

**Generic design assessment
AP1000 nuclear power plant design by
Westinghouse Electric Company LLC**

**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

Assessment report –discharges of gaseous radioactive waste

Protective status	This document contains no sensitive nuclear information or commercially confidential information.
Process and Information Document¹	<p>The following sections of Table 1 in our Process and Information document are relevant to this assessment:</p> <p>1.2 General information relating to the facility including:</p> <p>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.</p> <p>2.1 A description of how radioactive wastes will arise, be managed and disposed of throughout the facility's lifecycle.</p> <p>2.2 Design basis estimates for monthly discharges of gaseous and liquid radioactive</p> <p>2.3 Proposed annual limits with derivation for radioactive gaseous and liquid discharges</p>
Radioactive Substances Regulation Environmental Principles²	<p>The following principles are relevant to this assessment:</p> <p>RSMDP3 – Use of BAT to minimise waste:</p> <p>RSMDP4 – Processes for Identifying BAT:</p> <p>RSMDP7 – BAT to Minimise Environmental Risk and Impact:</p> <p>RSMDP8 – Segregation of Wastes:</p> <p>RSMDP9 – Characterisation:</p> <p>RSMDP12 – Limits and Levels on Discharges:</p> <p>ENDP15 – Mechanical Containment Systems for Liquids And Gases:</p>
Report author	Julie Tooley

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

- a) During routine operations and maintenance;
- b) From anticipated operational events.

3 We conclude that the gaseous radioactive discharges from the AP1000 should not exceed those of comparable power stations across the world. We note that at this stage the proposed discharges of carbon-14 in gaseous waste are slightly higher than the range for other European PWRs.

4 Our conclusion is subject to one potential GDA Issue, and two other issues:

GDA Issue

- a) The radiologically controlled area ventilation system (VAS) and any other ventilation systems where there is the potential for the release of airborne radioactive waste to the atmosphere which do not have passive HEPA filtration as part of the design.

Other issues:

- b) Detailed arrangements for the hand over between Westinghouse and future operators shall be provided at site specific permitting, in particular with respect to matters that relate to the use of BAT to minimise radioactive discharges.
- c) A detailed and robust justification of options for carbon-14 abatement in radioactive waste discharges shall be provided at site specific permitting.

5 We conclude that any operational AP1000 should comply with the limits and levels set out below for the disposal of gaseous radioactive waste to air.

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

6 Our findings on the wider environmental impacts and waste management arrangements for the AP1000 reactor may be found in our Consultation Document (Environment Agency, 2010a).

2 Introduction

- 7 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, 2010b), we also expect new nuclear power plant to use BAT to minimise the impact of discharges of radioactive waste to the environment.
- 8 This assessment considers the design of the plant which gives rise to gaseous radioactive waste, the foreseeable levels of radioactivity in gaseous radioactive waste, and techniques that have been included in the design to minimise discharges of gaseous radioactive waste. The assessment considers the information provided by Westinghouse Electric Company (Westinghouse) for its AP1000 design, and the assessment aims to establish whether the design could be operated in the UK in line with UK Statute, policy and guidance on radioactive waste, and, if so, key issues that should be taken forward into any discharge permit that may be issued in the form of relevant limitations and conditions, along with any areas where insufficient information has been provided in GDA, which results in a potential issue being set out at this stage of our considerations.
- 9 With respect to gaseous radioactive waste, along with detailed information about waste treatment plant and techniques, key data relates to estimated discharges both on a monthly and annual basis. Our consideration as to the acceptability of proposed discharges will be carried forward into our impact assessment, both in terms of impact on members of the public and impact on non-human species. As part of this assessment and the impact assessments, we recognise that whilst monthly discharge data is important we need also to consider the profile of emissions over longer periods of time. Annual cycles may vary depending on the operational state of the reactor, and the monthly profile of emissions over longer periods, beyond single operating cycles, is important in this assessment as it enables us to assess short-term impacts for any peak emissions. It also enables us to compare the design with current operating power stations across the world. The discharge data should include radioactive waste arisings from all scenarios (e.g. routine operation, start-up and shut-down etc) and all reasonably foreseeable events (e.g. breakdown maintenance).
- 10 This assessment does not cover gaseous radioactive waste arising from decommissioning at the end of the reactor lifecycle.
- 11 The assessment aims to establish whether the design could be operated in the UK in line with UK Statute, policy and guidance on radioactive waste as currently written but it is recognised that the assessment should be kept under review to reflect changes in statute, policy and guidance that may occur between now and plant commissioning.

3 Assessment

- 12 This assessment considers the discharges of gaseous radioactive waste from the AP1000 and the techniques employed to minimise discharges. We expect new nuclear power plant to be designed to use BAT to minimise discharges of radioactive wastes in accordance with Statutory Guidance to the Environment Agency (DECC 2009) and our REPS (Environment Agency, 2010c, see RSMDP7).
- 13 The assessment has also considered the AP1000 design in the light of UK Statute, policy and guidance.
- 14 The key legislative areas that have been taken into account are:
- a) EU Commission Recommendation 2004/2/Euratom (EC, 2004) which sets out requirements for monitoring and reporting on radioactive discharges.
 - b) Environmental Permitting Regulations (EPR 10) [which replaced the Radioactive Substances Act 1993 (RSA93)] which is aimed at the control of radioactive substances (including waste) (Defra, 2010) (Environment Agency, 2010f) .

- c) Statutory guidance to the Environment Agency concerning the Regulation of Radioactive Discharges into the Environment (DECC, 2009) which sets out the principles for:
- i) regulatory justification of practices by the Government;
 - ii) optimisation of protection on the basis that radiological doses and risks to workers and members of the public from a source of exposure should be kept as low as reasonably achievable (the ALARA principle);
 - iii) application of limits and conditions to control discharges from justified activities;
 - iv) sustainable development;
 - v) the use of Best Available Techniques (BAT);
 - vi) the precautionary principle;
 - vii) the polluter pays principle;
 - viii) the preferred use of 'concentrate and contain' in the management of radioactive waste over 'dilute and disperse' in cases where there would be a definite benefit in reducing environmental pollution, provided that BAT is being applied and worker dose is taken into account.
- 15 Bearing in mind the legislative framework and our REPs, this assessment aims to establish the acceptability of the AP1000 design with respect to gaseous radioactive waste discharges.

3.1 Assessment Methodology

- 16 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) decide on any issues to carry forward from GDA in our Statement of Design Acceptability.
- 17 Westinghouse provided its submission for 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".
- 18 Westinghouse completely revised its submission during 2008 and provided an updated Environment Report with supporting documents.
- 19 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 that BAT is used.
- 20 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 production 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.
- 21 We raised a Regulatory Observation (RO), RO-AP1000-043 jointly with the HSE on Westinghouse in September 2009 that had an action to provide:
- a) a justification of the proposed arrangements for the HEPA filtration arrangements for each and all ventilation systems which have the potential for significant airborne contamination under either normal or fault conditions.
- 22 We raised 42 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.
- 23 Westinghouse responded to all the ROs and TQs. They reviewed and updated the Environment Report in April 2010 to include all the relevant information provided by the ROs and TQs. This report only uses and refers to the information contained in the updated Environment Report (UKP-GW-GL-790 (Revision3) and its supporting documents.

3.2 Assessment Objectives

- 24 Key areas of the submission made under the GDA arrangements by Westinghouse for the AP 1000 design that have been considered are:
- 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 arising 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.

3.3 Westinghouse documentation

25

We referred to the following documents to produce this report:

Document reference	Title	Version number
UKP-GW-GL-790	UK AP1000 Environment Report	3
UKP-GW-GL-026	AP1000 Nuclear Power Plant BAT Assessment	1
UKP-GW-GL-028	Proposed Annual Limits for Radioactive Discharge	1
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

4 Summarised description of the AP1000 gaseous radioactive waste management systems

26 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. 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.

27 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.

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

29 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.

4.1 Gaseous radioactive waste system (WGS)

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

31 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 70 hours per year (ER s3.3.1.2).

32 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.

33 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.

34 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 $0.99 \text{ m}^3 \text{ h}^{-1}$ based on a reactor cooling system hydrogen concentration of $45 \text{ cm}^3 \text{ kg}^{-1}$.

- 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 $0.85 \text{ m}^3 \text{ h}^{-1}$.

4.2 Condenser air removal system

35 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).

4.3 Containment building venting

36 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.

37 The containment air filtration system (VFS) (ERs3.3.2.2) 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 providing 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.

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

38 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.
- 39 Ventilation discharges from the auxiliary building and other radiologically controlled areas may contain activity as a result of leakage from process streams. If radioactivity is detected, the contaminated air is directed for treatment by the containment air filtration system. In the absence of detectable sources of contamination, discharges are made directly to the plant vent without treatment.
- 40 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.
- 41 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.
- 42 Extract air from the radioactive waste building is by means of low level extract grilles (ERs3.3.6) and is conveyed through high integrity ductwork to HEPA filters and discharged to the main plant exhaust stack by two 100% duty extract fans.

4.5 Plant vent

- 43 The main plant vent is a 55.7 m rectangular stack of dimensions 2.025 m x 2.311 m. The volumetric flow rate is $38.13 \text{ m}^3 \text{ s}^{-1}$ 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 3.3-3)

4.6 Condenser air removal (turbine) vent

- 44 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 $0.6 \text{ m}^3 \text{ s}^{-1}$ 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 3.3-4)
- 45 Information on the production of radionuclides in gaseous radioactive waste is in our assessment report on BAT to prevent or minimise the creation of radioactive wastes (EAGDAR AP1000-03, see Environment Agency, 2010b).

5 Gaseous Radioactive Waste Treatment System in the AP1000 design

5.1 Gaseous radioactive waste system (WGS)

46 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 m³ 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 m³ 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 m³ 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 m³ 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 m³/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.

5.2 Containment venting system

47 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.
- 48 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.
- 49 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.
- 50 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.
- 51 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.
- 52 We consider that Westinghouse have identified a range of accepted techniques for the treatment of gaseous radioactive waste which are similar to those used in comparable reactors. Westinghouse have not proposed any novel techniques for the treatment of gaseous radioactive waste.
- 53 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.
- 54 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 GALE¹) 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

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

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 m³/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 3.3-2 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 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(m³ 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 m³) 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 m³/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 m³/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 operate 70 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.'

- 55 Westinghouse incorporated the above response to TQ-AP1000-148 in paragraph 3.3.9, Figure 3.3-2 and Table 3.3-2 in its Environment Report and provided further supporting information.
- 56 On the basis of its BAT optioneering assessment, Westinghouse claims there are a number of measures in the design of the AP1000 which will prevent or minimise waste at source (ERs3.3.9) 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.
- 57 We raised a Regulatory Observation (RO-AP1000-043) jointly with the HSE on 14 September 2009. The Regulatory Observation set out that insufficient justification had been provided by Westinghouse for the proposed HEPA filtration arrangements for each and all the ventilation systems which have a potential for significant airborne contamination under either normal or accident conditions. We noted that HEPA filtration would not be routinely used on the discharge from the radiologically controlled area ventilation system. In line with the regulatory expectation that all ventilation systems which have the potential to experience significant airborne contamination have passive HEPA filtration as part of the discharge route we sought further

information to demonstrate that discharges would be minimised using best available techniques. Westinghouse responded on 5 March 2009 stating that detailed arguments and evidence would be provided to show that the design is both ALARP and BAT by 30 April 2010. Westinghouse propose to incorporate comments from the HSE and Environment Agency in a final response which will be provided by 24 September 2010.

- 58 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.
- 59 We consider that Westinghouse have considered a comprehensive range of techniques for the minimisation of gaseous radioactive waste at source, however we recognise that techniques may be developed in the future which may be worthy of consideration. We consider the overall outcome of the BAT optioneering relating to minimising the production of gaseous radioactive waste at source to be reasonable and to fulfil the requirements of REP RSMDP3 at this stage. We note however that ventilation from radiologically controlled areas is passed through the exhaust air filtration unit, which includes HEPA filtration, only if radioactivity is detected. We consider that further information is required to demonstrate that this approach is BAT. Whilst we have raised this as a concern with Westinghouse, its final response will be outside the timeframe for inclusion in our consultation process, therefore this matter is currently a potential GDA Issue (AP1000-I2) attached to our draft interim Statement of Design Acceptability:
- a) The radiologically controlled area ventilation system (VAS) and any other ventilation systems where there is the potential for the release of airborne radioactive waste to the atmosphere which do not have passive HEPA filtration as part of the design.

6 Information on the treatment and abatement of radionuclides in gaseous radioactive waste

60 Westinghouse have provided information on the abatement of certain radionuclides they would expect to utilise during AP1000 operations. 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.

61 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.

62 The outcomes of the BAT optioneering exercise are as follows:

6.1 Tritium

63 Westinghouse predict that averaged over the 18 month cycle 1.8 TBq y⁻¹ of tritium will be discharged in gaseous radioactive waste. The discharges of tritium in the highest 12 months of the 18 month cycle are estimated to be 1.867 TBq. Westinghouse estimate the impact of discharging 1.867 TBq of tritium in 12 months will be 0.19 µSv y⁻¹ to the local resident family (2.5% of total dose to local resident family). (BAT Assessment Form 1)

64 Westinghouse have identified the following options for abatement:

- a) Adsorption.
- b) No abatement– direct discharge of gaseous radioactive waste to the environment.
- c) Isotopic concentration/separation.
- d) Use of carbon delay beds.
- e) Use of a condenser.
- f) Cryogenics.
- g) Minimisation of plant shutdowns.

65 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 claim that a condenser is included in the AP1000 design.

66 Westinghouse provide little detail on some of the techniques for abatement of tritium in gaseous radioactive waste. We consider the optioneering study contains insufficient detail to identify the best option however we recognise that the impact of tritium discharges without abatement is low. We will provisionally accept that the AP1000

design is BAT for minimising gaseous discharge of tritium. 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. **This matter is the subject of another issue:**

a) **Detailed arrangements for the hand over between Westinghouse and future operators shall be provided at site specific permitting, in particular with respect to matters that relate to the use of BAT to minimise radioactive discharges.**

67 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 3.2-6)

68 Westinghouse propose a discharge limit for tritium from the AP1000. They have predicted monthly discharges over an 18 month cycle and used data from the 12 months in which the discharges are highest (months 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 the proposed limit. (ERs6.1.5)

69 Westinghouse has proposed annual limit of 3,000 GBq for tritium discharges. (ER Figure 6.1-3 and ER Table 6.1-5)

70 From our examination of historic discharges from European and US PWRs operating over the last 10 to 15 years we conclude that the range for the sector in terms of discharge to atmosphere of tritium is 100 to 3600 GBq per annum for a 1000 MWe power station (see Annex 3 of our Consultation Document for the AP1000 (Environment Agency, 2010a)). 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.

71 Westinghouse estimate 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 of $0.19 \mu\text{Sv y}^{-1}$. (ER table 5.2-2)

72 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. The annual limit for tritium in gaseous discharges from Sizewell B is 3,000 GBq.

73 Based on the information provided by Westinghouse for GDA on the discharges of tritium in the 3 months where they are expected to be the highest, our proposed quarterly notification level for tritium is 600 GBq.

6.2 Carbon-14

74 Westinghouse predict that averaged over the 18 month cycle 606 GBq y^{-1} of carbon-14 will be discharged in gaseous radioactive waste. The discharges of carbon-14 in the highest 12 months of the 18 month cycle are estimated to be 638 GBq. Westinghouse estimate the impact of discharging 638 GBq of carbon-14 in 12 months will be $7.0 \mu\text{Sv y}^{-1}$ to the local resident family (92% of total dose to local resident family). (BAT Assessment form 2)

75 Westinghouse have considered the following options for abatement of carbon-14 in gaseous radioactive waste:

- a) Alkaline slurry scrubbing.
- b) Alkaline packed bed column.

- c) Double alkali process.
 - d) Gas absorption by wet scrubbing.
 - e) Ethanolamine scrubbing.
 - f) Absorption by a fluorocarbon solvent.
 - g) Physical absorption on an active surface.
 - h) Reaction with magnesium.
 - i) Isotopic separation.
 - j) Cryogenics.
 - k) No abatement – direct discharge of gaseous radioactive waste to the environment.
- 76 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.
- 77 Westinghouse claim that ion exchange and direct discharge without abatement are included in the AP1000 design. We consider that the techniques considered by Westinghouse for abatement of carbon-14 in gaseous discharges from the AP1000 are sufficiently comprehensive and represent feasible techniques at this stage, however we recognise that techniques may be developed in the future which may be worthy of consideration.
- 78 **We provisionally conclude that the AP1000 design is BAT for minimising the gaseous discharge of carbon-14 however while the impact from discharges is low, carbon-14 is a significant contributor to doses from gaseous discharges and our conclusion is subject to another issue :**
- a) **A detailed and robust justification of options for carbon-14 abatement in radioactive waste discharges shall be provided at site specific permitting.**
- 79 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 3.3-6)
- 80 Westinghouse propose a discharge limit for carbon-14 from the AP1000. They have predicted monthly discharges over an 18 month cycle and used data from the 12 months in which the discharges are highest (months 7 – 18) to calculate the representative 12 month plant discharge to be 638 GBq. Westinghouse has applied our limit setting methodology to calculate the annual worst case plant discharge (WCPD) which it has rounded to give the proposed limit. (ERs6.1.5)
- 81 Westinghouse proposes an annual limit of 1,000 GBq for carbon-14 discharges. (ER Figure 6.1-3 and ER Table 6.1-5)
- 82 From our examination of historic discharges (where available) from European PWRs operating over the last 10 to 15 years (see Annex 3 of our Consultation Document for the AP1000) we conclude that the range for the sector in terms of discharge to atmosphere of carbon-14 is 40 to 530 GBq per annum for a 1000 MWe power station. The predicted annual gaseous discharge of carbon-14 from UK AP1000 normalised for power slightly exceeds this range.
- 83 Westinghouse estimate 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 $7.0 \mu\text{Sv y}^{-1}$. (ER table 5.2-2)
- 84 We have independently calculated limits for carbon-14 discharges that we may grant and based on the information provided by Westinghouse for GDA our proposed disposal limit for carbon-14 by discharge to atmosphere is 1,000 GBq in any 12 rolling calendar months. The annual limit for carbon-14 in gaseous discharges from Sizewell B is 500 GBq.

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

6.3 Strontium-90

86 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 $4.4\text{E-}04 \text{ GBq}$. Westinghouse estimate the impact of discharging $4.4\text{E-}04 \text{ GBq}$ of strontium-90 in 12 months will be $9.6\text{E-}05 \text{ } \mu\text{Sv y}^{-1}$ to the local resident family (0.001% of total dose to local resident family). (BAT Assessment form 4).

87 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.

88 Westinghouse claim 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 claim will provide adequate filtration. However Westinghouse have not provided evidence to support this claim at the time of writing.

89 We consider that the techniques considered by Westinghouse for the abatement of beta emitting particulates in the AP1000 are sufficiently comprehensive and represent feasible techniques at this stage.

90 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 $0.000096 \text{ } \mu\text{Sv y}^{-1}$.

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

92 We have independently calculated limits on radioactive particulates discharges that we may grant and based on the information provided by Westinghouse for GDA our proposed limit for the disposal of radioactive particulates by discharge to the atmosphere is 0.03 GBq in any 12 rolling calendar months. The annual limit for beta particulates in gaseous discharges from Sizewell B is 0.1 GBq.

93 Based on the information provided by Westinghouse for GDA our proposed quarterly notification level (QNL) for total radioactive particulates is 0.003 GBq.

6.4 Iodine-131

94 Westinghouse predict that averaged over the 18 month cycle, 0.21 GBq y^{-1} of iodine-131 will be discharged in gaseous radioactive waste. The discharges of iodine-131 in the highest 12 months of the 18 month cycle are estimated to be 0.207 GBq. Westinghouse estimate the impact of discharging 0.207 GBq of iodine-131 in 12 months will be $2.60\text{E-}01 \text{ } \mu\text{Sv y}^{-1}$ to the local resident family (3% of total dose to local resident family). (BAT Assessment form 5)

95 Westinghouse have considered the following abatement techniques for iodine-131 in gaseous radioactive waste:

- a) Deposition – by spraying, sedimentation, diffusio-phoresis and thermophoresis.

- b) Delay beds.
 - c) Silver reactor – using silver nitrate.
 - d) Mercurex process.
 - e) Iodox.
 - f) Electrolytic scrubbing.
 - g) Organic liquids.
 - h) Caustic scrubbing.
 - i) Silver containing sorbents – such as silver substituted zeolites and silver nitrate impregnated amorphous silica.
 - j) No abatement – direct discharge of gaseous radioactive waste to the environment.
- 96 Westinghouse have scored the options against the attributes as described in the BAT report, and the highest scoring option is deposition, with delay beds having a mid range score. Westinghouse claim that the AP1000 design includes the use of delay beds and deposition techniques using natural processes such as sedimentation, diffusiophoresis and thermophoresis.
- 97 We consider that the techniques considered by Westinghouse for the abatement of iodine radionuclides in gaseous radioactive waste from the AP1000 are sufficiently comprehensive and represent a range of feasible proven techniques and techniques at the development stage. We conclude that Westinghouse have demonstrated that BAT is used to minimise discharges of iodine radionuclides from the AP1000.
- 98 Westinghouse predicts that the annual average discharge of iodine radionuclides over the 18 month cycle from the AP1000 to atmosphere will be: (ER Table 3.3-5)
- a) Iodine-131 = 0.21 GBq
 - b) Iodine-133 = 0.35 GBq
 - c) Total iodine radionuclides = 0.56 GBq.
- 99 Westinghouse proposes a discharge limit for iodine radionuclides from the AP1000. They have predicted monthly discharges over an 18 month cycle and used data from the 12 months in which the discharges are highest (months 7 – 18) to calculate the representative 12 month plant discharge to be 0.595GBq. Westinghouse has applied our limit setting methodology to calculate the annual worst case plant discharge (WCPD) which it has rounded to give the proposed limit. (ERs6.1.5)
- 100 From our examination of historic discharges from European and US PWRs operating over the last 10 to 15 years we conclude that the range for the sector in terms of discharge to atmosphere of iodine-131 is 10 to 200 MBq per annum for a 1000 MWe power station (see Annex 3 of our Consultation Document for AP1000). 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.
- 101 Westinghouse proposes an annual limit of 1 GBq for discharges of iodine radionuclides assuming a 0.25% failed fuel rate. (ER Figure 6.1-1 and ER Table 6.1-5)
- 102 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 0.27 $\mu\text{Sv y}^{-1}$. (ER table 5.2-2).
- 103 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. The annual limit for iodine-131 in gaseous discharges from Sizewell B is 0.5 GBq.

104 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 radioiodine 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% of the disposal limit.

6.5 Noble gases

105 Westinghouse predict that noble gases will be present in gaseous radioactive waste in the following amounts (BAT Assessment 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

106 Westinghouse have provided information on the abatement options for noble gases in the AP1000:

- a) Carbon delay beds- with 60 day hold up.
- b) Minimise plant shutdowns.
- c) Cryogenics-to liquefy and separate noble gases.
- d) No abatement – direct discharge of gaseous radioactive waste to the environment.

107 Westinghouse claim the highest scoring options for abating noble gases in gaseous radioactive waste are to minimise plant shutdowns and for Argon-41 to use delay beds.

108 We accept the use of delay beds is current best practice for minimising noble gases in gaseous radioactive waste.

109 We conclude that the techniques considered by Westinghouse for the abatement of xenon and krypton radionuclides in gaseous radioactive waste from the AP1000 are sufficiently comprehensive and represent feasible techniques at this stage.

110 Westinghouse have 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 3.3-6

Radionuclide	Activity in gaseous discharge (GBq y ⁻¹)
Argon-41	1,300
Krypton radionuclides	3,170

Xenon radionuclides	3,577
Total	8,047

111 Westinghouse propose a discharge limit for noble gases (excluding argon-41) from the AP1000. They have predicted monthly discharges over an 18 month cycle and used data from the 12 months in which the discharges are highest (months 7 – 18) to calculate the representative 12 month plant discharge to be 8099 GBq. Westinghouse has applied our limit setting methodology to calculate the annual worst case plant discharge (WCPD) which it has rounded to give the proposed limit. (ERs6.1-5)

112 Westinghouse proposes an annual limit of 13,000 GBq for noble gases (excluding argon-41) based on a 0.25% failed fuel rate. (ER Figure 6.1-2 and ER Table 6.1-5).

113 From our examination of historic discharges from European and US PWRs operating over the last 10 to 15 years we conclude that the range for the sector in terms of discharge to atmosphere of noble gases is 100 to 10,000 GBq per annum for a 1000 MWe power station. The predicted annual 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.

114 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 5.2-2)

- a) estimated dose from argon-41 is 0.13 $\mu\text{Sv y}^{-1}$
- b) estimated dose from krypton-85 is 0.0016 $\mu\text{Sv y}^{-1}$
- c) estimated dose from xenon-133 is 0.0028 $\mu\text{Sv y}^{-1}$

115 We have independently calculated limits on noble gas discharges that we may grant and based on the information provided by Westinghouse for GDA our proposed disposal limit for the disposal of noble gases (excluding argon-41) by discharge to the atmosphere is 13,000 GBq in any rolling 12 calendar months. The annual limit for noble gases in gaseous discharges from Sizewell B is 30,000 GBq.

116 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% of the disposal limit.

6.6 Beta emitting particulates

117 Westinghouse predict that beta emitting particulates will be present in gaseous radioactive waste in the following amounts (BAT Assessment 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 ($\mu\text{Sv y}^{-1}$)	% 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		

- 118 Westinghouse have provided information on the abatement options for beta particulate activity (cobalt-58, cobalt-60, iron-55 and nickel-63) in gaseous radioactive waste in the AP1000:
- a) Wet scrubbing.
 - b) No abatement — direct discharge of liquid radioactive waste to the environment.
 - c) Carbon delay beds.
 - d) HEPA filtration.
- 119 Westinghouse claim the highest scoring option for abating beta emitting particulates in gaseous radioactive waste is the use of carbon delay beds and HEPA filtration.
- 120 We conclude that the techniques considered by Westinghouse for the abatement of beta emitting particulates in gaseous radioactive waste from the AP1000 are sufficiently comprehensive and represent feasible techniques at this stage.
- 121 Westinghouse claim that the use of carbon delay beds and HEPA filtration in the gaseous radwaste system and the containment air filtration system, respectively, is BAT for particulates in the gaseous waste stream.
- 122 Westinghouse claim that delay beds and HEPA filtration for radiologically controlled areas is included in the AP1000 design, however HEPA filtration of gaseous waste from radiologically controlled areas is not considered necessary by Westinghouse unless the waste is found to contain radioactivity. In this event it will be treated using filters in the VFS.
- 123 We consider the use of carbon delay beds and HEPA filtration in the gaseous radwaste system and the containment air filtration system, respectively, is BAT for minimising discharges of beta emitting particulates in gaseous radioactive waste from the AP1000.
- 124 Westinghouse has predicted that the annual average discharge of radioactive particulates from the AP1000 to atmosphere will be: ER Table 3.3-7

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

- 125 Westinghouse propose a discharge limit for radioactive particulates from the AP1000. They have predicted monthly discharges over an 18 month cycle and used data from the 12 months in which the discharges are highest (months 7 – 18) to calculate the representative 12 month plant discharge to be 0.0284 GBq. Westinghouse has applied our limit setting methodology to calculate the worst case annual plant discharge (WCPD) which it has rounded to give the proposed limit. (ERs6.1.5)
- 126 Westinghouse proposes an annual limit of 0.03 GBq for discharges of radioactive particulates. (ER Figure 6.1-7 and ER Table 6.1-5)
- 127 From our examination of historic discharges from European and US PWRs operating over the last 10 to 15 years we conclude that the range for the sector in terms of discharge to atmosphere of fission and activation products is 0.5 to 1000 MBq per annum for a 1000 MWe power station. (see Annex 3 Of our Consultation Document for AP1000 (environment Agency, 2010a)). The predicted gaseous discharge of

- radioactive particulates from AP1000 is within this range. We conclude that gaseous discharge of radioactive particulates is comparable to other power stations across the world.
- 128 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 $0.0011 \mu\text{Sv y}^{-1}$. (ER table 5.2-2).
- 129 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 $0.00041 \mu\text{Sv y}^{-1}$.
- 130 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 $0.000096 \mu\text{Sv y}^{-1}$.
- 131 We have independently calculated limits on radioactive particulates discharges that we may grant and based on the information provided by Westinghouse for GDA our proposed limit for the disposal of radioactive particulates by discharge to the atmosphere is 0.03 GBq in any 12 rolling calendar months. The annual limit for beta particulates in gaseous discharges from Sizewell B is 0.1 GBq.
- 132 Based on the information provided by Westinghouse for GDA our proposed quarterly notification level for total radioactive particulates is 0.003 GBq.

7 BAT Assessments for Gaseous Radioactive Waste Treatment and abatement

- 133 On the basis of its BAT optioneering assessment, Westinghouse claims there are a number of measures in the design of the AP1000 which will represent the best available techniques to prevent or minimise the discharges of gaseous radioactive waste including:
- a) Natural deposition to minimise the discharges of iodine-131.
 - b) Carbon delay beds to minimise the discharges of iodine-131, noble gases, beta emitting particulates, strontium-90.
 - c) HEPA filtration to minimise the discharges of beta emitting particulates, strontium-90.
 - d) Use of a condenser to minimise the discharges of gaseous tritium and divert tritiated water vapour to the liquid waste stream where its impact is estimated to be lower.
 - e) Minimising plant shutdown to minimise the discharges of tritium.
- 134 Westinghouse state that the AP1000 design does not include any abatement to minimise aerial discharges of carbon-14 and tritium which will be discharged directly into the environment.
- 135 Our Radioactive Substances Regulation Environmental Principle RSMDP4 on processes for identifying BAT requires that best available techniques should be identified by a process that is timely, transparent, inclusive, based on good quality data, and properly documented.
- 136 We consider that the BAT assessment carried out by Westinghouse is qualitative in nature and there is a lack of data provided to back up scoring and ranking. Additionally Westinghouse have considered the use of techniques in isolation and have not considered the use of combinations of techniques. Westinghouse have not included a consideration of the effect of each technique on other waste streams in detail. For example diversion of carbon-14 from the liquid waste stream to the atmospheric waste stream may reduce doses to members of the public but this may be offset by other factors such as cost.
- 137 Whilst we recognise the overall outcome of the BAT assessment may be valid based on the information provided, the outcomes have not been demonstrated conclusively. However taking into account the low magnitude of the impact of gaseous radioactive waste, we believe the BAT assessment is suitable for purpose at this stage. We will include a condition in any permit we grant for the disposal of gaseous radioactive waste which will require the permit holder to demonstrate that BAT is used to minimise discharges. We would expect the BAT assessment to be kept under review to reflect developments in techniques to prevent and minimise the production of gaseous radioactive waste.

8 Gaseous radioactive waste discharge system in the AP1000 design

138 Radioactive gaseous waste is discharged using the plant vent or the condenser air removal (turbine) vent.

8.1 Plant vent

139 The main plant vent is a 55.7 m rectangular stack with dimensions 2.025 m x 2.311 m. The volumetric flow rate is $38.13 \text{ m}^3 \text{ s}^{-1}$ 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.

8.2 Condenser air removal (turbine) vent

140 The condenser air removal (turbine) vent is a 38.4 m circular stack which is 0.3038 m in diameter. The volumetric flow rate is $0.6 \text{ m}^3 \text{ s}^{-1}$ 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.

8.3 Sampling and monitoring

141 At the time of writing Westinghouse claim that the detailed design of the main stack monitoring system was being undertaken and the exact locations of the monitoring point, flow measurement point, upstream and downstream disturbances and filtration system had not been determined. Westinghouse claim a sample point will be chosen in well mixed flow where the velocity profile across the stack cross section is relatively constant and sufficiently remote from upstream and downstream disturbances.

9 Estimates of annual gaseous radioactive waste discharges

142 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.

143 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.

144 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.

145 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.

146 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 and further detailed data is given in Annex 1.

Table 1: 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

147

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.

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

148 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.

149 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.

10 Comparison of radionuclides in AP1000 data with the Requirements of EU Commission Recommendation 2004/2/Euratom

150 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.

Table 3: 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

151 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.

152 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.

11 Comparison of AP1000 Gaseous Radioactive Waste Discharges with Other European Pressurised Water Reactors

- 153 Westinghouse have 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.
- 154 We have compared gaseous discharges from the AP1000 with historic discharges from European and US PWRs operating over the last 10 to 15 years and the results are shown in Table 4.

Table 4: Gaseous discharges from the AP1000 compared with historic discharges from European and US PWRs

Radionuclides or group of radionuclides	Average annual discharges (GBq) 12/18 th of discharges over 18 month cycle	Average annual discharges normalised to power (GBq/1000MWe) Based on 1117 MWe	Representative annual discharges (GBq) Discharges in highest 12 months of 18 month cycle	Representative annual discharges normalised to power (GBq/1000 MWe) Based on 1117MWe	Normal operating range (GBq/1000 MWe)	Comments
Tritium	1800	1611	1867	1495	100-3600	Within range
Carbon-14	606	543	638	571	40-530	Higher than range. In report APP-WLS-M3C-056 Rev 0 WEC state that the AP1000 estimate for carbon-14 in gaseous releases is 41% to 71% higher than that found at two US operating stations measured using continuous gas samples
Iodine-131	0.21	0.188	0.207	0.185	<1 - 2	Within range
Noble gases excluding Argon-41	8047	7204	8099	7251	100 -10000	Within range
All other radionuclides (excepting tritium, carbon-14, iodine radionuclides and noble gases)	0.017	0.0152	0.0172	0.0154	<1-1	Within range

11.1 Orphan gaseous waste

- 155 Westinghouse claim that the gaseous radioactive waste system is designed to handle all gaseous effluents and other anticipated events using installed equipment.
- 156 We consider that the AP1000 gaseous radioactive waste treatment system will be able to process and treat all foreseeable gaseous radioactive waste.

12 Measures for the prevention of contamination in the AP1000 design

- 157 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.

13 Proposed discharge limits

- 158 Our limit setting guidance sets out a number of criteria which we will use to identify radionuclides and/or groups of radionuclides which will be subject to numerical limits on activity in discharges of gaseous radioactive waste. The guidance sets out 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.
- 159 In addition the guidance states that discharge limits should be set so as to minimise the 'headroom' between the actual levels of discharges expected during normal operation and the limits themselves.
- 160 The guidance also states that discharges from new plant should be capped at the levels for which approval is first given for full operation, however caps may be reconsidered in the light of operating experience.
- 161 Notification levels may be set to contribute to the information required to demonstrate BAT.
- 162 The discharge limit setting guidance sets out our methodology for assessing proposed discharges in order to set annual discharge limits in terms of a rolling 12 month period. We have considered whether limits could be set on the basis of different timescales, for example, activity limits set per cycle or per calendar year.
- 163 Discharge limits set for a rolling 12 month period provide 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 humans species. However, as part of our assessment of the impact of discharges we have assessed the impact of short term releases above the normal routine levels in order to determine the impact of any foreseeable elevated short term releases on humans. The outcome of this assessment is presented on our Assessment Report EAGDAR AP1000-11 Radiological Impact on members of the public (Environment Agency, 2010d).
- 164 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 Convention² and in UK publications such as the annual publication on Radioactivity in Food and the Environment (e.g. see Environment Agency, et al 2009).
- 165 Discharge limits set in terms of activity discharge per cycle 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.
- 166 After consideration we are minded to set discharge limits on the basis of a 12 month rolling limit on the amount of activity that can be discharged to the environment, and in our Process and Information document we required Westinghouse to provide information on discharges of gaseous radioactive waste on a month by month basis to allow us to come to a view on appropriate 12 month rolling discharge limits in regard to the activity in gaseous radioactive waste discharges.

13.1 Significant radionuclides

- 167 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.
- 168 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.
- 169 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.
- 170 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.
- 171 In addition, Westinghouse claim that carbon-14 is significant because it has a long half life and may persist or accumulate in the environment.
- 172 In terms of radionuclides which indicate plant performance, Westinghouse claim that cobalt-60 is an indicator of particulate emissions.
- 173 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.

² Convention for the Protection of the Marine Environment of the North-East Atlantic, 1992 (“OSPAR Convention”)

- 174 We believe that the following radionuclides should be subject to individual annual limits:
- 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.
 - 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 $1 \mu\text{Sv y}^{-1}$.
 - Iodine radionuclides – significant as an indicator of plant performance.
 - 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.
 - 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.
- 175 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.

13.2 Estimated discharges and proposed discharge limits

- 176 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.
- 177 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 factor of 1.5 to take into account operational fluctuations; and
 - a factor of 1.1 to take into account increases in discharges that may result from plant ageing.
- 178 Using these factors Westinghouse has estimated values for the WCPD for a range of radionuclides which are given in Table 6.1-5 (air emissions) and Table 6.1-6 (liquid discharges) and have calculated limits based on these values.

Table 5: 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.

179

We have considered the information provided by Westinghouse and the independent dose assessment carried out on our behalf by Enviro Consulting Ltd (Environment Agency, 2010e) taking into account our Considerations document³ (Environment Agency, 2009). The Considerations document recommends that following criteria for identifying radionuclides or groups of radionuclides for which to set plant limits:

- critical group dose from the established worst case plant discharges (EWCPD) is greater than 1 µSv per year;
- collective dose from the EWCPD is greater than 0.1 manSv;
- the EWCPD exceeds 1 TBq per year;
- the EWCPD exceeds 50% of the current limit (not applicable to a new plant on a new site); and
- 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.

³ 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, 2010f.

180 The total terrestrial critical group dose is calculated to be $4.4 \mu\text{Sv y}^{-1}$ to an infant. We note from our independent dose assessment that carbon-14 contributes greater than $1 \mu\text{Sv y}^{-1}$ to the terrestrial critical group dose and that a dose of $4 \mu\text{Sv y}^{-1}$ 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 $2.5 \mu\text{Sv y}^{-1}$ to doses to an infant. Our dose assessment report EAGDAR AP1000-11 and the independent dose assessment carried out by Enviro provide more detail (Environment Agency, 2010d and 2010e).

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

182 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.

183 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.

184 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.

185 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.

186 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:

$$\text{WCPD} = (1.5 \times D \times T \times A \times B) + C + L + N - I$$

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.
- 187 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.
- 188 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.
- 189 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.

190 We consider therefore that:

$$WCPD (TBq) = (1.5 \times D \times 1 \times 1.1 \times 1) + 0 + 0 + 10\% - 0$$

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.

Table 6: 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.

191 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.

192 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.

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

Table 7: 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

194 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.

195 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.

14 Compliance with Environment Agency requirements

P&I Table 1 section or REP	Compliance comments
General information relating to the facility	Westinghouse provided general information relating to the facility.
1.5 An analysis should be provided that includes an evaluation of options considered and shows that the Best Available Techniques will be used to minimise the production and discharge or disposal of waste.	Westinghouse provided a BAT Assessment Report which considered BAT in relation to minimising the discharge of radioactive material and waste.
2.1 A description of how radioactive wastes will arise, be managed and disposed of throughout the facility's lifecycle.	Westinghouse provided a description of how radioactive wastes will be managed and disposed of.
2.2 Design basis estimates for monthly discharges of gaseous and aqueous radioactive waste	Westinghouse provided design basis estimates for monthly discharges of gaseous radioactive waste.
2.3 Proposed annual limits with derivation for radioactive gaseous and aqueous discharges	Westinghouse derived and proposed annual limits for discharges of gaseous radioactive waste.
Principle RSMDP3 – Use of BAT to minimise waste: The best available techniques should be used to ensure that production of radioactive waste is prevented and minimised where that is not practicable with regard to activity and quantity.	Westinghouse provided a BAT Assessment Report which considered BAT in relation to preventing and minimising the discharge of radioactive material and waste.
Principle RSMDP4 – Processes for Identifying BAT: The best available techniques should be identified by a process that is timely, transparent, inclusive, based on good quality data, and properly documented.	Westinghouse provided a BAT Assessment Report which considered BAT in relation to minimising the discharge of radioactive material and waste using a systematic process which identified, scored and ranked options.
Principle RSMDP7 – BAT to Minimise Environmental Risk and Impact: When making decisions about the management of radioactive substances, the best available techniques should be used to ensure that the resulting environmental risk and impact are minimised.	Westinghouse provided a BAT Assessment Report which considered BAT in relation to minimising the discharge of radioactive material and waste which included information on the impact.
RSMDP8 – Segregation of Wastes: The best available techniques should be used to prevent the mixing of radioactive substances with other materials, including other radioactive substances, where such mixing which might compromise subsequent effective management or increase environmental impacts or risks	

P&I Table 1 section or REP	Compliance comments
RSMDP9 – Characterisation: Radioactive substances should be characterised using the best available techniques so as to facilitate their subsequent management, including waste disposal.	Westinghouse provided design basis estimates for monthly discharges of gaseous radioactive waste by radionuclide for each plant system which will generate gaseous radioactive waste
RSMDP12 – Limits and Levels on Discharges: 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	Westinghouse provided design basis estimates for monthly discharges of gaseous radioactive waste and proposed discharge limits.
ENDP15 – Mechanical Containment Systems for liquid and Gases: Best Available techniques should be used to prevent and/or minimise releases of radioactive substances to the environment, either under routine or accident conditions.	

15 Public Comments

196 No public comments were received during the assessment which related to discharges of gaseous radioactive waste.

16 Conclusion

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

- a) During routine operations and maintenance;
- b) From anticipated operational events.

198 We conclude that the gaseous radioactive discharges from the AP1000 should not exceed those of comparable power stations across the world. We note that at this stage the proposed discharges of carbon-14 in gaseous waste are slightly higher than the range for other European PWRs.

199 Our conclusion is subject to one potential GDA Issue and two other issues:

GDA Issue

- a) The radiologically controlled area ventilation system (VAS) and any other ventilation systems where there is the potential for the release of airborne radioactive waste to the atmosphere which do not have passive HEPA filtration as part of the design.

Other issues

- b) Detailed arrangements for the hand over between Westinghouse and future operators shall be provided at site specific permitting, in particular with respect to matters that relate to the use of BAT to minimise radioactive discharges.
- c) A detailed and robust justification of options for carbon-14 abatement in radioactive waste discharges shall be provided at site specific permitting.

200 We conclude that any operational AP1000 should comply with the limits and levels set out below for the disposal of gaseous radioactive waste to air.

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

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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
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: Expected Annual Release to Atmosphere presented in the AP1000 European Design Control Document and in the Environment Report

Expected Annual Release of Airborne Iodine radionuclides to the Atmosphere (ER Table 3.3-5)

Nuclide	Activity Release ⁽¹⁾ , GBq y ⁻¹					Total Release
	Waste Gas System	Building / Area Ventilation			Condenser Air Removal System	
		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 3.3-6)

Nuclide	Activity Release ⁽¹⁾ , GBq y ⁻¹					Total Release
	Waste Gas System	Building / Area Ventilation			Condenser Air Removal System	
		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 + 4Bq) 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.

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