 BAT to minimise discharges of gaseous radioactive waste

14 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*."

15 We published our Radioactive Substances Regulation Environmental Principles (REPs) in August 2009 (now RGN RSR 1 (Environment Agency 2010a)) and principle RSMDP3 (Use of BAT to minimise waste) states that:

"*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.*"

16 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, 2010b). 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].

17 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 several respondents]

18 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 several respondents]

19 In this report we assess the techniques Westinghouse use in the AP1000 to minimise the discharge and impact of gaseous radioactive wastes and present our conclusions on whether BAT is demonstrated.

20 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*".

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

22 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.

23 We raised 43 Technical Queries (TQs) on Westinghouse during our assessment. Three were relevant to this report.

a) TQ-AP1000-148 - Gaseous radioactive waste – abatement systems. 1 June 2009.

b) TQ-AP1000-149 - Gaseous radioactive waste – limits and levels of discharges. 1 June 2009.

c) TQ-AP1000-165 - Gaseous radioactive waste – grouping of radionuclides in discharge limits. 17 June 2009.

24 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.

25 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 publicly available on the AP1000 website.

26 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), publicly available on the AP1000 website (www.ukap1000application.com).

1.2 Comparison of discharges with other stations

27 We commissioned a study to help us compare discharges from designs put forward for GDA with currently operating nuclear power plant. Our Science Report SC070015/SR1 "*Study of historic nuclear reactor discharge data*" was published in September 2009. We used data from this report and our own sources to establish annual discharge ranges for significant radionuclides for "*comparable stations across the world*", see Annex 4 of our Decision Document (Environment Agency, 2011a).

28 This report compares the predicted gaseous discharges from the AP1000 with the ranges quoted in Annex 4 of the Decision Document.

Radionuclides or group of radionuclides	AP1000 predicted annual discharge	AP1000 normalised to 1000 MWe	Range for 1000 MWe station
Tritium GBq	1800	1611	100 - 3600
Carbon-14 GBq	606	542	40 - 530
Noble gases GBq	8047	7204	100 - 10000
Iodine-131 MBq	210	185	<1 - 2000
Other radionuclides not specifically limited MBq	13.44	12	<1 - 1000

29 The Committee on Medical Aspects of Radiation in the Environment (COMARE) (GDA130) suggested that as '*part of a new generation of plants, it might be expected that discharges would be lower than existing facilities, rather than 'within the range of historic discharges' which seems to be the criterion being applied by EA*'. We discuss the data we used to confirm discharges were comparable to current power stations in the Decision Document, Annex 4. We had difficulty that data was very variable and affected by matters such as shutdowns for periods that were not known. Also the data for the AP1000 are based on predictions as no AP1000 is yet running. Therefore attempting comparison to show lower discharges for the AP1000 was not possible. We have indicated throughout this report areas where the AP1000 has been improved

[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.

and the discharge reductions that are expected.

30 Westinghouse compared the AP1000 total predicted gaseous radioactive waste discharges from the AP1000 with published discharges from other nuclear reactors operating over the period 1995-1998. The reactors chosen by Westinghouse for the comparison are South Texas 1, Braidwood 1, Cook 1, Vogtle 1 and Sizewell B. These reactors were chosen because they are recently built Westinghouse PWRs in the USA and UK. Westinghouse claim that the data indicates that the predicted AP1000 annual discharges normalised to 1000 MWe output are lower than those from all but one of the reactors and are similar to that one. Examination of updated Westinghouse data shows the predicted AP1000 annual discharges normalised to 1000 MWe output are lower than those from Cook 1 and Sizewell B, but higher than those from South Texas 1, Braidwood 1 and Vogtle 1. (AP1000 BAT Table 4-11)

1.3 Discharge limits and levels

1.3.1 Radionuclides on which limits should be set

31 We recommended in the P&ID that RPs should take account of our Science Report SC010034/SR "*Development of Guidance on setting limits on discharges to the Environment from nuclear sites*" (Environment Agency, 2005). The report sets outs that limits should be set on radionuclides and / or groups of radionuclides which:

a) are significant in terms of radiological impact for humans and non human species, including radionuclides that may be taken up in food;

b) are significant in terms of the quantity of radioactivity discharges, whether or not they are significant for radiological impact;

c) have long radioactive half-lives, that may persist and / or accumulate in the environment and that may contribute significantly to collective dose;

d) are good indicators of plant performance and process control; or

e) provide for effective regulatory control and enforcement.

This advice from the report was essentially confirmed in the *Considerations* section of RSMDP12 in our REPs.

32 In addition our Considerations document (Environment Agency, 2009) recommends the following criteria for identifying radionuclides or groups of radionuclides for which to set plant limits:

a) Critical group dose from the established worst case plant discharges (EWCPD) is greater than 1 μSv per year;

b) Collective dose from the EWCPD is greater than 0.1 manSv;

c) The EWCPD exceeds 1 TBq per year;

d) Discharges of the radionuclide are a good indicator of plant performance or process control, or limits are otherwise felt to be necessary for effective regulatory control and enforcement.

33 We used the above advice and criteria to determine appropriate radionuclides and groups of radionuclides on which to set limits.

1.3.2 Time basis of limits

34 We decided that the most appropriate limit basis was that of a rolling 12 month period. This provides an element of flexibility for the site operator with respect to normal fluctuation in discharges on a month by month basis whilst exerting a smoothing effect. This encourages operators to ensure that discharges are made, wherever possible, at relatively consistent levels and to avoid short term elevations in the amount of

radioactivity discharged which may increase the impact on humans or non human species.

35 Discharge limits set on a rolling 12 month basis also allow derivation of information about discharges in any calendar year and such information is used to assess impact in terms of dose which is generally expressed in terms of dose in a calendar year. Additionally discharge limits set on a 12 month rolling basis allow reporting on annual discharges required under such things as the OSPAR Convention[2] and in UK publications such as the annual publication on Radioactivity in Food and the Environment (e.g. Environment Agency *et al* 2009).

36 We discarded the concept of discharge limits set in terms of activity discharge per cycle as this adds complexity to the regulatory process as in practice cycle lengths may vary from the operational aims of an 18 month cycle and it is difficult to set limits to take into account any unexpected changes in cycle length.

37 For simplicity we use the term *Annual Limit* later in this report and in the Decision Document but it should be taken that this would be expressed in a permit as a *12 month rolling limit*.

1.3.3 Limit setting

38 Our limit setting report recommends the use of a formula to determine the headroom which is appropriate to apply to average discharges to give operational flexibility and to take into account other conditions which might change during the period for which the limits would apply. The report recommends the use of a formula to calculate the "worst case annual plant discharge" (WCPD):

39 WCPD = (1.5 x D x T x A x B) + C + L + N – I where:

a) 1.5 is an Environment Agency-established factor which relates 'worst case' to average discharges and takes account of the requirement to minimise headroom.

b) D is the representative average 12-month plant discharge. The average excludes discharges due to faulty operation of plant but includes discharges arising from minor unplanned events.

c) T is a factor, which allows for any future increases in throughput, power output etc relative to the review period.

d) A is a factor, which allows for plant ageing – that is, for increases in discharges which result from changes within the plant as it ages that cannot be remedied or controlled by the operator.

e) B is a factor, which allows for other future changes that are beyond the control of the operator.

f) C is an allowance for decommissioning work beyond that carried out in the review period (and included in D).

g) L is an allowance for dealing with legacy wastes, beyond those dealt with in the review period (and included in D).

h) N is an allowance for new plant.

i) I is the reduction in discharges expected as a result of introducing improvement schemes before the new authorisation comes into force.

40 The discharge setting report recommends that WCPD for new plant should be a factor of 2 times the best estimate of discharges of radioactive waste.

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[2] Convention for the Protection of the Marine Environment of the North-East Atlantic, 1992 ("OSPAR Convention")

41 Subsequent to the report Statutory Guidance (DECC, 2009) to us states that we should set limits:

a) *based on the use of BAT; and*

b) *at the minimum levels necessary to permit "normal" operation of a facility.*

42 Statutory Guidance also states that "*Where the prospective dose to the most exposed group of members of the public from discharges from a site at its current discharge limits is below 10 μSv y^{-1} the Environment Agency should not seek to reduce further the discharge limits that are in place, provided that the holder of the authorisation applies and continues to apply BAT".* While this applies to existing sites we consider the 10 μSv y^{-1} is an appropriate guide to consider when deciding if BAT are used to minimise the impact of radioactive discharges for new sites.

43 We have assessed that the impact of radioactive discharges from the AP1000 to the most exposed person to be 8 μSv y^{-1} (our report EAGDAR AP1000-11, (Environment Agency, 2011d). We indicate in our assessment below the impact attributable to each considered radionuclide or group of radionuclides and have targeted our assessment time at those with the highest contribution to the total. Where some radionuclides have only minimal contribution (much less than 10 μSv y^{-1}) to the impact we have reduced our assessment time.

44 Our REPs reiterate the Statutory Guidance in relation to limits in the *Considerations* for principle RSMDP12:

a) *limits should be based on the level of releases achievable by the use of BAT by operators;*

b) *limits should be set such that there is a minimum headroom between actual levels of discharge expected during normal operation and the discharge limit.*

45 Westinghouse provided design basis estimates for discharges of gaseous radioactive waste that should include normal operational events such as start-up, shutdown, refuelling and maintenance (reference 2.2 P&ID). These were the '*representative 12-month plant discharge*' values given in the table below. These were the starting point for determining limits, our methodology allows the addition of contingencies to allow for such matters as uncertainty (an AP1000 has not yet operated so all figures are predictions) or infrequent but foreseeable events. The methodology also allows a factor to be applied to the expected value (up to x2 for a new plant) so that a limit is somewhat above the normally expected value to allow for operational variance and measurement accuracy. Westinghouse applied our methodology (see ERs6.1.2) and provided their '*worst-case plant discharge*' values as proposed limits. We reviewed the basis of both sets of values to decide ourselves the right limit to set.

1.3.4 Notification level setting

46 Our REPs state, in the *Considerations* for principle RSMDP12, that advisory levels should be set that:

a) *prompt review of whether the best available techniques are being used; and*

b) *ensure early assessment of the potential impact of increased discharges*.

47 Advisory levels should also require early reporting of:

a) *operational performance issues leading to increases in discharges; and*

b) *events that have given rise to higher than normal short term discharges*.

48 We have in the past set quarterly, weekly or daily advisory levels. We consider that as the radioactivity discharges from the AP1000 are of a relatively low quantity and reasonably even over time that only quarterly notification levels (QNL) should be set.

49 The QNL is defined precisely by a condition in any permit we issue, a typical condition would be:
If, in any quarter, the activity in waste discharged of any radionuclide or group of radionuclides specified in (the relevant Table) exceeds the relevant Quarterly Notification Level, the operator shall provide the Agency with a written submission which includes:

a) *Details of the occurrence;*

b) *A description of the techniques used to minimise the activity of waste discharged;*

c) *A review of those techniques having regard to the following:*

   i) The operator shall use the best available techniques to minimise the activity of radioactive waste produced on the premises that will require disposal to be disposed of on or from the premises;

   ii) The operator shall use the best available techniques in respect of the disposal of radioactive waste pursuant to this permit to:

      a) minimise the activity of gaseous and aqueous radioactive waste disposed of by discharge to the environment;

      b) minimise the volume of radioactive waste disposed of by transfer to other premises;

      c) dispose of radioactive waste at times, in a form, and in a manner so as to minimise the radiological effects on the environment and members of the public.

Not later than 14 days from making the record which demonstrates such excess.

50 The exceedence of a QNL set in a permit is not an offence. But it would be an offence for an operator to fail to notify us of the exceedence of a QNL in accordance with the relevant condition of the permit.

51 Normally we would use operational discharge data over at least 5 years to set QNLs. But as the AP1000 has not yet operated anywhere in the world we cannot do this at GDA. The simplest way to set a QNL would be to take a proportion of the annual limit, say 25%. However annual limits have contingency factors built in and we need to get early warning if discharges are above normal (without any contingency) so that we can ensure that BAT are still being used. We have therefore usually taken the “*expected performance*” figures quoted in the ER as our start point to set QNLs. The detail of how we set each QNL is given below.

52 It is possible that with operational discharge data from AP1000s currently under construction will become available during specific site permitting. We will review this and may need to revise the QNLs for any permit we issue.

53 A future operator (GDA128), was concerned that our rationale for setting QNLs as well as not being able to be based on operating data did not take account of operator or site-specific factors. We accept that different operators may have different waste management practices and there may be site-specific factors. Operators may propose their own basis for QNLs when applying for their permit. We have proposed an initial set of QNLs to show that we intend QNLs to reflect actual predicted discharges and provide notification to us for unusual discharges. The limits have contingencies built in and should not be considered as a starting point for QNLs.

54 An individual respondent (GDA124) considered some QNLs set at too high a level. When we have set a QNL at high level compared to a limit this is because we expect most of an annual discharge to be made in one quarter around a shutdown. We accept this may give us inadequate notification of high discharges in ‘normal’ operating times, we are considering using two levels of QNL, one for ‘normal’ operation and one for a shutdown period. This will need to be decided at site-specific permitting when we have the operators’ proposed discharge management regime.

55 An individual respondent suggested that QNLs should be based on limits but we use QNLs to help us ensure BAT is being used. QNLs should be based on expected normal discharges and the Operator would need to demonstrate that BAT has been used. If BAT is used then limits should be complied with as they are based on BAT.

56 An individual respondent asked that limits and QNLs be kept under review to ensure they are appropriate. We confirm that we review limits and QNLs whenever circumstances warrant this but also on a regular periodic basis.

2 Assessment

2.1 Assessment Methodology

57 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 discharges of gaseous radioactive waste using our internal guidance and regulatory experience and decide if they represent BAT;

e) liaise with HSE on matters of joint interest;

f) decide on any GDA Issues;

g) identify assessment findings to carry forward from GDA.

h) compare gaseous discharges from the AP1000 to ranges quoted in Annex 4 of the Decision Document (Environment Agency, 2011a);

i) assess the Westinghouse proposals for limits, compare with our own methodology and then propose our own limits and levels.

2.2 Assessment Objectives

58 We started our assessment with some key questions to answer:

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

b) Are all the significant radionuclides relating to gaseous radioactive waste identified and quantified, and has the quantity of secondary waste arisings from processing of gaseous radioactive wastes been included in estimates of waste streams?

c) Are all the assumptions in the submission relating to gaseous radioactive waste valid? For example, assumptions about the efficacy of abatement, the extent of liquid / gaseous partitioning which have a bearing on potential discharges need to be justified.

d) Have the proposed treatment techniques been identified and are these similar to those used in comparable reactors? Are there any novel features?

e) Are measures in place to detect leakage and prevent contamination of the environment?

f) Has variability in the nature of gaseous radioactive waste, ie in form and quantity, been identified and explained?

g) Have all discharge routes for gaseous radioactive wastes been identified? Has BAT been applied to all gaseous radioactive waste streams, and where appropriate has BAT been applied to particular radionuclides within a set of waste streams. The requirement to use BAT applies to both the treatment of wastes prior to disposal, and the method of operation of the process giving rise to the waste. BAT should take into account both the best technology and techniques available now, and any technology and techniques that they could avail themselves of in the foreseeable future.

h) Specific requirements for gaseous disposals may include:

   i) The use of the BAT to minimise the activity of waste discharged, for example by filtration or delay systems;

   ii) The use of the BAT to provide good dispersion, for example the height and location of discharge stacks relative to the surrounding terrain.

i) Are the proposed discharges of gaseous radioactive waste justified and reasonable and include a justified and reasonable contingency for variations in discharge levels during operations.

2.3 Westinghouse documentation

59 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 Designs - AP1000 Calculation Note	0

2.4 Origins of gaseous radioactive waste

60 The sources of gaseous discharges for the AP1000 are:

a) the reactor coolant system which discharges through the gaseous radioactive waste system;

b) the ventilation systems for the containment building, auxiliary building, turbine building, radwaste building and ILW store; and

c) the secondary circuit condenser air removal system.

61 The release points for gaseous radioactive discharges in normal operation are (ER s3.3.4) the main plant vent which is 5 m higher than the highest building in the vicinity (ER table 3.3-4) and located on the side of the reactor containment building and the ILW store ventilation stack for which design details are not yet available.

62 Radioactivity could be released under abnormal circumstances from the condenser air removal system and the turbine building ventilation system. These releases would be combined and discharged from the turbine building vent which is 38.4 m high (ER table 3.3-5) and located on the turbine building.

63 Westinghouse provides data on the annual amount of radioactivity in gaseous discharges, which they have calculated using the revised GALE Code (NUREG-0017,US NRC) and modified by proprietary calculations. (ER Tables 3.3-6 to 3.3-8). Westinghouse also proposes emission limits (ER s6.1 and Table 6.1-5). We have summarised the information in the table below and included information on our

proposed limits and QNLs which are explained further below.

	Westinghouse estimate of representative 12-month plant discharge in months 7 to 18 of the cycle (GBq y^{-1})	Westinghouse estimate of worst-case plant discharge (WCPD) (GBq y^{-1})	Annual limit proposed by Environment Agency (GBq y^{-1})	QNL proposed by Environment Agency (GBq in any 3 calendar months)
Tritium	1,867	3,081	3,000	600
Carbon-14	638	1,053	1,000	210
Argon-41	1,323	2,182	BAT condition applies	
Cobalt-60	0.00322	0.0053	Included in 'other particulate' limit	
Krypton-85	4,070	6,716	Included in noble gas limit	
Strontium-90	0.000444	0.000733	Included in 'other particulate' limit	
Iodine-131	0.207	0.0342	0.3	0.03
Xenon-133	1,335	2,203	Included in noble gas limit	
Caesium-137	0.00133	0.0022	Included in 'other particulate' limit	
Iodine radionuclides	0.595	0.98	Limit on iodine-131	
Noble gases	8,099	13,363	13,000	1,300
Other particulates(1)	0.0122	0.0201	0.03	0.003

(1) Other particulates are particulate radionuclides not individually listed which are present at very low individual activity levels.

64 Westinghouse considered the requirements of the EU Commission Recommendation 2004/2/Euratom to justify the basis for reporting gaseous radioactive waste discharges.

65 We will set limits and levels on the quantities of radioactivity that can be discharged into the environment where these are necessary to secure proper protection of human health and the environment. We have assessed the information within the ER against our criteria described above as follows:

a) critical group dose greater than 1 μSv y^{-1}: carbon-14 at 7 μSv y^{-1};

b) discharge exceeds 1 TBq y^{-1}: tritium and noble gases;

c) indicator of plant performance:

i) iodine radionuclides for fuel pin failures, we will use iodine-131 as an indicator;

ii) "all other radionuclides" to be monitored as particulates will confirm performance of filters in the ventilation systems.

66 We have set out our proposed disposal limits for tritium, carbon-14, noble gases, iodine-131 and other radionuclides in the Table above. The definition of "all other radionuclides" will be specified more completely in our permit with reference to the monitoring technique to be employed.

67 Our assessment concluded that:

a) all sources of gaseous radioactive waste have been identified;

b) the nature and form of gaseous radioactive waste has been identified in enough detail to demonstrate that treatment processes and disposal routes can be envisaged for all gaseous radioactive waste;

c) the data provided by Westinghouse relating to the sources of gaseous radioactive waste is comprehensive, justified and reasonable at the GDA stage.

2.5 AP1000 gaseous radioactive waste management systems

68 During reactor operation gaseous radioactive isotopes are created by neutron activation and fission and include tritium, carbon-14, argon-41 and radionuclides of xenon, krypton and iodine. Some of the gaseous radionuclides are formed in the primary coolant or air and some are formed in the fuel and released to the primary coolant through fuel cladding defects. The primary coolant undergoes degassing to remove gaseous radionuclides for appropriate treatment and processing.

69 Additionally as a result of reactor coolant leakage, primary gaseous radionuclides can be released into the containment atmosphere and collected for appropriate treatment and processing. Westinghouse claim that the primarily welded construction of the gaseous radioactive waste system will minimise leakage, and that air-operated diaphragm pumps or pumps with mechanical seals which are used will minimise system leakage in the form of releases of radioactive gas that might be entrained in the leaking fluid to the building atmosphere.

70 Releases of gaseous radioactive waste arise from:

a) Gaseous radioactive waste system.

b) Condenser air removal system.

c) Venting of the containment.

d) The ventilation system in the auxiliary and turbine buildings.

71 The management of gaseous radioactive waste is described in detail in the DCD Chapter 11.3.

72 Estimates of the radioactive source terms and annual average flow rate that will be processed in the gaseous radioactive waste system or discharged to the environment during normal operation have been provided in Table 11.3-3 of the European DCD.

2.5.1 Gaseous radioactive waste system (WGS)

73 The processing and treatment of gaseous radioactive waste takes place primarily in the gaseous radioactive waste system (WGS).

74 The gaseous radioactive waste system is used intermittently. Based on the maximum input gas volume, the gaseous radioactive waste system is expected to operate for approximately 100 hours per year (ER s3.3.1.2).

75 The gaseous radioactive waste system is designed to perform on an intermittent basis to:

a) Collect radioactive or hydrogen bearing gaseous wastes.

b) Process and discharge the waste gas while keeping offsite releases of radioactivity within acceptable limits.

76 The gaseous radioactive waste system is a once-through ambient temperature, activated carbon delay system which includes a gas cooler, a moisture separator, an activated carbon guard bed and two activated carbon delay beds. The radioactive gases entering the system are carried by hydrogen and nitrogen gas.

77 The radioactive fission gases entering the gaseous radioactive waste system (WGS) successively pass through:

a) The gas cooler, where they are cooled to about 4°C by the chilled water system.

b) The moisture separator, which is a 0.02 m^3 stainless steel receiver, collects condensed water vapour (including condensed tritiated water vapour) from the cooled gas thus removing it from the gaseous radioactivity stream. The moisture separator design pressure is 150 psig and the design temperature is 93°C. The collected water is periodically discharged automatically to the liquid radioactive waste system (WLS).

c) An activated carbon-filled guard bed, which protects the delay beds from abnormal moisture carryover or chemical contaminants. It absorbs radioactive iodine with efficiencies of 99% for methyl iodine and 99.9% for elemental iodine. It also provides increased delay time for xenon and krypton and deep bed filtration of particulates entrained in the gas stream. The guard bed is made of stainless steel with a volume of 0.277 m^3 and a design pressure of 100 psig and a design temperature of 66°C.

d) Two activated carbon-filled delay beds in series where xenon and krypton are delayed by a dynamic adsorption process. Radioactive decay of the fission gases during the delay period significantly reduces the radioactivity of the gas flow leaving the system. The delay beds are made of carbon steel with a volume of 2.265 m^3 and a design pressure of 100 psig and a design temperature of 66°C.

e) The minimum calculated holdup times are 38.6 days for Xenon and 2.2 days for Krypton which are based upon a continuous input flowrate to the gaseous radioactive waste system of 0.85 $m^3\ h^{-1}$. However, the design basis period of operation is the last 45 days of a fuel cycle when the reactor coolant system dilution and subsequent letdown is greatest. The average input flowrate is 0.024 m^3/h which results in longer hold up times being achieved.

f) Each delay bed is designed to provide 100 percent of the required system capacity under design basis conditions. During normal operation a single bed provides adequate performance. This provides operational flexibility to permit continued operation of the gaseous radioactive waste system in the event of operational upset in the system that requires isolation of one bed.

g) A radiation monitor before discharge to the ventilation exhaust duct.

78 Westinghouse claim (ERs3.3.1.2) that the gaseous radioactive waste system provides the capability to reduce the amounts of radioactive nuclides released in the gaseous wastes through the use of activated carbon delay beds. Inputs into the gaseous radioactive waste system are as follows:

a) **Reactor coolant system degassing**: The gaseous radioactive waste system periodically receives gases from the liquid radioactive waste system degasifier used in the processing of the chemical and volume control system letdown during dilution, boron addition and before shutdown. The liquid radioactive waste system degasifier discharge is the largest input to the gaseous radioactive waste system. The maximum input flowrate from the degasifier separator is 0.99 $m^3 h^{-1}$ based on a reactor cooling system hydrogen concentration of 45 $cm^3 kg^{-1}$.

b) **Reactor coolant drain tank degassing**: The reactor coolant drain tank contents are also subject to degassing in the liquid radioactive waste system degasifier and the resulting gas is then routed to the gaseous radioactive waste system. In addition the reactor coolant drain tank is vented to the gaseous radioactive waste system. The maximum input flowrate from the reactor coolant drain tank is 0.85 $m^3 h^{-1}$.

2.5.2 Condenser air removal system

79 The AP1000 design includes a condenser which is operated during plant start up, cool down and normal operation. The condenser collects air in-leakage and non-condensable gases from the turbine exhaust steam and exhausts them to the atmosphere via the condenser air removal stack. Whilst the condenser air removal system normally contains a low inventory of radioactivity it might become contaminated in the event of a steam generator tube leak (ERs3.3.4).

2.5.3 Containment building venting

80 The containment building can contain activity as a result of leakage of reactor coolant and as a result of activation of naturally occurring Ar-40 in the atmosphere resulting in the formation of Ar-41.

81 The containment venting system includes a containment air filtration system (VFS) which provides the following functions:

a) Intermittent flow of outdoor air to purge the containment atmosphere of airborne radioactivity during normal plant operation, and continuous flow during hot or cold plant shutdown conditions to provide an acceptable airborne radioactivity level prior to personnel access.

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) Directing 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.

82 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% 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.

83 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.

84 During normal plant operation, the containment air filtration system (VFS) is operated on a periodic basis 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.

85 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.

2.5.4 Building ventilation (Radiologically Controlled Area Ventilation System, VAS)

86 The radiologically controlled area ventilation system, VAS serves the fuel handling area of the auxiliary building and the radiologically controlled parts of the auxiliary and annex buildings [except for the health physics and hot machine shop areas which are provided with a separate ventilation system]. (ERs3.3.3) The VAS:

a) provides ventilation to maintain the equipment rooms within their design temperature range;

b) provides ventilation to maintain airborne radioactivity in the access areas at safe levels for plant personnel;

c) maintains the overall airflow direction within the areas it serves from areas of lower potential airborne contamination to areas of higher potential contamination;

d) maintains each building area at a slightly negative pressure to prevent the uncontrolled release of airborne radioactivity to the atmosphere or adjacent clean plant areas; and

e) automatically isolates selected building areas from the outside environment by closing the supply and exhaust duct isolation dampers and starting the containment air filtration system (VAS), when high airborne radioactivity in the exhaust air duct or high ambient pressure differential is detected.

87 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).

88 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 Air Filtration System, VFS, on detection of radioactivity. Changes have been made to the VAS and other ventilation 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 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.

89 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.

90 **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.

91 HSE have included an assessment finding for the licensee to ensure that the design changes associated with the provision of passive HEPA filtration for the nuclear ventilation systems in response to RO-AP1000-43 are completed and that the necessary design and safety documentation is updated accordingly. They have also included an assessment finding for the licensee to establish an appropriate filter change doctrine for all safety important filters within the nuclear ventilation systems.

92 The turbine building ventilation system (VTS) (ERs3.3.5) maintains acceptable air temperatures in the turbine building for equipment operation and for personnel working in the building. Air is exhausted from the turbine building to the atmosphere by roof exhaust ventilators. The roof exhaust ventilators are manually started and stopped as required to satisfy space temperature conditions.

93 Under normal operations the turbine building atmosphere is not radioactively contaminated. The potential for radioactive contamination only arises in the event of a primary-secondary cooling leak failure.

94 Extract air from the radioactive waste building is by means of low level extract grilles (ERs3.3.2.6) and is conveyed through high integrity ductwork to HEPA filters and discharged to the main plant exhaust stack by two 50% duty extract fans.

2.5.5 Plant vent

95 The main plant vent is 5 m higher than the highest building in the vicinity and is a rectangular stack of dimensions 2.025 m x 2.311 m. The volumetric flow rate is 38.13 $m^3 s^{-1}$ with a nominal discharge velocity of 8.15 m s^{-1}. The exhaust temperature is 285 to 315°K. The main plant vent is located on the side of the reactor containment building. (ER Table 3.3-4)

2.5.6 Condenser air removal (turbine) vent

96 The condenser air removal (turbine) vent is a 38.4 m circular stack which is 0.3048 m in diameter. The volumetric flow rate is 0.6 $m^3 s^{-1}$ with a nominal discharge velocity of 8.2 m s^{-1}. The exhaust temperature is 285 to 315°K. The condenser air removal (turbine) vent is located on the turbine building. (ER Table 3.3-5)

2.5.7 BAT for filters and delay beds

97 We raised a Technical Query, TQ-AP1000-148, on 1 June 2009 requiring Westinghouse to provide information:

a) to demonstrate that the AP1000 design included an adequate number of appropriate filters for gaseous radioactive waste which are of a suitable design and construction;

b) on the arrangements relating to gaseous radioactive waste delay beds; and

c) on the arrangements for moisture separation.

98 Westinghouse responded on 14 July 2009 and its response included the information set out in the following section, and which was subsequently included in the revised ER:

'*BAT – Waste Gas System*

The WGS [Waste Gas System] *is described in Chapter 11.3 of the European DCD. The system includes a gas cooler, a moisture separator, an activated carbon-filled guard bed, and two activated carbon-filled delay beds. Also included in the system is a gas sampling subsystem.*

The carbon delay beds were designed with a folded serpentine configuration to minimise space requirements and maximise the length of the gas pathway. The waste gas flow is generally vertical (up and down) through columns of granular activated carbon. Each serpentine bed has four legs. The number of legs, and hence the volume of carbon in the delay bed has been optimised by evaluating the radioactive releases (by analysis in GALE[3]) expected as a function of the number of legs.

Increasing the number of legs above 8 has a diminishing benefit in terms of reducing releases of radioactivity. Increasing the size of the delay bed is not warranted in terms of the cost of increasing volumetric space requirements within the auxiliary building which is a Category 1 seismic building; the cost of purchase, installation and decommissioning of the additional serpentine legs and the additional cost of activated carbon..

The delay bed is protected from moisture, iodine, and particulate loading by a moisture separator and an activated carbon-filled guard bed. The flow rate through the delay beds is very low, typically 0.014 scfm (0.0004 m^3/min) and with an upward flow the velocity is insufficient to suspend particulates, so there is no need for a HEPA filter after the delay beds.

BAT-Ventilation filters.

The containment air filtration system is described in Section 9.4.7 of the European DCD. The specification of the ventilation filters is described in Table 3.3-3 of the ER, reproduced below.

Each exhaust air filtration unit consists of an electric heater, an upstream high efficiency filter bank, a HEPA filter bank, a charcoal adsorber with a downstream postfilter bank, and an exhaust fan. The HEPA filter housing design will be capable of holding a range of different specification filters. Higher specification filters are available. However, these filters may increase differential pressure and have shorter replacement intervals than the specified filters. This would result in increased energy

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[3] NUREG-0017, Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactor, PWR-Gale Code, Rev. 1

use on the extraction fans and larger filter element waste volumes requiring disposal as LLW. The final choice of filter element is best determined by operator experience; the balance between filter performance, optimum cost of filters, and cost of filter disposal can be evaluated.

Information on the filters is included in the table [below, reproduced from the ER]:

	Pre High Efficiency Filter	HEPA Filter	Charcoal Filter	Post High Efficiency Filters
Design Type	High Efficiency	HEPA	Type III rechargeable cell	High Efficiency
Design Code or Standard	ASME N509	ASME N509	ASME N509	ASME N509
Dimensions (Approximate maximum for each unit)	35' x 6.5' x 5.6' (10.7m x 2.0m x 1.7m			
Construction Material / Filter Material	Utility specific	Utility specific	Utility specific	Utility specific
Filter Pass (Pore) Size	Utility specific	Utility specific	Utility specific	Utility specific
Typical Flow rate Per Unit(m^3 hr^{-1})	6800	6800	6800	6800
Efficiency	80% minimum ASHRAE efficiency	99.97% DOP	90% decontamination efficiency	95% DOP
Monitoring of Efficiency	Periodic DOP testing	Periodic DOP testing	Periodic DOP testing	Periodic DOP testing
Detection of Filter Blinding	Differential pressure instrument	Differential pressure instrument	Radiation monitoring in the plant vent	Differential pressure instrument
Typical 'In-Service' Periods	Once a week for 20 hours			
Arrangement to Take Filter Out of Service	Both filter units are 100% redundant. When one is being maintained it can be bypassed and the other can be used.			

VAS [the radiologically controlled area ventilation system] *will have 8 filters (4 pre-filters and 4 Hi-Efficiency filters) and VFS will have 24 filters (each air handling unit has 4 pre-filters, 4 HEPA filters, and 4 Hi-Efficiency filters and two air handling units per system). Change out of each of these filters, in addition to the filters in the non-radioactive auxiliary building ventilation system (VBS) during a fuel cycle will yield ~120 cu. feet (3.4 m^3) of low-activity waste* [LLW]

The filter selection has no impact on the gaseous radioactive emissions which constitute more than 99% of all atmospheric radioactive releases. The filter selection can improve the capture of radioactive particulate emissions. The HEPA filters proposed will reduce particulate emissions by >99.97%. Further reduction is possible by specification of higher efficiency filters. However, it is likely that the filter elements may have to be replaced more frequently generating additional LLW. The final choice of filter element is best determined by operator experience; the balance between filter performance, optimum cost of filters, and cost of filter disposal can be evaluated

Design information on the delay beds used to treat radioactive waste is provided in the table below. The minimum calculated hold-up times are 38.6 days for xenon and 2.2 days for krypton, based upon a continuous input flowrate of 0.5 scfm (0.014 m^3/min) to the gaseous radwaste system, WGS. Because the WGS operates intermittently, the actual anticipated delay will be much longer; for example, the limiting (maximum WGS input) period of the cycle is the last 45 days, during which the average input flowrate is 0.014 scfm (0.0004 m^3/min). (See European DCD 11.3.1.2.1.1) However, the benefit of this intermittent operation has been conservatively neglected by Westinghouse.

The two delay beds are identical and the table below applies to both:

	Delay Beds
Design Type	20 in. (0.5 m), S-20 Pipe, Folded Vertical, Serpentine
Design Code or Standard	ASME Section VIII, Division I, stamped
Dimensions	See APP-MV6H-V0-001
Construction Material / Adsorptive Media	Carbon Steel / Granular or Coconut Shell Carbon
Typical Flowrate (m3 hr^{-1})	1.0 – 1.83
Efficiency	Each bed alone: 92%; Two beds together: 97%
Monitoring of Efficiency	Radiation monitoring
Detect Failure of Bed	Hydrogen monitor in delay bed compartment, low pressure indication
Typical 'In-Service' Periods	Design basis period is last 45 days of the fuel cycle. Based on input gas volume, system expected to operate70 hours per year.
Arrangement to Take Bed Out of Service	Isolation valves allow bypass of either bed

The liquid discharges from the moisture separator are directed to the liquid radwaste, WLS degasifier separator and then to the Effluent Hold-up Tank. The contents of the tank are processed through filters and demineralisers before being monitored and discharged.’

99 Westinghouse incorporated the above response to TQ-AP1000-148 in section 3.3.9, Figure 3.3-2 and Table 3.3-2 in its Environment Report and provided further supporting information.

100 On the basis of its BAT options assessment, Westinghouse claims there are a number of measures in the design of the AP1000 which will prevent or minimise waste at source (ERs3.3.5) and with respect to minimising gaseous radioactive waste these include:

a) **Optimisation of delay bed sizing**: Westinghouse claim the carbon delay beds have been designed as a folded serpentine configuration to minimise space requirements and the potential for voids in the activated carbon. The length to diameter ratio is claimed to maximise the ratio of breakthrough time to mean delay time. The waste gas flow is generally vertical (up and down) through columns of granular activated carbon. No retention screens are required on the delay bed since the flow is low velocity and enters and leaves each delay bed at its top. Westinghouse confirm no failure mechanisms have been identified that could increase discharge flow rates high enough to suspend activated carbon particulates from the delay beds.

   Each serpentine has four legs. Westinghouse claim the number of legs, and hence the volume of carbon in the delay bed has been optimised by evaluating the radioactive releases (using the GALE code) expected as a function of the number of legs. Westinghouse claim the optimum number of legs in the delay bed system is eight and that increasing the number of legs above eight has a diminishing benefit in terms of reducing releases of radioactivity. Westinghouse claim that increasing the size of the delay bed is not warranted in terms of the cost of increasing volumetric space requirements within the auxiliary building which is a Category 1 seismic building; the cost of purchase of, installation and decommissioning of the additional serpentine legs and the additional cost of activated carbon.

b) **HEPA filter selection:** Westinghouse claim the HEPA filter housing design will be capable of holding a range of different specification filters. Higher specification HEPA filters are available than those identified by Westinghouse in the Environment Report Table 3.2-2. However, Westinghouse claim these filters may increase differential pressure and have shorter replacement intervals than the specified filters. This would result in increased energy use on the extraction fans and a larger filter element waste volumes requiring disposal as LLW. Westinghouse suggest that the final choice of filter element is best determined by operator experience when the optimum balance between cost of filters, cost of filter disposal and filter performance can be evaluated.

c) **Radiologically controlled area ventilation (VAS)**: Westinghouse claim that the normal operating condition is one in which radioactivity is not detected within the radiologically controlled areas of the auxiliary and annex buildings. Under these circumstances the air extracted by the ventilation system is emitted to atmosphere via the plant vent without treatment. Westinghouse claim that the advantage of this system is that the exhaust air filtration units of the VFS are not being used to filter uncontaminated air which prolongs the life of the filters and charcoal adsorber and minimises the generation of LLW.

101 Our Radioactive Substances Environmental Principle RSMDP3 requires that 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. We consider that Westinghouse have considered a comprehensive range of techniques for the minimisation of gaseous radioactive waste discharges. We conclude that the overall outcome of the BAT options assessment relating to minimising the discharge of gaseous radioactive waste to be reasonable and to fulfil the requirements of REP RSMDP3 at this stage.

2.6 BAT, limits and QNLs

102 Westinghouse undertook a BAT options assessment on the abatement of certain key radionuclides, the UK AP1000 Nuclear Power Plant BAT Assessment. They have provided information for tritium, carbon-14, iodine-131, noble gases (argon-41, krypton-85m, krypton 85, xenon-133m and xenon-133) and beta emitting particulates (cobalt-58, cobalt-60, iron-55 and nickel-63) in gaseous radioactive waste.

103 For each radionuclide Westinghouse have considered the options for abatement 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.

104 The outcomes of the BAT options assessment exercise are below, with our conclusions on BAT followed by impact information and then our proposals for limits and QNLs:

2.6.1 Tritium

105 Tritium is present in the coolant usually replacing one or more hydrogen atoms in water (tritiated water) or less prevalent as a dissolved gas. The majority of tritium will remain in liquid effluent after letdown of coolant to the chemical and volume control system (CVS) (some 800 m^3 y^{-1}). Gaseous tritium collected in the CVS is sent to the gaseous radwaste system (WGS) and will be discharged to air through the main vent.

106 Westinghouse considers the abatement options to minimise the gaseous discharge of tritium to be (AP1000 BAT Form 1):

a) decay by delay. Westinghouse considers this option to be impractical as the half-life of tritium is 12.3 years;

b) adsorption processes. Westinghouse considers that adsorption cannot be used to separate tritiated and non-tritiated gas;

c) isotopic concentration may be possible but the technology is not well developed and costs of development would be significant and difficult to justify against the impact of unabated discharges;

d) the use of a condenser will not affect discharge of gaseous tritium but may reduce the discharge of tritiated water vapour. The WGS has a condenser to dry gaseous effluent before it enters the delay beds. This has the benefit of reducing tritium discharge to air by minimising the level of tritiated water vapour in the gaseous effluent. The condensate is directed to liquid effluent;

e) cryogenic systems could be used to liquefy tritium but will be expensive and difficult to justify against impact of unabated discharges. In addition they are complex and could give higher occupational radiation exposure, produce increased amounts of waste for disposal during operation and at decommissioning and require long-term storage of the separated tritium which may difficult to contain;

f) optimising plant design, plant availability and operating practices all contribute to minimising tritium production.

107 The highest scoring options were direct discharge, the use of a condenser and the minimisation of plant shutdowns. Westinghouse claim that using a condenser will divert tritiated water vapour from the gaseous waste stream into the liquid waste where the impact on the environment and members of the public are reduced. Westinghouse state that a condenser is included in the AP1000 design. Westinghouse claims the AP1000 has an improved design and capability to minimise tritium production. Westinghouse claims that no abatement techniques for minimising gaseous tritium discharges are BAT for use on the AP1000. The use of a condenser in the WGS minimises potential for tritiated water discharge to air.

108 Our assessment concluded that while the study is low on detail, as the impact of tritium discharges on the environment is low, we accept that no abatement for gaseous tritium is BAT for the AP1000 design.

109 We recognise, however, that operational techniques to minimise tritium discharges 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, a topic in report AP1000-01, Management Systems (Environment Agency 2011c).

110 Westinghouse predicts that the annual average discharge of tritium over the 18 month cycle from the AP1000 to atmosphere will be 1,800 GBq. (ER Table 3.3-7)

111 Westinghouse proposes a discharge limit for tritium from the AP1000. It has predicted monthly discharges over an 18-month cycle and used data from the 12 months in which the discharges are highest (month 7 – 18) to calculate the representative 12-month plant discharge to be 1867 GBq. Westinghouse has applied our limit setting methodology (Environment Agency, 2005) to calculate the annual worst-case plant discharge (WCPD), which it has rounded to give its proposed limit. (ERs6.1.3)

112 Westinghouse has proposed an annual limit of 3,000 GBq for tritium discharges. (ER Figure 6.1-3 and ER Table 6.1-7)

113 We examined historic discharges (where available) from European and US PWRs operating over the last 10 to 15 years and consider that the range of discharges to atmosphere of tritium is 100 to 3600 GBq per year for a 1000 MWe power station. We conclude that the gaseous discharge of tritium from UK AP1000 at the predicted annual discharge of 1,800 GBq is comparable to other power stations across the world.

114 Westinghouse estimates that the radiological impact from the representative 12-month plant discharge of tritium to atmosphere will result in a dose to the local resident family selected to represent exposure pathways associated with atmospheric releases from the AP1000 of 0.086 $\mu Sv\ y^{-1}$. (ER table 5.2-16). The local resident family comprises infants, children and adults who live 100 m from the aerial discharge point. They spend most of their time at home, some of which is spent outdoors. They eat food from local sources and milk from local farms which are 500 m from the aerial discharge point. They eat locally caught fish and shellfish.

115 COMARE (GDA130) note that the recent report of the Advisory Group on Ionising Radiation (AGIR) (November 2007) suggests that current dose estimates for tritiated water are too low. In April 2008 the Health Protection Agency advised us on the implications of the AGIR report on tritium for our regulatory dose assessments. Their advice was that the current dose assessment methods should remain unchanged – they endorsed our approach to the assessment of doses from tritium; that is, the use of standard International Commission on Radiological Protection (ICRP) dose coefficients. The impacts for tritium provided by Westinghouse and ourselves throughout this document are therefore based on current standard ICRP recommendations. The HPA identified examples of when the AGIR recommendation

could be taken into account, which would be for estimates of dose and risk to individuals, for the purposes of calculation of probability of cancer causation, including more precise relative biological effectiveness (RBE) values and risk factors specific to those individuals.

116 We have independently calculated limits for tritium discharges that we may grant and based on the information provided by Westinghouse for GDA, our proposed disposal limit for tritium by discharge to atmosphere is 3,000 GBq in any rolling 12 calendar months.

117 Based on the information Westinghouse has provided for GDA on the discharges of tritium in the three months where they are expected to be the highest, our proposed quarterly notification level for tritium is 600 GBq.

118 An individual respondent (GDA39) suggested the QNL for tritium be reduced to 500 GBq. We based the QNL on the highest three month discharge at the end of a cycle just before shutdown for refuelling when monthly discharges are nearly two times that at the beginning of a cycle. The lowest three monthly discharge is less than 400 GBq. We noted above that we may consider two levels of QNL, in that case we might set 500 GBq as ‘normal’ and 600 GBq as ‘shutdown’.

2.6.2 Carbon-14

119 The main source of carbon-14 is the activation of oxygen and nitrogen in the reactor coolant. The carbon-14 is mainly present as carbon atoms in dissolved hydrocarbon gases (75-95 per cent), mainly methane (CH_4) and a small fraction as carbon dioxide (CO_2). A portion of the coolant continually passes through the CVS where dissolved gases are removed and directed to the WGS. The WGS does not remove carbon-14 from the gaseous waste steam and it is discharged through the main plant vent. A small portion of carbon-14 will remain in liquid effluent from the CVS, some of which will become solid waste such as filter elements and spent ion exchange resins.

120 Westinghouse provides a review of available gaseous abatement techniques to minimise carbon-14 discharges. Most of the techniques relate to removing CO_2 from gas streams. As most of the carbon-14 is in the form of hydrocarbons a pre-treatment (for example, high temperature catalytic oxidation) is needed to convert the hydrocarbons to CO_2. This would make any option more expensive and complicated. The options reviewed were: (AP1000 BAT Form 2)

a) alkaline slurry scrubber;

b) alkaline packed bed column;

c) double alkali process;

d) gas absorption by wet scrubbing;

e) ethanolamine scrubbing;

f) absorption in a fluorocarbon solvent;

g) physical absorption on an active surface;

h) reaction with magnesium;

i) isotopic concentration and / or separation;

j) cryogenic systems to give liquid CO_2.

121 Westinghouse have scored the options against the attributes described in the BAT report and the highest scoring option is direct discharge without abatement. The use of alkaline scrubbing or an alkaline packed column have mid range scores. Westinghouse indicates that there are issues for all the above options such as high cost because no system is a proven technique for PWRs and they would need developing. In addition, systems would become more complex and there would be

increased occupational radiation exposure. There may also be disposal issues relating to the carbon-14 containing waste generated and additional equipment, which would need to be decommissioned at the end of life.

122 Westinghouse claims that no option considered is BAT for use on the AP1000 and proposes direct discharge of carbon-14 without abatement. It recognises, however, that ion exchange systems provided to remove other radionuclides may remove carbon-14 that is present in the form of carbonate and bicarbonate in the coolant. This may reduce the amount of carbon-14 becoming gaseous radioactive waste.

123 We consider that the techniques Westinghouse has considered for abatement of carbon-14 in gaseous radioactive waste from the AP1000 are comprehensive enough and represent current feasible techniques.

124 Our assessment concluded that the AP1000 design uses BAT to minimise the discharge of gaseous carbon-14.

125 We included the need for a '*detailed and robust justification of options for carbon-14 abatement*' as an other issue in our Consultation Document. We now consider that such options are longer term and have not carried this forward as an assessment finding for GDA. We will look for future operators to consider this in their periodic BAT reviews.

126 The Institution of Mechanical Engineers (GDA146) said that more information was needed for a BAT assessment on carbon-14 abatement. We conclude that the AP1000 is BAT in this regard at present but, as noted above, this is an area where developing technology needs to be kept under review by future operators.

127 Westinghouse predicts that the annual average discharge of carbon-14 over the 18-month cycle from the AP1000 to atmosphere will be 606 GBq. ER Table 3.3-7.

128 Westinghouse proposes a discharge limit for carbon-14 from the AP1000. It has predicted monthly discharges over an 18-month cycle and used data from the 12 months in which the discharges are highest (month 7 – 18) to calculate the representative 12-month plant discharge to be 638 GBq. Westinghouse has applied our limit setting methodology (Environment Agency, 2005) to calculate the annual worst-case plant discharge (WCPD), which it has rounded to give its proposed limit. (ERs6.1.3)

129 Westinghouse proposes an annual limit of 1,000 GBq for carbon-14 discharges. (ER Figure 6.1-4 and ER Table 6.1-7)

130 We examined historic discharges (where available) from European PWRs operating over the last 10 to 15 years and we consider that the range of discharges to atmosphere of carbon-14 is 40 to 530 GBq per year for a 1000 MWe power station. The predicted annual average gaseous discharge of carbon-14 from UK AP1000 normalised for power (542 GBq) slightly exceeds this range.

131 Westinghouse estimates that the radiological impact from the representative 12-month plant discharge of carbon-14 to atmosphere will result in a dose to the local resident family of 3.3 $\mu Sv\ y^{-1}$. (ER table 5.2-16)

132 We have independently calculated limits for carbon-14 discharges that we may grant and, based on the information Westinghouse has provided for GDA, our proposed disposal limit for carbon-14 by discharge to atmosphere is 1,000 GBq in any 12 rolling calendar months.

133 COMARE (GDA130) noted that carbon-14 dominated the dose impact and recommended carbon-14 be monitored in the discharge. We confirm that we will require a monitoring method specific to carbon-14 to be used on gaseous discharges.

134 Based on the information Westinghouse provided for GDA, our proposed quarterly notification level for carbon-14 is 210 GBq.

135 A respondent (GDA39) suggested that the QNL for carbon-14 be reduced to 180 GBq. We based the QNL on the highest three month discharge at the end of a cycle just before shutdown for refuelling when monthly discharges approach two times that at the beginning of a cycle. The lowest three monthly discharge is less than 140 GBq. We noted above that we may consider two levels of QNL, in that case we might set 180 GBq as ‘normal’ and 210 GBq as ‘shutdown’.

2.6.3 Strontium-90

136 Westinghouse predict that averaged over the 18 month cycle, 0.44 MBq y^{-1} of strontium-90 will be discharged in gaseous radioactive waste. The discharges of strontium-90 in the highest 12 months of the 18 month cycle are estimated to be 4.4E-04 GBq. Westinghouse estimate the impact of discharging 4.4E-04 GBq of strontium-90 in 12 months will be 9.6E-05 μSv y^{-1} to the local resident family (0.001% of total dose to local resident family). (BAT Assessment form 4).

137 Westinghouse have provided information on the abatement options for strontium-90 in gaseous radioactive waste in the AP1000:

a) Wet scrubbing – no information provided.

b) No abatement -– direct discharge of liquid radioactive waste to the environment.

c) Carbon delay beds – half life of strontium-90 is 29.1 years.

d) HEPA filtration on the radioactively contaminated area ventilation system.

138 Westinghouse say that the highest scoring option for abating strontium-90 in gaseous radioactive waste is the use of HEPA filtration. Westinghouse claim that HEPA filtration for radiologically controlled areas is included in the AP1000 design. HEPA filtration of gaseous waste other than that from radiologically controlled areas is not considered necessary by Westinghouse as this waste will be treated using carbon delay beds which Westinghouse state will provide adequate filtration.

139 Westinghouse estimate that the radiological impact from the representative 12 month discharge of strontium-90 to atmosphere will result in a dose to the local resident family of 0.000096 μSv y^{-1}.

140 We will include strontium-90 in the limit set for beta emitting particulates.

2.6.4 Noble gases

141 Westinghouse predict that noble gases will be present in gaseous radioactive waste in the following amounts (AP1000 BAT Form 8):

Radionuclide	Discharge averaged over the 18 month cycle (GBq y^{-1})	Discharge in the highest 12 months of the 18 month cycle (GBq y^{-1})	Dose to local resident family (μSv y^{-1})	% of total dose to resident family
Argon-41	1.3E+03	1.323E+03	1.3E-01	1.7
Krypton-85m	2.4E+01	Not given		
Krypton-85	3.1E+03	4.07E+03	1.6E-03	0.02
Xenon-133m	1.1E+02	Not given		
Xenon-133	1.3E+03	1.335E+03	2.8E-03	0.04

142 Removing xenon and krypton radionuclides from the coolant is not normally necessary provided fuel defects are within normally anticipated ranges. However, degassing of the coolant is carried out from time to time, in particular during dilutions of the boron content of the coolant, borations and before shutdowns using the vacuum degasifier within the liquid radwaste system (WLS). (ERs3.3.1.1)

143 Gases from degassing enter the gaseous radwaste system (WGS). The WGS is expected to be operated around 100 hours a year. (ERs3.3.1.2)

144 Argon-41 arising from the activation of naturally occurring argon-40 in the air around the reactor is sent to the main stack by the ventilation systems. It does not pass through the WGS but is monitored in the stack before discharge.

145 Noble gases are inert and, therefore, difficult to remove from gaseous effluent. Westinghouse has provided information on the abatement options for noble gases in the AP1000 (AP1000 BAT Form 8):

a) Carbon delay beds with a 38.6 day delay for xenon and a 2.2 day delay for krypton.

b) Minimise plant shutdowns.

c) Cryogenics to liquefy and separate noble gases.

146 Westinghouse considers that cryogenics would be expensive in capital and running costs, be complex, increase occupational radiation dose and produce waste that is difficult to dispose of. Westinghouse does not consider cryogenic systems BAT for the AP1000, but chooses to rely on carbon beds in the WGS to delay the discharge of noble gases and, therefore, reduce discharged radioactivity through radioactive decay.

147 The WGS is a once-through, ambient temperature, activated carbon delay system comprising (ERs3.3.1.2):

a) the gas cooler, where they are cooled to about 4°C by the chilled water system;

b) the moisture separator, which is a 0.01 m^3 stainless steel receiver, removes condensed water vapour (including condensed tritiated water vapour) from the cooled gaseous radioactivity stream. The moisture separator design pressure is 150 psig and the design temperature is 93°C. The collected water is periodically discharged automatically to the liquid radioactive waste system;

c) an activated carbon-filled guard bed, which protects the delay beds from abnormal moisture carryover or chemical contaminants. It absorbs radioactive iodine with efficiencies of 99 per cent for methyl iodine and 99.9 per cent for elemental iodine. It also provides increased delay time for xenon and krypton and deep bed filtration of particulates entrained in the gas stream. The guard bed is made of stainless steel with a volume of 0.277 m^3 and a design pressure of 100 psig and a design temperature of 66°C;

d) two activated carbon-filled delay beds in series where xenon and krypton are delayed by a dynamic adsorption process. Radioactive decay of the fission gases during the delay period significantly reduces the radioactivity of the gas flow leaving the system. The delay beds are made of carbon steel with a volume of 2.265 m^3 and a design pressure of 100 psig and a design temperature of 66°C.

    i) The minimum calculated holdup times are 38.6 days for xenon and 2.2 days for krypton, which are based upon a continuous input flowrate to the gaseous radioactive waste system of 0.85 $m^3\ h^{-1}$. However, the design basis period of operation is the last 45 days of a fuel cycle when the reactor coolant system dilution and subsequent letdown is greatest. The average input flowrate is 0.024 $m^3\ h^{-1}$ which results in longer hold up times being achieved. Xenon-133, with a maximum half-life of 5.25 days should be decayed to less than 0.5 per cent of the activity entering the WGS. Krypton-85m, krypton-87 and krypton-88 with half-lives of only a few hours will be substantially reduced, but krypton-85 with a half-life of 10.72 years will be unaffected;

ii) The two delay beds together provide 100 percent of the required system capacity under design basis conditions. During normal operation a single bed provides adequate performance. This provides operational flexibility to permit continued operation of the gaseous radioactive waste system in the event of operational upset in the system that requires isolation of one bed;

e) a radiation monitor before discharge to the ventilation exhaust duct.

148 Westinghouse provided a BAT assessment to justify the sizing of the delay bed (ERs3.3.5.1). The beds have a folded serpentine design so that each has four adsorption legs where the length to diameter ratio maximises delay time. The two beds are in series and each has four adsorption legs. Westinghouse claims that (ER Figure 3.3-3) increasing the total number of legs beyond eight has a limited effect in reducing activity. Westinghouse concludes that providing two beds in series is BAT, our own assessment confirmed that conclusion.

149 Our assessment concluded that the techniques considered by Westinghouse for the abatement of xenon and krypton radionuclides in gaseous radioactive waste from the AP1000 are BAT.

150 The Institution of Mechanical Engineers (GDA146), while recognising the value of carbon delay beds, warns that these can present a significant fire hazard requiring mitigation by the installation of appropriate fire detection and protection equipment. We have passed this comment to the HSE

151 Westinghouse has predicted the annual average discharge of noble gases over the 18-month cycle from the AP1000 to atmosphere set out in the table below (ER Table 3.3-7):

Radionuclide	**Activity in gaseous discharge (GBq y^{-1})**
Argon-41	1,300
Krypton radionuclides	3,170
Xenon radionuclides	3,577
Total	**8,047**

152 Westinghouse proposes a discharge limit for noble gases (excluding argon-41) from the AP1000. It has predicted monthly discharges over an 18-month cycle and used data from the 12 months in which the discharges are highest (month 7 – 18) to calculate the representative 12-month plant discharge to be 8099 GBq. Westinghouse has applied our limit setting methodology (Environment Agency, 2005) to calculate the annual worst-case plant discharge (WCPD), which it has rounded to give its proposed limit. (ERs6.1.3)

153 Westinghouse proposes an annual limit of 13,000 GBq for noble gases (excluding argon-41). (ER Figure 6.1-2 and ER Table 6.1-7).

154 COMARE (GDA130) make some important points on fuel integrity: *'Both designs depend to a great extent on the manufacturing quality control and reliability of fuel elements in order to control waste arisings. It will be important to ensure that operators adhere to the intended operating standards over the lifetime of the plant and that it is made mandatory to implement any improvements made by the manufacturers. What arrangements would be available if current manufacturers went out of business? We support the EA approach of using QNLs in order to give early warning of problems arising from fuel assemblies.'*
Our permit conditions require operators to use and review BAT, the scope of which includes fuel integrity matters. There are a number of suppliers of nuclear fuel

worldwide and operators are free to select an appropriate manufacturer based on relevant criteria, for example on technical and commercial specifications. Irrespective of who manufactures the nuclear fuel, operators will need to ensure that any fuel used in their reactors meets quality expectations and that its design represents BAT. The QNL we set below is intended to alert our Inspectors to any fuel issues to enable early investigation and possible intervention

155 Westinghouse say that the AP1000 GDA design basis is using Westinghouse fuel type 17RFA. Westinghouse provide information 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}*' (less than 10^{-5} means less than 10 in a million or 1 in 100,000)(ERs3.2.4)

156 The Health Protection Agency (GDA89) was concerned on the lack of fuel pin integrity data and a case for 18 month refuelling cycles. As noted above Westinghouse use a design basis for fission product discharge from fuel pins as '*that small cladding defects are present in fuel rods producing 0.25 per cent of the core power output*' (AP1000 European Design Control Document). However Westinghouse state in their Environment Report that the '*fuel leak rate is much less than the design basis*'. The final choice of fuel and refuelling cycle length will be for the future operators. As noted in our paragraph above future operators will need to demonstrate to us that they have used BAT to source the supply of best available fuel (that with the lowest failure rate) and set the length of refuelling cycles used.

157 We examined historic discharges (where available) from European and US PWRs operating over the last 10 to 15 years and we consider that the range of discharges to atmosphere of noble gases is 100 to 10,000 GBq per year for a 1000 MWe power station. The predicted annual average gaseous discharge of noble gases from AP1000 at 8047 GBq is within this range. We conclude that gaseous discharge of noble gases is comparable to other power stations across the world.

158 Westinghouse estimates that the radiological impact from the representative 12-month plant discharge disposal to atmosphere will result in doses to the local resident family set out below: (ER table 5.2-16)

a) estimated dose from argon-41 is 0.029 $\mu Sv\ y^{-1}$

b) estimated dose from krypton-85 is 0.00137 $\mu Sv\ y^{-1}$

c) estimated dose from xenon-133 is 0.00064 $\mu Sv\ y^{-1}$

159 We have independently calculated limits on noble gas discharges that we may grant and based on the information Westinghouse provided for GDA, our proposed disposal limit for the disposal of noble gases (excluding argon-41) by discharge to the atmosphere is 13,000 GB in any rolling 12 calendar months.

160 The annual average discharge includes an allowance for failed fuel pins. Westinghouse has not provided an estimate of discharge without pin failures and we normally base our QNL on this level. Our assessment of data suggests that noble gas discharges are often low or at detection levels with no failed pins but increase rapidly with pin failures. To give us early indication of pin failures, we will set the QNL at 1,300 GBq, which is 10 per cent of the disposal limit.

2.6.5 Iodine radionuclides

161 Iodine radionuclides are formed by fission in the fuel and can escape into the coolant through cladding defects. Escape through defects can be accentuated by changes in reactor condition such as power output, in particular at shut-down.

162 As is the case for noble gases, gaseous effluent containing iodine radionuclides is sent to the WGS from the degasifier. Westinghouse claims that iodine radionuclides will be

delayed by the carbon delay beds in the WGS, however they do not provide an estimate of reduction in discharges as a result of delay.

163 Iodine radionuclides can also enter the containment atmosphere through leaks of coolant. In such an event Westinghouse claims that most of the iodine radionuclides are deposited on surfaces in the containment area by natural processes. Whenever the containment is ventilated the exhaust air is passed through HEPA filters and impregnated charcoal filters.

164 Westinghouse provides a review of available gaseous abatement techniques to minimise discharge of iodine radionuclides (AP1000 BAT Form 5). These include using:

a) silver reactor technology using solid absorber coated with silver nitrate which retains iodine radionuclides and allows them to decay;
b) mercurex process which is a liquid scrubbing process using mercuric nitrate / nitric acid solution;
c) iodox which is a liquid scrubbing process using hyperazeotropic nitric acid;
d) electrolytic scrubbing which employs an electrolytically generated chemical oxidant;
e) liquid scrubbing with various organic liquids;
f) solid absorption by organic resins;
g) caustic liquid scrubbing using sodium or potassium hydroxide;
h) iodine trapping using silver containing sorbents such as treated zeolites.

165 Westinghouse indicates issues with technical development, complexity or cost for all the above techniques. Westinghouse claims that deposition in the containment and using delay beds are BAT for minimising the discharge of iodine radionuclides to atmosphere from the AP1000.

166 We consider that the techniques Westinghouse has considered for the abatement of iodine radionuclides in gaseous radioactive waste from the AP1000 are comprehensive enough and represent a range of feasible proven techniques from which to assess BAT.

167 Our assessment concluded that Westinghouse has demonstrated that BAT is used to minimise discharges of iodine radionuclides from the AP1000.

168 Westinghouse predicts that the annual average discharge of iodine radionuclides over the 18 month cycle from the AP1000 to atmosphere will be: (ER Table 3.3-6)

a) Iodine-131 = 0.21 GBq
b) Iodine-133 = 0.35 GBq
c) Total iodine radionuclides = 0.56 GBq.

169 Westinghouse proposes a discharge limit for iodine radionuclides from the AP1000. It has predicted monthly discharges over an 18-month cycle and used data from the 12 months in which the discharges are highest (month 7 – 18) to calculate the representative 12-month plant discharge to be 0.595 GBq. Westinghouse has applied our limit setting methodology (Environment Agency, 2005) to calculate the annual worst-case plant discharge (WCPD), which it has rounded to give its proposed limit. (ERs6.1.3)

170 Westinghouse proposes an annual limit of 1 GBq for discharges of total iodine radionuclides. (ER Figure 6.1-1 and ER Table 6.1-7)

171 We examined historic discharges (where available) from European and US PWRs operating over the last 10 to 15 years and we consider that the range of discharges to atmosphere of iodine-131 is 10 to 200 MBq per year for a 1000 MWe power station.

The predicted annual gaseous discharge of iodine-131 normalised for power is 185 MBq which is within the range. We conclude that gaseous discharge of iodine radionuclides is comparable to other power stations across the world.

172 Westinghouse estimates that the radiological impact from the representative 12-month plant discharge of iodine radionuclides to atmosphere will result in a dose to the local resident family of 0.13 μSv y^{-1} (ER table 5.2-16).

173 We have independently calculated limits on discharges of iodine radionuclides that we may grant and based on the information provided by Westinghouse for GDA. We consider that a limit on iodine-131 is appropriate and our proposed disposal limit for iodine-131 by discharge to the atmosphere is 0.3 GBq in any 12 rolling calendar months.

174 The annual average discharge includes allowance for a failed fuel pin fraction. Westinghouse has not provided an estimate of discharge without pin failures and we normally base our QNL on this level. Our assessment of data suggests that gaseous iodine radionuclide discharges are often low or at detection levels with no failed pins but increase rapidly with pin failures. To give us early indication of fuel failures, we will set the QNL for iodine-131 at 0.03 GBq, which is 10 per cent of the disposal limit.

2.6.6 Other radionuclides

175 Westinghouse predict that other radionuclides, in particular, beta emitting particulates shown below, will be present in gaseous radioactive waste (AP1000 BAT Form 9):

Radionuclide	Discharge averaged over the 18 month cycle (GBq y^{-1})	Discharge in the highest 12 months of the 18 month cycle (GBq y^{-1})	Dose to local resident family (μSv y^{-1})	% of total dose to resident family
Cobalt-58	8.5E-03	not available		
Cobalt-60	3.2E-03	3.22E-03	1.1E-03	<0.02
Iron-55	not available	not available		
Nickel-63	not available	not available		

176 Activated corrosion products are present in the reactor coolant and may be found in aerosols (a dispersion of solid or liquid particles in a gas) produced from:

a) equipment leaks into the containment area. Coolant from these leaks can dry out and the radioactive dust can be re-suspended in air and enter the ventilation systems.

b) treatment of the coolant in the degasifier in the WLS, the gas phase is sent to the WGS.

177 Activated corrosion products can be present as particulate in the final discharge to air. The most significant are particulates containing the radionuclides cobalt-58 and cobalt-60.

178 Fission products may be present in the coolant in the event of fuel cladding failures. The main particulate fission of concern that may be present in gaseous waste discharged to atmosphere is caesium-137.

179 The AP1000 relies on the purification loop in the CVS to control the level of particulates in the coolant and, therefore, minimise radioactivity reaching the WLS or present in leaks. The loop contains mixed bed demineralisers to remove dissolved

corrosion products and filters to remove suspended particulate corrosion products.

180 Westinghouse provides a review of abatement techniques to minimise particulates in gaseous discharges (AP1000 BAT Form 9):

a) wet scrubbing;

b) direct discharge;

c) using carbon delay beds in the WGS to provide an effective deep bed filter for removing particulates. Westinghouse claims that HEPA filters are not considered necessary after these beds;

d) use of HEPA filtration in the radiologically controlled area ventilation systems.

181 We consider that the techniques Westinghouse has considered for the abatement of particulates in gaseous radioactive waste from the AP1000 are comprehensive enough and represent feasible techniques to assess BAT.

182 Westinghouse claims that using carbon delay beds as deep bed filters in the gaseous radwaste system and HEPA filtration in the ventilation systems is BAT for minimising the discharge of radioactive particulates in the gaseous waste streams in the AP1000.

183 We assessed ventilation systems for the AP1000 in detail in report AP1000-03 (Environment Agency, 11b) and concluded they were BAT.

184 Our assessment concluded that the use of carbon delay beds as deep bed filters in the gaseous radwaste system and HEPA filtration in the ventilation systems is BAT for minimising discharges of particulates in gaseous radioactive waste from the AP1000.

185 The Health Protection Agency (GDA89) emphasised the importance of applying filtration to all potential particulate discharges, in particular with regard to the GDA Issue AP1000-I2 that was in our Consultation Document. We noted above, section 2.5.4, that design changes have been approved by Westinghouse and we are now content that the AP1000 has appropriate filtration, AP1000-I2 has been closed out.

186 Westinghouse has predicted that the annual average discharge of radioactive particulates from the AP1000 to atmosphere will be (ER Table 3.3-8):

Radionuclide	Expected annual release, MBq
Cobalt-58	8.5
Cobalt-60	3.2
Caesium-137	1.3
Strontium-90	0.44

187 Westinghouse proposes a discharge limit for radioactive particulates from the AP1000. It has predicted monthly discharges over an 18-month cycle and used data from the 12 months in which the discharges are highest (month 7 – 18) to calculate the representative 12-month plant discharge to be 28.4 MBq. Westinghouse has applied our limit setting methodology (Environment Agency 2005) to calculate the worst-case annual plant discharge (WCPD), which it has rounded to give its proposed limit. (ERs6.1.3)

188 Westinghouse proposes an annual limit of 30 MBq for discharges of radioactive particulates. (ER Figure 6.1-7 and ER Table 6.1-7)

189 We examined historic discharges (where available) from European and US PWRs operating over the last 10 to 15 years and we consider that the range of discharges to atmosphere of fission and activation products is 1 to 1000 MBq per year for a 1000 MWe power station (see Annex 4). The predicted annual average gaseous discharge of radioactive particulates from the AP1000 is within this range. We conclude that

gaseous discharge of radioactive particulates is comparable to other power stations across the world.

190 Westinghouse estimates that the radiological impact from the representative 12-month discharge of cobalt-60 to atmosphere will result in a dose to the local resident family of 0.0028 μSv y^{-1}. (ER table 5.2-16).

191 Westinghouse estimates that the radiological impact from representative 12-month discharge of caesium-137 to atmosphere will result in a dose to the local resident family of 0.00013 μSv y^{-1}.

192 Westinghouse estimates that the radiological impact from the representative 12-month discharge of strontium-90 to atmosphere will result in a dose to the local resident family of 0.000045 μSv y^{-1}.

193 We have independently calculated limits on radioactive particulates discharges that we may grant and, based on the information Westinghouse has provided for GDA, our proposed limit for the disposal of radioactive particulates by discharge to the atmosphere is 30 MBq in any 12 rolling calendar months.

194 Based on the information Westinghouse has provided for GDA, our proposed quarterly notification level for total radioactive particulates is 3 MBq.

195 An individual respondent (GDA120) was concerned that we were not putting a zero limit on alpha-emitting radionuclides and about the sensitivity of detection methods. We discuss the source and type of potential alpha-emitters in section 3.9 of our assessment report EAGDAR AP1000-03 (Environment Agency, 2011b) of this document. There is no expected discharge of alpha-emitters but we will require monitoring as a precaution. The monitoring method will be specified by future operators, we will require the best available techniques at time of installation[4]. The use of 'zero' limits is difficult as measurements can usually only be stated as 'below limit of detection' and at very low levels measurements can be affected by trace background interference, a true zero measurement is almost impossible to achieve. We prefer to rely on the standard BAT conditions in our permits that, in this case, would require operators to demonstrate effectively zero discharge of alpha-emitting radionuclides.

2.7 Gaseous radioactive waste disposal to the environment

196 The only release points for gaseous radioactive discharges in normal operation are (ERs3.3.4):

a) the main plant vent which is 5 m higher than the highest building in the vicinity and located on the side of the reactor containment building. Westinghouse have approved a design change proposal (APP-GW-GEE-1942) to increase the height of the nuclear ventilation plant stack to 5m above the highest building in the vicinity, the shield building (including a grating that extends on top of that building);

b) ILW store ventilation stack for which the design details are not yet available.

197 Radioactivity could be released under abnormal circumstances from:

a) the condenser air removal system;

b) the turbine building ventilation system.

198 These releases are combined and discharged from the turbine building vent which is 38.4 m high and located on the turbine building.

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4 We are revising our monitoring guidance M11 but this will be available for future operators to apply. We also require monitoring to conform to the European Commission's (EC) recommendation 2004/2/Euratom) on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation. See our joint guidance with SEPA: http://www.sepa.org.uk/radioactive_substances/publications/idoc.ashx?docid=cefd6d99-5000-4fd5-b028-5f8a39efc7a0&version=-1.

199 We are satisfied that all gaseous radioactive wastes from the AP1000 are collected into the main plant and turbine building vents for discharge. The vents will be fitted with continuous monitoring equipment to measure radioactive materials entering the air.

200 Westinghouse has assumed an 'effective' stack height of 40 m for GDA (ERs5.2.3.2). The effective stack height allows for factors such as the effect of nearby large buildings causing downwash, which results in discharges reaching the ground closer to the point of discharge than in an open area. The effective height is much less than the actual heights noted above. Dose assessment for the generic site gives an annual dose of 5.6 μSv for gaseous discharges at limit values. The doses are low enough that we accept that the (GDA) vent heights are BAT to reduce impact to a minimum. The future operator for each specific site will need to demonstrate by modelling that the vent heights proposed will be BAT for adequate dispersion allowing for topography (the surface features of the local land area surrounding the site).

201 At the time of our Consultation Westinghouse had assessed doses based upon a lower stack height (22.5 m). Since then Westinghouse have approved a design change proposal (see 195 a) above) to increase the stack height and have updated their dose assessment. An increased discharge height gives better dispersion and a lower dose impact.

3 Public Comments

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

203 We did not receive any public comments by this route during this assessment relating to the discharge of gaseous radioactive waste.

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

4 Conclusion

205 Our conclusion remains unchanged since our consultation.

206 We conclude that overall the AP1000 utilises the best available techniques (BAT) to minimise discharges of gaseous radioactive waste:

a) during routine operations and maintenance;

b) from anticipated operational events.

207 We conclude that the gaseous discharges from the AP1000 should not exceed those of comparable power stations across the world. The proposed discharge of carbon-14 in gaseous waste is slightly higher than the range for other European PWRs but this may be accounted for by the increased availability expected of the AP1000.

208 We conclude that any operational, single AP1000 unit should comply with the limits and levels set out below for the disposal of gaseous radioactive waste to air. The limits and levels will be the starting point for any site-specific permit, but will be reviewed as part of the site permitting process based on any additional information provided by a future AP1000 operator. The limits would also be reviewed periodically thereafter, as data becomes available from operational AP1000 reactors.

Radionuclides or group of radionuclides	Annual limit (GBq)	Quarterly notification level (GBq)
Tritium	3,000	600
Carbon-14	1,000	210
Iodine-131	0.3	0.03
Noble gases excluding Argon-41	13,000	1,300
All other radionuclides (excepting tritium, carbon-14, iodine radionuclides and noble gases)	0.03	0.003

209 We conclude that the AP1000 stack provides adequate dispersion under GDA generic site conditions. However dispersion is very location specific and will need to be demonstrated as adequate by modelling for each specific site.

References

(DECC 2009)	Statutory Guidance to the Environment Agency concerning the regulation of radioactive discharges into the environment, Department of Energy and Climate Change and Welsh Assembly Government, 2009. http://www.decc.gov.uk/media/viewfile.ashx?filepath=what%20we%20do/uk%20energy%20supply/energy%20mix/nuclear/radioactivity/dischargesofradioactivity/1_20091202160019_e_@@_guidanceearadioactivedischarges.pdf&filetype=4
(EC, 2004)	EU Commission Recommendation 2004/2/Euratom of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation http://ec.europa.eu/energy/nuclear/radioprotection/doc/legislation/2004_2_en.pdf
(Environment Agency, 2005)	Development of Guidance on Setting Limits on Radioactive Discharges to the Environment from Nuclear Sites, (Science Report: SC010034/SR, Environment Agency, December 05) http://publications.environment-agency.gov.uk/pdf/SCHO1205BIVK-e-e.pdf
(Environment Agency, 2007)	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
(Environment Agency, 2009)	Considerations for Radioactive Substances Regulation under the Radioactive Substances Act at Nuclear Sites in England and Wales, Environment Agency, Jan 2009 (version 2).
(Environment Agency, et al 2009)	*Radioactivity in Food and the Environment, 2008* (RIFE – 14), Environment Agency, Food Standards Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency, 2009.
(Environment Agency, 2010a)	Generic design assessment. AP1000 nuclear power plant design by Westinghouse Electric Company LLC. Consultation Document. http://publications.environment-agency.gov.uk/pdf/GEHO0510BRUW-e-e.pdf
(Environment Agency, 2010b)	RSR: Principles of optimisation in the management and disposal of radioactive waste http://www.environment-agency.gov.uk/static/documents/Business/GEHO0709BQSA-E-E.pdf
(Environment Agency, 2010c)	RGS, No RGN RSR 1: Regulatory Environmental Principles (REPs), 2010 http://publications.environment-agency.gov.uk/pdf/GEHO0709BQSB-e-e.pdf
(Environment Agency, 2010d)	EAGDAR AP1000-14: Generic design assessment. UK AP1000 nuclear power plant design by Westinghouse Electric Company LLC. assessment report – Independent Dose Assessment. http://publications.environment-agency.gov.uk/pdf/GEHO0510BSKO-e-e.pdf

(Environment Agency, 2011a)	Generic design assessment. UK AP1000 nuclear power plant design by Westinghouse Electric Company LLC: Decision Document http://publications.environment-agency.gov.uk/pdf/GEHO1211BTOI-e-e.pdf
(Environment Agency, 2011b)	EAGDAR AP1000-03 Generic design assessment. UK AP1000 nuclear power plant design by Westinghouse Electric Company LLC. Final assessment report: Best Available Techniques to prevent or minimise the creation of radioactive wastes http://publications.environment-agency.gov.uk/pdf/GEHO1211BTNV-e-e.pdf
(Environment Agency, 2011c)	EAGDAR AP1000-01: Generic design assessment. UK AP1000 nuclear power plant design by Westinghouse Electric Company LLC. Final assessment report: Management Systems http://publications.environment-agency.gov.uk/pdf/GEHO1211BTNT-e-e.pdf
(Environment Agency, 2011d)	EAGDAR AP1000-11: Generic design assessment. UK AP1000 nuclear power plant design by Westinghouse Electric Company LLC. Final assessment report: Radiological impact on members of the public http://publications.environment-agency.gov.uk/pdf/GEHO1211BTOD-e-e.pdf

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

Abbreviations

ALARP	As Low As Reasonably Practicable
BAT	Best available techniques
CVS	Chemical and Volume control system
CWS	Circulating water system
DCD	Design Control Document
EPRI	Electrical Power Research Institute – an independent USA organisation
ER	Environment Report
EWCPD	Established worst case plant discharges
GDA	Generic design assessment
HEPA	high efficiency particulate air filter
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
VAS	The radiologically controlled area ventilation system
VBS	The non-radioactive auxiliary building ventilation system
VFS	containment air filtration system
VTS	turbine building ventilation system
WCPD	Worst case plant discharge
WEC	Westinghouse Electric Company LLC
WGS	Gaseous radioactive waste system
WLS	Liquid radioactive waste system

Annex 1: Westinghouse gaseous discharge data

210 Estimates of annual gaseous radioactive waste discharges have been provided based on proprietary calculations determined from the revised GALE Code (US NRC NUREG-0017). We raised a Technical Query (TQ-AP1000-149) on 1 June 2009 requesting Westinghouse to:

a) provide further information on the derivation of values for annual discharges of gaseous radioactive waste;

b) to clarify and reconcile the data in the DCD and in various submission documents;

c) to explain the adjustment applied to gaseous radioactive waste discharge values in the DCD to take into account contingencies; and

d) to reconsider its approach to deriving 12 month rolling discharge values.

211 In its response Westinghouse sets out its approach to estimating gaseous radioactive waste discharges in which they benchmarked values derived using the current GALE methodology against operating plant data. The approach included a review of gaseous radioactive waste discharge data from operational plants and a comparison of that data with values derived using the GALE code, and then the modification of either input parameters or the computer code to give results that reflect the actual plant data. Operating data from US plants relating to discharges made between 2001 and 2004 were used. Westinghouse claim that the comparison is appropriate as the data is fairly recent and reflects the waste management techniques and approaches that have been incorporated into the AP1000 design. They do not, however, take into account certain design improvements that have been made in the AP1000 design and on this basis Westinghouse claim that the estimates are likely to be conservative. Westinghouse claim the following design improvements are expected to result in lower discharges of gaseous radioactive waste:

a) fewer valves and components which reduces the number of potential leakage paths;

b) reactor coolant pumps without seals result in less leakage into the containment.

212 We noted in our assessment that the gaseous radioactive waste discharges data set out in the European DCD differed from that in the Environment Report and Westinghouse claim this is as a result of the changes made to the GALE code during the benchmarking exercise, and that the data in the Environment Report is more realistic than that in the DCD. With this in mind we have considered the data provided in the Environment Report in our assessment.

213 As a result of Technical Query 149 Westinghouse amended its estimates of 12 month rolling values for gaseous radioactive waste discharges to represent the values for the 12 months at the end of each 18 month cycle when discharges are highest.

214 Westinghouse have provided data for expected annual releases of airborne radionuclides which have no contingency added to allow for anticipated operational occurrences. Summarised data is given in Table 1 followed by further detailed data.

Estimate of annual activity of gaseous radioactive waste discharges

Radionuclide	Estimate of annual activity to be discharged (GBq) averaged over an 18 month cycle
Tritium	1.78E+03
Carbon-14	6.07E+02
Argon-41	1.26E+03
Radioiodine	5.6E-01
Noble gases	6.7E+03
Beta emitting particulates	1.7E-02

215 As fuel burnup increases over the fuel cycle, less boron is needed in the reactor cooling water. This adjustment in boron concentration is achieved by bleeding borated water from the reactor coolant system and replacing it with unborated water. A larger volume of water needs to be removed each month, and therefore, the radioactive discharges increase each month of the cycle. This results in the variability in activity in gaseous discharges from the reactor coolant by month over each cycle. In general total gaseous discharge activity rises on a month by month basis throughout the cycle as shown in Table 2.

Predicted activity in gaseous discharges (GBq) by month of cycle

Month	Total predicted activity in gaseous discharges (GBq)
1	568
2	575
3	583
4	592
5	602
6	614
7	628
8	644
9	664
10	687
11	717
12	755
13	805
14	875
15	980
16	1152
17	1494
18	2527
Total	**15463**

216 Profiles of gaseous discharges on a month by month basis are given in the Environment Report for radioiodine, noble gases, tritium, carbon-14, argon-41, cobalt-60, krypton-85, strontium-90, iodine-133, xenon-133, caesium-137, and other particulates. The activity of each of these radionuclides in gaseous radioactive waste discharges all follow a similar trend and rise towards the end of the 18 month cycle with the largest monthly increases in month 17 and 18. Westinghouse claim this is because the adjustment in boron concentration is achieved by bleeding borated water from the reactor coolant system and replacing it with unborated water. A larger volume of water needs to be removed each month, and therefore, the radioactive discharges increase each month of the cycle.

217 The volume of gaseous discharges from non-reactor coolant system sources is expected to be almost constant during each month of the cycle, and therefore, the radioactive non-reactor coolant system discharges are expected to be constant.

Expected Annual Release of Airborne Iodine radionuclides to the Atmosphere (ER Table 3.3-6)

Nuclide	Activity Release (1), GBq y^{-1}					
	Waste Gas System	Building / Area Ventilation			Condenser Air Removal System	Total Release
		Containment Building	Auxiliary Building	Turbine Building		
I-131	7.4E-03	1.9E-02	1.8E-01	2.4E-03	9.6E-04	2.1E-01
I-133	1.1E-02	7.4E-02	2.6E-01	7.4E-04	3.0E-03	3.5E-01
Total Airborne Radioiodine						5.6E-01

Notes:

(1) Values less than 1 microcurie (3.7E+4Bq) are considered to be negligible, but their values are included in the totals.

Expected Annual Release of Radioactive Noble Gases to the Atmosphere (ER Table 3.3-7)

Nuclide	Activity Release (1), GBq y^{-1}					
	Waste Gas System	Building / Area Ventilation			Condenser Air Removal System	Total Release
		Containment Building	Auxiliary Building	Turbine Building		
Kr-85m	4.6E-01	1.4E-01	1.6E+01	8.5E-04	7.8E+00	2.4E+01
Kr-85	3.0E+03	1.1E+01	5.2E+01	2.9E-03	2.6E+01	3.1E+03
Kr-87	negl.	4.4E-02	1.7E+01	2.6E-04	2.2E+00	1.9E+01
Kr-88	6.7E-03	1.0E-01	1.8E+01	9.6E-04	8.5E+00	2.7E+01
Xe-131m	1.1E+03	3.1E+01	1.8E+02	9.3E-03	8.1E+01	1.4E+03
Xe-133m	3.6E-02	6.7E+00	7.4E+01	4.1E-03	3.5E+01	1.1E+02
Xe-133	2.4E+02	8.9E+01	6.3E+02	3.3E-02	2.9E+02	1.3E+03
Xe-135m	negl.	6.7E-02	1.3E+02	7.0E-03	5.9E+01	1.9E+02
Xe-135	negl.	3.1E+00	1.7E+02	2.9E-02	2.6E+02	4.4E+02
Xe-137	negl.	negl.	3.4E+01	1.8E-03	1.6E+01	4.8E+01
Xe-138	negl.	2.9E-02	5.9E+01	3.3E-03	2.9E+01	8.9E+01
Total Noble Gas						6.7E+03

Tritium Release via Gaseous Pathway (2) (TBq/y) = 1.8.

Carbon-14 Released via Gaseous Pathway (TBq/y) = 0.606(3)

Argon-41 Released via Gaseous Pathway (TBq/y) = 1.3

Notes:

(1) Values less than 1 microcurie (3.7E+4Bq) are considered to be negligible, but their values are included in the totals.

(2) Tritium release based on Westinghouse TRICAL computer code.

(3) Carbon-14 from Westinghouse calculation APP-WLS-M3C-056 Rev 0, 2009.

Expected Annual Release of Radioactive Particulates to the Atmosphere (ER Table 3.3-8)

Nuclide	Activity Release (1), GBq y^{-1}				
	Waste Gas System	Building / Area Ventilation			Total Release
		Containment Building	Auxiliary Building	Turbine Building	
Cr-51	negl.	negl.	1.2E-04	6.7E-05	2.3E-04
Mn-54	negl.	negl.	negl.	1.1E-04	1.6E-04
Co-57	negl.	negl.	negl.	negl.	negl.
Co-58	negl.	9.3E-05	7.0E-04	7.8E-03	8.5E-03
Co-60	negl.	negl.	1.9E-04	3.0E-03	3.2E-03
Fe-59	negl.	negl.	negl.	negl.	negl.
Sr-89	negl.	4.8E-05	2.8E-04	7.8E-04	1.1E-03
S-90	negl.	negl.	1.1E-04	3.0E-04	4.4E-04
Zr-95	negl.	negl.	3.7E-04	negl.	3.7E-04
Nb-95	negl.	negl.	negl.	8.9E-04	9.3E-04
Ru-103	negl.	negl.	negl.	negl.	negl.
Ru-106	negl.	negl.	negl.	negl.	negl.
Sb-125	negl.	negl.	negl.	negl.	negl.
Cs-134	negl.	negl.	2.0E-04	6.3E-04	8.5E-04
Cs-136	negl.	negl.	negl.	negl.	negl.
Cs-137	negl.	negl.	2.7E-04	1.0E-03	1.3E-03
Ba-140	negl.	negl.	1.5E-04	negl.	1.6E-04
Ce-141	negl.	negl.	negl.	negl.	negl.
Total Particulates					1.7E-02

Notes:

(1) Values less than 1 microcurie (3.7E+04 Bq) are considered to be negligible, but their values are included in the totals.

(2) The fuel handling area is within the auxiliary building but is considered separately.

Annex 2: Comparison with EU Commission Recommendation 2004/2/Euratom

218 Recommendations for the radionuclides to be determined in gaseous discharges and the relevant limits of detection are specified in EU Commission Recommendation 2004/2/Euratom of 18 December 2003 on standardised information on radioactive airborne and gaseous discharges into the environment from nuclear power reactors and reprocessing plants in normal operation.

Radionuclides to be determined in gaseous discharges as specified in Commission Recommendation 2004/2/Euratom

Key Nuclides	Requirement for the detection limit (in Bq m^{-3})
H-3	1E+03
C-14	1E+01
S-35	1E+01
Co-60	1E-02
Kr-85	1E-04
Sr-90	2E-02
I-131	2E-02
Xe-133	1E+04
Cs-137	3E-02
Pu-239 + Pu-240	5E-03
Am-241	5E-03
Total alpha	1E-02

219 Westinghouse have provided predicted annual discharges for a range of radionuclides including tritium, carbon-14, argon-41, krypton-85, iodine-131, xenon-133, cobalt-60, strontium-90 and caesium-137. Data has not been provided for plutonium-239, plutonium-240, americium-241, total alpha and other nuclide-specific alpha emitters. Data for sulphur-35 has not been provided as this is relevant only to gas cooled reactors.

220 We consider that the range of radionuclides for which Westinghouse have provided data on predicted activity levels in gaseous discharges is adequate for assessment under the generic phase of the GDA process.

Annex 3: Limit and QNL setting detail

Significant radionuclides

221 Westinghouse have provided information on expected discharges of radioactive waste on a month by month basis and proposed limits for discharges of gaseous radioactive waste for a range of radionuclides they consider to be significant.

222 We raised a Technical Query (TQ-AP1000-165) on 17 June 2009 requiring Westinghouse to provide information on radionuclides which they considered to be significant in gaseous radioactive waste discharges from the AP1000 bearing in mind the criteria set out in our Considerations Document. Westinghouse responded on 20 August 2009 and included the information in the ERs 6.1.1.

223 Westinghouse claim that the radionuclides significant in terms of radiological impact are tritium, carbon-14, argon-41, and iodine-131 because in the dose assessment carried out by Westinghouse these radionuclides individually contribute greater than 1% to annual doses to members of the public.

224 Westinghouse claim that tritium, krypton-85, xenon-131m, xenon133 and argon-41 are also significant because they contribute greater than 10% of the total activity (in Bq) discharged in a year.

225 In addition, Westinghouse claim that carbon-14 is significant because it has a long half life and may persist or accumulate in the environment.

226 In terms of radionuclides which indicate plant performance, Westinghouse claim that cobalt-60 is an indicator of particulate emissions.

227 In terms of radionuclides which provide for effective regulatory control, Westinghouse claim that krypton-85, strontium-90, iodine-131, caesium-137, xenon-133 and nitrogen-16 should be monitored continuously and noble gases, iodine, particulates and tritium should be monitored in grab samples.

228 We believe that the following radionuclides should be subject to individual annual limits:

a) Tritium – significant in terms of contribution to the amount of activity released. Tritium accounts for 1.78 TBq out of a total discharge of 10.3 TBq.

b) Carbon-14 – significant in terms of contribution to dose. At our proposed limits the dose from gaseous carbon-14 discharges is estimated to be around 1 μSv y^{-1}.

c) Iodine radionuclides – significant as an indicator of plant performance.

d) Noble gases - significant in terms of contribution to the amount of activity released. Noble gases account for 6.7 TBq out of a total discharge of 10.3 TBq. Noble gases are also significant as an indicator of plant performance.

e) Caesium-137 - significant as an indicator of plant performance. We consider caesium-137 should not be limited individually but be included in the limit on 'other radionuclides' in gaseous radioactive waste.

229 We believe that all other activity discharged should be limited in a grouped limit on all other radionuclides (excepting tritium, carbon-14, noble gases and iodine radionuclides) taken together.

Estimated discharges and proposed discharge limits

230 Westinghouse have used the methodology set out in our guidance which aims to consider expected discharges and apply a reasonable headroom to the discharge activities in order to provide some flexibility for reactor operations. Our guidance suggest applying factors to the expected discharges to take into account such things as operational fluctuations, increases in throughput or power output, plant ageing, legacy waste, decommissioning and plant improvements in order to derive the 'Worst

Case Plant Discharges' (WCPD). Westinghouse claims that at this stage no account need be taken of increases in throughput or power output, decommissioning, legacy waste or plant improvements for its design.

231 Westinghouse has calculated the expected average discharges which would be made in month 7 to 18 of each 18 month cycle when discharges are expected to be highest and applied the following factors:

a) a factor of 1.5 to take into account operational fluctuations; and

b) a factor of 1.1 to take into account increases in discharges that may result from plant ageing.

232 Using these factors Westinghouse has estimated values for the WCPD for a range of radionuclides which are given in ER Table 6.1-5 (air emissions) and ER Table 6.1-6 (liquid discharges) and have calculated limits based on these values.

Discharge limits for gaseous radioactive waste calculated by Westinghouse [from ER Table 6.1-5]

	Average monthly discharge in months 7 to 18 of the cycle (TBq y^{-1})	Westinghouse estimate of Worst Case Plant Discharge (WCPD) (TBq y^{-1})	Annual Limit calculated by Westinghouse (TBq y^{-1})
Iodine radionuclides	5.95E-04	9.82E-04	1E-03
Noble gases	8.099	13.363	13
Tritium	1.867	3.081	3
Carbon-14	0.638	1.053	1
Argon-41	1.323	2.182	2
Cobalt-60	3.22E-06	5.32E-06	5E-06
Krypton-85	4.070	6.716	7
Strontium-90	4.44E-07	7.33E-07	7E-07
Iodine-131	2.07E-04	3.42E-04	3E-04
Xenon-133	1.335	2.203	2
Caesium-137	1.33E-06	2.20E-06	2E-06
Other particulates(1)	1.22E-05	2.01E-05	2E-05

Note (1) Other particulates are particulate radionuclides not individually listed in ER Table 6.1-5 which are present at very low individual activity levels.

233 We have considered the information provided by Westinghouse and the independent dose assessment carried out on our behalf by Enviros Consulting Ltd (Environment Agency, 2011d) taking into account our Considerations document[5] (Environment

[5] Our Considerations document was superseded with the introduction of the Environmental Permitting Regulations (EPR 10) in April 2010 and the issue of related guidance documents – see Environment Agency, 2010c.

Agency, 2009). The Considerations document recommends that following criteria for identifying radionuclides or groups of radionuclides for which to set plant limits:

a) critical group dose from the established worst case plant discharges (EWCPD) is greater than 1 μSv per year;

b) collective dose from the EWCPD is greater than 0.1 manSv;

c) the EWCPD exceeds 1 TBq per year;

d) the EWCPD exceeds 50% of the current limit (not applicable to a new plant on a new site); and

e) discharges of the radionuclide are a good indictor of plant performance or process control, or limits are otherwise felt to be necessary for effective regulatory control and enforcement.

234 The total terrestrial critical group dose is calculated to be 4.4 μSv y^{-1} to an infant. We note from our independent dose assessment that carbon-14 contributes greater than 1 μSv y^{-1} to the terrestrial critical group dose and that a dose of 4 μSv y^{-1} results from carbon-14 by all exposure routes. The highest contribution to the terrestrial critical group dose is from carbon-14 in milk which contributes 2.5 μSv y^{-1} to doses to an infant. Our dose assessment report EAGDAR AP1000-11 and the independent dose assessment carried out by Enviros provide more detail (Environment Agency, 2011d and 2010d).

235 The Westinghouse dose assessment also showed carbon-14 in food to contribute greater than 1 μSv y^{-1} to the terrestrial critical group dose. For comparison here, the Westinghouse dose assessment estimated the total terrestrial critical group dose to be 4.0 μSv y^{-1} and the dose from carbon-14 in food to be 2.7 μSv y^{-1}.

236 Additionally the average UK, Europe and World collective dose from carbon-14 at the EWPCD exceeds 0.1 man Sv and for these reasons we consider that carbon-14 should be subject to an individual limit.

237 Tritium, argon-41, krypton-85 and xenon-133 are radionuclides with an EWCPD that exceeds 1 TBq per year. For this reason we consider that tritium should be subject to an individual discharge limit. We consider that a discharge limit on noble gases which includes argon-41, krypton-85 and xenon-133 would be appropriate.

238 We consider that iodine-131, cobalt-60 and caesium-137 are good indicators of plant performance and process control. Cobalt-60 levels are a useful indicator of levels of corrosion in the primary circuit which in turn reflects the effectiveness of primary cooling water chemistry control. Iodine-131 and caesium-137 are useful indicators of fuel failures as these radionuclides would be released in the event of a fuel pin failure in which the fuel cladding was breached. In order to ensure that the discharge of gaseous radioactive waste is controlled we consider that an individual limit should be placed on iodine-131. We also consider that a limit should be placed on all other beta or gamma emitting radionuclides (excepting tritium, carbon-14, noble gases and iodine radionuclides) taken together. The radionuclides grouped in this limit will include cobalt-60 and caesium-137.

239 In summary we consider that gaseous radioactive waste discharge limits should be placed on:

a) tritium

b) carbon-14

c) noble gases

d) iodine radionuclides

e) all other beta or gamma emitting radionuclides (excepting tritium, carbon-14, noble gases and iodine radionuclides) taken together.

240 Our limit setting guidance recommends the use of other factors to determine the headroom which is appropriate to allow operational flexibility and to take into account other conditions which might change during the period for which the limits would apply. The guidance recommends the use of the formula:

WCPD = (1.5 x D x T x A x B) + C + L + N -I

where

a) 1.5 is an Environment Agency-established factor which relates 'worst case' to average discharges and takes account of the requirement to minimise headroom.

b) D is the representative average 12-month plant discharge. The average excludes discharges due to faulty operation of plant but includes discharges arising from minor unplanned events.

c) T is a factor, which allows for any future increases in throughput, power output etc relative to the review period.

d) A is a factor, which allows for plant ageing – that is, for increases in discharges which result from changes within the plant as it ages that cannot be remedied or controlled by the operator.

e) B is a factor, which allows for other future changes that are beyond the control of the operator.

f) C is an allowance for decommissioning work beyond that carried out in the review period (and included in D).

g) L is an allowance for dealing with legacy wastes, beyond those dealt with in the review period (and included in D).

h) N is an allowance for new plant.

i) I is the reduction in discharges expected as a result of introducing improvement schemes before the new authorisation comes into force.

241 The discharge setting guidance recommends that WCPD for new plant should be a factor of 2 times the best estimate of discharges of radioactive waste, however in the light of the amount of detailed information available we have considered each factor in turn.

242 In terms of determining the headroom to be applied to expected discharges of gaseous radioactive waste we consider that the Environment Agency-established factor of 1.5 which relates 'worst case' to average discharges whilst taking into account the requirement to minimise headroom between the actual levels of discharges expected during normal operation and the limits themselves should be applied.

243 We consider that:

a) The representative average discharge levels (D) over 12 months used in limit setting should be the discharges averaged over the highest 12 months in the 18 month cycle which for the AP1000 are those predicted to be made in months 7 to 18 inclusive for all radionuclides.

b) T should be taken to be 1 as we do not foresee any changes in throughput or power output in the early stages of plant operation. Westinghouse have confirmed this to be the case.

c) A should be taken to be 1.1. We recognise that plant ageing is unlikely to result in increased discharges before the first review of any authorisation which we grant but we are mindful of the requirement in the Statutory Guidance that discharges from new plant should be capped at levels for which approval is first given for operation.

d) B should be taken to be 1 as we do not foresee any future changes in operation that are beyond the control of the operator.

e) C should be taken to be 0 as we do not foresee any decommissioning work will take place in the next decade or two.

f) L should be taken to be 0 as there is no legacy waste associated with new build of an AP1000.

g) N should be taken to be 10% because whilst the estimated discharges of gaseous waste from the AP1000 have been calculated using a US NRC recommended computer code (GALE code), and the estimated discharge levels have been compared to discharge levels from other PWRs throughout the world, there is no actual operational data for AP1000 discharges which could be used to verify the estimates. We consider an allowance of 10% should be made for the fact that the AP1000 is a new plant.

h) I should be taken to be 0 as at this stage there are no improvement schemes in place which might reduce discharges.

244 We consider therefore that:

WCPD (TBq) = (1.5 x D x 1 x 1.1 x 1) + 0 + 0 + 10% – 0

Which simplifies to:

WCPD = 1.815D

In cases where our calculations result in higher proposed limits than those proposed by Westinghouse we have reduced our proposed limits to the levels proposed by Westinghouse.

Discharge limits for gaseous radioactive waste proposed by the Environment Agency

	Average monthly discharge in months 7 to 18 of the cycle (D) (TBq y^{-1})	Environment Agency Worst Case Plant Discharge (WCPD) (TBq y^{-1})	Annual Limit proposed by Environment Agency (TBq y^{-1})
Iodine-131	2.08E-04	3.77E-04	3E-04
Noble gases (excluding Argon-41)	8.095	14.7	13
Tritium	1.867	3.39	3
Carbon-14	0.638	1.16	1
Total beta emitting particulates(1)	1.72E-05	3.12E-05	3E-05

Note 1: Total beta emitting particulate includes ‘other particulate’, cobalt-60, strontium-90 and caesium-137 figures from Table 5 above.

245 In summary the discharge limits proposed by the Environment Agency are:

a) Iodine-131 – 0.3 GBq in any 12 calendar months.

b) Noble gases – 13 TBq in any 12 calendar months.

c) Tritium – 3 TBq in any 12 calendar months.

d) Carbon-14 - 1 TBq in any 12 calendar months.

e) Other radionuclides (excepting tritium, carbon-14, iodine radionuclides and noble gases) taken together – 0.03 GBq in any 12 calendar months.

246 To ensure ongoing control of gaseous radioactive waste, we consider it appropriate to include the requirement for notification of discharges at certain levels for specific radionuclides. This ensures that operator and regulator attention is drawn to those discharges where, over the specified time period, the discharges reach the notification level. We consider that it is appropriate to set quarterly notification levels for tritium, carbon-14, noble gases, iodine radionuclides, and other radionuclides (excepting tritium, carbon-14, noble gases and iodine radionuclides) taken together. We consider it appropriate to set the quarterly notification levels to be the sum of the estimated discharges in months 16 to 18 inclusive of the operating cycle as that is when they are expected to the highest. This means that should discharges exceed the quarterly notification level in any three calendar months the operator should notify the Environment Agency forthwith and take steps to investigate the cause of the exceedence and report the outcome of the investigation to the Environment Agency.

247 We consider the following quarterly notification levels to be appropriate:

Proposed quarterly notification levels proposed by Environment Agency

	Annual Limit proposed by Environment Agency (TBq y^{-1})	Quarterly notification level proposed by Environment Agency (TBq in any calendar 3 months)	Decision basis
Iodine-131	3E-04	3.0E-05	10% of limit to identify fuel pin failures
Noble gases (excluding argon-41)	13	1.3	10% of limit to identify fuel pin failures
Tritium	3	0.6	Highest 3 months rounded up
Carbon-14	1	0.21	Highest 3 months rounded up
Total beta emitting particulates(1)	3E-05	3E-06	Highest 3 months rounded up

248 Our Radioactive Substances Regulation Environmental Principle RSMDP12 states that limits and levels should be established on the quantities of radioactivity that can be discharged into the environment where these are necessary to secure proper protection of human health and the environment.

249 We consider that the limits we propose for quantities of radionuclides that can be discharged into the atmosphere are necessary to secure proper protection of human health and the environment.

GEHO1211BTNW-E-E

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