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AP1000 Generic Design Measurement and Assessment of Discharges

This reference provided in Section 2.6 contains Technical Report SERCO/TAS/002730/003 Issue 02 (UKP-GW-GL-029, Revision 0), "AP1000 Generic Design Measurement and Assessment of Discharges," prepared by SERCO for the Westinghouse "UK AP1000 Environment Report," UKP-GW-GL-790, Revision 1.

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AP1000 Generic Design Measurement and Assessment of Discharges

Westinghouse Electric Company

Your Reference: Customer Ref

Our Reference: SERCO/TAS/002730/003 Issue 02 (UKP-GW-GL-029, Revision 0)

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Executive Summary

The design process used throughout the development of the AP1000 is to create a safe nuclear power plant with radiation exposures and radioactive discharges as low as reasonably practicable.

In this report the scope and details of the discharge monitoring arrangements included in the AP1000 design are compared against the following UK regulatory guidance:

- European Union Commission Recommendation 2004/2/Euratom
- Environment Agency Technical Guidance Notes M11 and M12

For each discharge stream the AP1000 monitoring systems are detailed and key radionuclides for monitoring purposes are defined. It was found that for both aerial and liquid effluent streams AP1000 monitoring systems are in good agreement with UK regulatory guidance.

Where gaps have been identified suggestions are made on how these can be mitigated, if appropriate. Generally these gaps, for example operator procedures, apply to the site specific stage of the design/licensing process.

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Contents

List of Tables

List of Figures

1 Introduction

1.1 Scope of Assessment

In this report the scope and details of the discharge monitoring arrangements included in the AP1000 design are compared against regulatory guidance in the UK.

Westinghouse Electric Company LLC (WEC) submitted their AP1000 nuclear power plant design for generic design assessment (GDA) in the UK in August 2007 [1]. The Environment Agency (EA) have carried out a preliminary assessment of WEC's submission and produced a statement of findings [2].

One of the conclusions by the EA was that the submission did not contain the level of information needed regarding proposed discharge monitoring arrangements:

> "General arrangements for monitoring have been described but lack consideration of the issues raised by the Process and Information Document [3]
>
> - Adequacy against European Union Commission Recommendation 2004/2/Euratom [4]
> - How a decision on adequacy of arrangements has been reached
> - Justification that the monitoring represents the Best Available Technique (BAT)
> - Compare the proposals to guidance on monitoring: M11 [5] and M12 [6]."

1.2 AP1000 Documentation

In order to assess the discharge monitoring systems of the AP1000 design in light of the EA's comments information from relevant chapters in the Safety, Security and Environment Section of the AP1000 European Design Control Document (DCD) [7] was compiled as well as from supporting data sources such as US Standards and Regulatory Guidelines.

The following sections of the DCD were reviewed: Sections 9.3 (Process Auxiliaries), 11.2 (Liquid Waste Management Systems), 11.3 (Gaseous Waste Management Systems) and 11.5 (Radiation Monitoring).

Information provided in the DCD does not always go into full detail on procedures followed when determining the design of the monitoring systems. The aerial and liquid discharge monitoring systems of the AP1000 have been designed to conform to the following American standards and NRC (US Nuclear Regulatory Commission) Regulatory Guidance documents:

- American National Standard ANSI N13.1. Guide to sampling airborne radioactive materials in nuclear facilities [8].
- American National Standard ANSI N42.18. Specification and performance of on-site instrumentation for continuously monitoring radioactivity in effluents [9].
- NRC Regulatory Guide 1.21. Measuring evaluating and reporting radioactivity in solid wastes and releases of radioactive materials in liquid and gaseous effluents from light-water cooled nuclear power plants [10].
- NRC Regulatory Guide 1.97. Instrumentation for light-water-cooled nuclear power plants to assess plant and environs conditions during and following an accident [11].

1.3 UK Guidance Documents

During normal operation the AP1000 plant will produce liquid and aqueous waste contaminated with low levels of radionuclides. This waste is regulated by the Radioactive Substance Act 1993 (RSA93). It is not practicable to monitor all radionuclides which could occur in the waste discharges. Instead the standard procedure is to define a number of key radionuclides for which monitoring is carried out. Key radionuclides can be defined as those that are present in waste in largest numerical quantities, which have the potential for affecting public radiation doses or which act as indicators of a change of conditions on the plant. Once the AP1000 design has been licensed for operation in the UK further key radionuclides may need to be considered, depending on which radionuclides or radionuclide categories will be limited by the RSA93 discharge authorisation.

The aim of the Euratom Recommendation 2004/2 is to ensure that standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation is provided by member states. “Normal operation” is defined as normal activities relating to the operation of a nuclear power station or reprocessing plant, including the decommissioning phase, but not the dismantling phase. Article 35 of the Euratom Treaty requires member states to establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in discharges and to report information on radioactive discharges to the Commission. The aim is for standardised information to be provided across member states to allow for direct comparison of discharge information of individual radionuclides and the implementation of minimum measuring standards.

Euratom Recommendations are without legal force but are negotiated and voted on according to the appropriate procedure. The Recommendation is an instrument of indirect action, often anticipating its implementation in legislation.

M11 and M12 are Technical Guidance notes issued by the Environment Agency (EA). They are designed to provide assistance to Agency staff (e.g. site inspectors) and contractors, industry and other interested parties on the monitoring of releases from nuclear facilities. Key points to be considered in the planning and operation of an effective monitoring programme that supports compliance for aerial releases with UK authorisations under RSA93 are raised. In detail, M11 and M12 describe the objectives of monitoring programmes, the planning, principles and design of monitoring programmes, approaches and techniques for sampling and measurement, and quality assurance. The Technical Guidance Notes are not binding under UK law but rather highlight the key criteria that nuclear site inspectors would take into account when assessing for compliance with an authorisation.

It should be noted that much of the requirements described in the three UK guidance documents considered here are geared towards the operation of existing facilities rather than those at the design stage. The principal requirements of the recommendation and guidance notes are designed to demonstrate compliance with site discharge authorisation limits by United Kingdom site inspectors and with Article 35 verification visits by the EU Commission for the Euratom Treaty. As a result, not all of the recommendations given are applicable to this stage of the generic design assessment of the AP1000 design. Nevertheless, the Technical Guidance Notes include discussion of some important design parameters that may help to eliminate or at least minimise sources of error in discharge data reporting.

2 AP1000 Aerial Effluents

2.1 Summary of Aerial Effluent Processes

Gaseous radioactive effluents arise from a number of processes and in a number of different areas of the AP1000 plant. Discharges to atmosphere from the plant are through two main vents:

- Main plant vent
- Turbine building vent

Figure 1 provides a schematic overview of the aerial release points.

The main plant vent provides the release path for containment venting releases, auxiliary building ventilation releases, annex building releases, radwaste building releases and gaseous radwaste. The AP1000 gaseous radwaste system receives, processes and discharges radioactive waste gases received during normal modes of plant operation including power generation, shutdown and refuelling. About 90% of total annual aerial discharges (in Bq/y) are through the main plant vent.

The turbine building vent provides the release path for the condenser air removal system, gland seal condenser exhaust and the turbine building ventilation releases. Under ideal normal operation conditions no radioactive waste is discharged through the turbine building vent. However it is possible that a number of small leaks from the primary coolant to the secondary coolant cycle occur during the plant's operations, resulting in the possibility of a small aerial release from the turbine building vent.

2.2 Aerial Effluent Proposed Monitoring System

Table 1 lists the monitors that are associated with each of the vents, together with information on the type of monitor, radionuclides monitored and detection ranges. The monitoring point (MP) numbers relate to Figure 1. Details of the detectors at each monitoring point are given in Chapter 11.5 of the DCD, including the type of monitor and the radionuclides it can detect. The characteristics of the monitors are briefly summarised below:

The main plant vent radiation monitor (MP 8) is an off-line monitor for particulates, iodine and noble gases. All main plant aerial discharge streams have converged at this point and the main plant vent monitor provides the data needed for discharge reporting. Sampling is continuous under routine operating conditions by normal range noble gas, particulate and iodine detectors. The particulate monitor uses a beta-sensitive scintillation detector that views a fixed filter. The iodine detector is a gamma-sensitive, thallium-activated, sodium iodide, scintillation detector that views a fixed charcoal filter. Krypton-85 and xenon-133 are monitored by an in-line beta-sensitive scintillation detector. In addition to the normal range krypton-85 and xenon-133 monitor, MP 8 also contains 2 accident range noble gas detectors, one for mid-range and one for high-range activity concentrations. These are beta/gamma-sensitive detectors with smaller sensitive volumes. Accident range particulate and iodine activity concentrations are monitored at MP 8 using particulate and iodine filters which would be taken to the on-site laboratory for analysis. In the event that elevated activity concentrations are detected by the normal range detectors, the monitored air flow would be redirected from the normal range detectors to the accident range detectors. In this way, the normal range detectors would not be damaged and/or contaminated by higher activity concentrations and remain available to resume monitoring once activity concentrations fall subsequently. The main plant vent monitor uses an isokinetic sampling nozzle assembly that has flow and temperature sensors. Plant vent flow measurements are also provided to allow for calculation of total flow. The monitor at MP 8 also includes the capability to collect grab samples for further analysis in the on-site laboratory.

The turbine building vent discharge monitor (MP 10) is an in-line monitor for krypton-85 and xenon-133, using two beta/gamma-sensitive Geiger-Mueller tubes with overlapping detector ranges. The main purpose of this monitor is to provide data for discharge reporting in the event of a primary-to-secondary coolant leak. In addition, MP 9 provides nitrogen-16 detectors that are sensitive for detecting primary-to-secondary coolant leakage and are located near the steam generator main steam outlet and upstream of the turbine. The facility to collect manual grab samples is provided at two points before the turbine vent effluents converge and are released to atmosphere: at the condenser air removal system and at the gland seal system. The grab samples can be analysed in the on-site laboratory.

There are additional monitoring points (MPs 1-7) upstream of the main plant vent that provide information that allow operators to locate the origin of any abnormal releases prior to dilution downstream in the main plant vent. In addition, these internal vent monitors function as back-up monitors for the main plant vent. They are discussed in the following paragraphs.

The radwaste building exhaust monitor (MP 1) and the health physics and hot machine shop exhaust monitor (MP 3) are off-line particulate monitor for measuring caesium-137 and strontium-90. Beta-sensitive scintillation detectors viewing fixed particulate filters are used in each. The monitors are located downstream of the exhaust fans. The primary purpose of these monitors is to alert the control room should activity concentrations exceed a predetermined set-point.

The annex building (MP 2), containment air filtration and exhaust (MP 4), auxiliary building (MP 5) and fuel handling area (MP 6) exhaust radiation monitors are in-line monitors for krypton-85 and xenon-133, using beta-sensitive scintillation detectors. The monitors are located upstream of isolation valves which, when triggered, can reroute the waste streams through filtration exhaust units. The primary purpose of these monitors is to alert the control room should activity concentrations exceed a predetermined set-point.

The gaseous radwaste exhaust radiation monitor (MP 7) is an in-line monitoring detector for krypton-85 and xenon-133, using a beta-sensitive scintillation detector. The monitor is situated before the discharge reaches the plant vent or is diluted by any other flows. The detection range is higher than that of MP 2, 5 and 6. The primary purpose of this monitor is to alert the control room should activity concentrations exceed a predetermined set-point.

2.3 Key Radionuclides for Aerial Discharges

The expected annual average aerial discharges from the main plant and turbine building vents are listed in Table 2. These data are based on proprietary calculations determined from the PWR-GALE code [12]. The release data are conservative estimates of releases for design purposes. Actual releases are expected to be much lower.

For gaseous discharges the key radionuclides are defined here as radionuclides that:

1. are more than 20% of the total radioactivity measured in discharges, or
2. result in a significant contribution to individual doses, or
3. are indicators of a change in operating conditions, or
4. will be limited by discharge authorisation.

For (1) the data on discharges from the AP1000 plant indicate that krypton-85, which represents 31% of the total aerial discharge in terms of Bq/y, is most significant. Tritium represents 18% of the total aerial release, followed by xenon-131m (14%), argon-41 (13%) and xenon-133 (12%). All other radionuclides contribute less than 5% individually.

For (2) the results of individual dose calculations presented in Reference [13] were consulted. The predicted annual dose from routine atmospheric releases is very low at 0.63 µSv/y. It is dominated by carbon-14 (75%), followed by iodine-131 (18%). All other radionuclides contribute less than 5% each.

For (3) the noble gases krypton-85 and xenon-133 can give early warning indications on changing operation conditions such as a coolant water leak. Iodines and particulates can also be important indicators on the operational status of the plant's gaseous waste handling system. For particulates cobalt-58 has the highest release (50% of all particulates), followed by cobalt-60 (19%), caesium-137 (7%) and strontium-89 (6%).

For (4) data on proposed radionuclide categories for authorisation has been taken from Reference [14]. Consequently, the following radionuclides and categories should be considered once the proposed categories have been agreed with the EA: tritium, carbon-14, radioiodine, noble gases and 'other particulates'.

As a result the following can be considered to be key radionuclides for the monitoring of aerial discharges from the AP1000 design:

- tritium
- carbon-14
- krypton-85
- iodine-131
- "other" particulate, e.g. cobalt-60 or caesium-137

The monitoring of krypton-85, iodine-131 and caesium-137 is already part of the proposed continuous monitoring systems for aerial releases from the AP1000 design.

The monitoring of tritium and carbon-14 is currently not included in the design of the continuous monitoring systems. Typically tritium and carbon-14 activity concentrations in the plant vent will be below minimum detectable levels of detectors. In order to determine their activity levels in aerial discharges from nuclear power plants, off-line bubbler systems can be used to concentrate levels over several days or weeks to obtain measurable activity concentrations. If the requirement to monitor and report levels of tritium and carbon-14 in aerial discharges from the AP1000 design is endorsed by the UK regulators then the capability to provide continuous measurement data for these radionuclides can be added.

2.4 Comparison of Aerial Discharge Monitoring Arrangements with Euratom Recommendations 2004/2

A comparison was carried out between the monitoring arrangements of the AP1000 design and the Euratom Recommendations on standardised information on radioactive airborne discharges into the environment from nuclear power reactors and reprocessing plants in normal operation [4]. Annex I of Euratom/2204/2 lists radionuclides commonly discharged by nuclear power stations and groups them into categories (e.g. noble gases, particulates, etc). For each category a number of key radionuclides are defined. Discharge reporting should be carried out for these key radionuclides. Minimum detection limits which need to be achieved by the measuring technique are also listed for each of the key radionuclides.

A direct comparison of the minimum detection limits specified in Euratom/2004/2 and in Table 11.5-1 of the AP1000 DCD can be seen in Table 3. The table shows the Euratom requirement for the minimum detection limit and the AP1000 minimum detection limits at the monitoring points for the two gaseous discharge points.

The monitoring of some of the key radionuclides identified in Euratom/2004/2 is currently not explicitly included in the AP1000 design, notably tritium, carbon-14 and cobalt-60. The facility to collect manual grab samples at each of the discharge streams has been included in the design and this could be used to collect samples for cobalt-60 analysis, if the requirement to report cobalt-60 levels in aerial discharges is endorsed by the UK regulators. If the requirement for the monitoring of tritium and carbon-14 is endorsed then the capability to provide off-line continuous monitoring of these radionuclides can be added to the design.

The monitor currently included in the turbine building vent design is an accident range continuous in-line monitor for noble gases. Under normal operating conditions no radioactivity would be released from the turbine building vent. In determining the annual average discharge data (see Table 2) it has been assumed that a number of small leaks between the primary and secondary coolant cycles occur every year, resulting in the possibility of a small aerial release from the turbine building vent. Due to the nature of those releases it would not be appropriate to provide continuous monitoring data for tritium, carbon-14 and iodines from that vent. Instead, the facility to collect and analyse grab samples when elevated noble gas activity concentrations are detected, is provided.

Regarding detection limits: the AP1000 aerial monitoring system conforms to recommended minimum detection limits for krypton-85, xenon-133 and iodine-131 monitoring at the main vent. The detection limits for strontium-90 and caesium-137 are comparable to the Euratom recommended minimum detection limit.

2.5 Comparison of Aerial Discharge Monitoring Arrangements with M11

A comparison between guidance provided in the Environment Agency's Technical Guidance Note M11 and the proposed monitoring arrangements for the AP1000 design was carried out. The guidance note contains information aimed at guiding nuclear site inspectors of existing operating nuclear facilities in the UK. In order to allow for comparison between M11 and the monitoring arrangements for the AP1000 the relevant recommendations for monitoring objectives and principles made in the Technical Guidance Note have been evaluated. Table 4 lists the M11 objectives and provides appropriate information on the AP1000 design for each. Similarly, Table 5 lists the relevant monitoring principles discussed in M11.

The AP1000 monitoring systems conform broadly with the objectives of a suitable aerial monitoring system given in M11. Some of the differences are expected to be addressed at future stages of the design and licensing process. Others, for example the design of sampling and analytical programmes, will be part of operator procedures, rather than design features.

The AP1000 systems also broadly follow the monitoring principles presented in M11. Not only does the M11 technical note provide guidance on sampling systems but also on the sampling collection and logging procedures as well as the radiochemical analysis. Many of these criteria do not form part of the plant design process but would be expected to be implemented by a future operator. Westinghouse Electric Company has issued a report which offers guidelines to the future plant operator, incorporating industry and regulatory standards, for the development of standardised procedures [15].

3 AP1000 Liquid Effluents

3.1 Summary of Liquid Effluent Processes

There are three discharge streams for liquid radioactive effluents at the AP1000 plant, all of which are released into the environment through the same pipeline.

- Liquid radwaste system
- Waste water system
- Service water system

Figure 2 provides a schematic overview of the liquid effluent processes.

The liquid radwaste system receives and stores radioactive liquid waste in the radwaste building. These include waste from the reactor coolant drain tank, the containment sump, the effluent holdup tanks and the waste holdup tanks. The liquid radwaste components store and process the waste under normal operation conditions. Liquid releases are made in batches that are mixed thoroughly before discharge.

Two other liquid effluent streams could contain low levels of radionuclides: the waste water and service water system wastes. They represent a minor discharge route for radionuclides under normal operating conditions.

The waste water system collects and processes liquid wastes from equipment drains, sumps and floor drains from the Turbine, Auxiliary, Diesel Generator and Annex buildings. The effluent is collected in the turbine building sumps. If levels of radioactivity are detected then the waste water can be routed to the liquid radwaste system for processing. Otherwise, it is discharged to either the cooling tower basin or to the waste water basin which is located outside of the turbine building. If discharged to the waste water retention basin, the water is held in the waste water basins where entrained solids can settle and grab samples of the water can be taken for analysis before final release to the environment or plant outfall.

The service water system provides cooling water to plant components. Service water blowdown flow can be diverted to a waste water basin outside of the turbine building then to the environment. When the service water flow is diverted to the waste water basin, the discharge to the basin is continuously monitored for radioactivity. If levels of radioactivity are detected then, the flow control valve can be remotely closed by the plant operators. The water is held in the waste water basins where entrained solids can settle and grab samples of the water can be taken for analysis before final release to the environment or plant outfall.

3.2 Liquid Effluent Proposed Monitoring System

Table 6 lists the monitors that are associated with each of the liquid discharge streams. The monitoring point (MP) numbers relate to Figure 2. Details of the detectors at each monitoring point are given in Chapter 11.5 of the DCD, including the type of monitor and the radionuclides it can detect. The characteristics of the monitors are summarised below and in Table 6.

The main liquid waste monitor (MP 1) is a continuous on-line monitor for caesium-137 in the final discharge pipe. The detector is a gamma-sensitive thallium-activated, sodium iodide scintillation detector. In addition samples from the discharge tanks are collected and analysed at the on-site laboratory before each batch is discharged into the environment to ensure that the release is within acceptable limits. Before sampling the liquid effluent in the tanks is mixed thoroughly. The data from the on-line monitor as well as from the tank samples can be used for discharge reporting.

The waste water discharge radiation monitor (MP 4) is a continuous off-line monitor for caesium-137 situated on the discharge line from the Turbine building sump. The data from this monitor can be used for discharge reporting. The detector is a gamma-sensitive thallium-activated, sodium iodide scintillation detector that views the liquid sampling volume. Grab sample capability is also provided for further analysis in the on-site laboratory.

The service water blowdown radiation monitor (MP 5) is a continuous off-line monitor for caesium-137. It measures the concentration of radionuclides in the service waste water system before it joins the waste water system and main liquid radwaste system flows. Discharges are batch releases and the sampling is continuous under normal operating conditions during the discharge. The detector is a gamma-sensitive, thallium-activated, sodium iodide scintillation detector that views the liquid sample volume. The main purpose of this monitor is to raise an alarm if activity concentrations exceed a predetermined set-point. Grab sampling is available upstream of the radiation monitor. Grab samples can be analysed in the on-site laboratory.

A further monitoring point for the final monitoring of the liquid wastes from minor discharge routes will be part of the Waste Water Basin design. Its specification and supply will be the responsibility of the future operator at a site-specific phase of the design planning.

3.3 Key Radionuclides for Liquid Discharges

The total expected annual average liquid discharges are listed in Table 7. These data are based on proprietary calculations determined from the PWR-GALE code [12]. The release data are conservative estimates of releases for design purposes. Actual releases are expected to be much lower.

For liquid discharges the key radionuclides are defined here as radionuclides that:

1. are more than 20% of the total radioactivity measured in liquid discharges, or
2. result in a significant contribution to individual doses, or
3. are indicators of a change in operating conditions, or
4. will be limited by discharge authorisation.

For (1) the data on discharges from the AP1000 plant indicate that tritium discharges dominate the liquid discharges in terms of Bq/y (>99%).

For (2) the results of individual dose calculations presented in Reference [13] were consulted. The annual dose from routine liquid releases is very low at 4.8 µSv/y. It is dominated by cobalt-60 (83%). All other radionuclides contribute less than 5% each.

For (3) the presence of elevated levels of any fission product can give early warning indications on changing operation conditions. Caesium-137 can give an indication of problems with the fuel, e.g. fuel leaks or fuel cladding breaches.

For (4) data on proposed radionuclide categories for authorisation has been taken from Reference [14]. The following radionuclides and categories need to be considered: tritium and ‘other radionuclides’.

As a result the following can be considered to be key radionuclides for the monitoring of liquid discharges from the AP1000 design:

- tritium
- a fission product, e.g. caesium-137

The monitoring of caesium-137 is already explicitly included in the design of the liquid discharge monitoring systems. Tritium activity concentrations in the liquid effluent are likely to be below minimum detectable levels of on-line continuous detectors. The assessment of tritium can be carried out through analysis of grab samples.

3.4 Comparison of Liquid Discharge Monitoring Arrangements with Euratom Recommendations 2004/2

A comparison was carried out between the monitoring arrangements of the AP1000 design and the Euratom Recommendations on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation [4]. Annex I of Euratom/2204/2 lists radionuclides commonly discharged by nuclear power stations and groups them into categories. For liquid discharges from nuclear power stations there are just two categories: tritium and 'other radionuclides'. For each category a number of key radionuclides are defined. Discharge reporting should be carried out for these key radionuclides. Minimum detection limits which need to be achieved by the measuring technique are also listed for each of the key radionuclides.

A direct comparison of the minimum detection limits specified in Euratom/2004/2 and in Table 11.5-1 of the Westinghouse DCD can be seen in Table 8. The table shows the Euratom requirement for the minimum detection limit and the AP1000 minimum detection limits at the monitoring points for the liquid discharge route.

The monitoring of some of the key radionuclides identified in Euratom/2004/2 is currently not explicitly included in the AP1000 design, notably tritium, cobalt-60 and strontium-90. However the facility to collect manual grab samples at each of the discharge streams has been included in the design. As a result the activity levels of these radionuclides in the liquid effluent stream can be determined by grab sample analysis, if the requirement to report cobalt-60, strontium-90 and tritium discharges is endorsed by the UK regulators.

The minimum detection limit for Cs-137 conforms to the minimum detection limit stated in Euratom/2004/2.

3.5 Comparison of Liquid Discharge Monitoring Arrangements with M12

A comparison between guidance provided in the Environment Agency's Technical Guidance Note M12 and the proposed monitoring arrangements for the AP1000 design was carried out. The guidance note contains information aimed at guiding nuclear site inspectors of existing operating nuclear facilities in the UK. In order to allow for comparison between M12 and the monitoring arrangements for the AP1000 the relevant recommendations for monitoring objectives and principles made in the Technical Guidance Note have been evaluated. Table 9 lists the M12 objectives and provides appropriate information on the AP1000 design for each. Similarly, Table 10 lists the relevant monitoring principles discussed in M12.

The AP1000 monitoring systems broadly conform with the objectives of a liquid monitoring system given in M12. Some of the differences are expected to be addressed at future stages of the design and licensing process. Others, for example the design of sampling and analytical programmes, will be part of operator procedures, rather than design features.

The AP1000 systems also broadly follow the monitoring principles presented in M12. Not only does the M12 technical note provide guidance on sampling systems but also on the sampling collection, sample logging procedures and the radiochemical analysis. Many of these criteria do not form part of the plant design process but would normally be expected to be implemented by a future operator. Westinghouse Electric Company has issued a report which offers guidelines to the future plant operator, incorporating industry and regulatory standards, for the development of standardised procedures [15].

4 Best Available Technique Consideration

A justification is required that the monitoring techniques incorporated into the reactor design represent the best available techniques (BAT).

Guidance on the processes for identifying BAT in the context of radioactive discharge monitoring is provided in the EA's Radioactive Environmental Principles consultation document [16]. Here BAT is defined as; "The most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole". This definition includes the concept defined as Best Practicable Means (BPM), which is fundamental to the EA Technical Guidance Notes M11 [5] and M12 [6]. However, it is noted that the EA Technical Guidance Notes, within the regulatory context description, require the operator to address BAT, but make no specific mention of BAT in the monitoring descriptions thereafter. The guidance for identifying BAT (as described in Reference [16]), relevant to the AP1000 design assessment can be summarised as:

1. The process is properly documented and capable of review
2. The decision on which measuring technique has been selected is made clear
3. The scope of the BAT study is clear and all boundaries and constraints relevant to the decision made are set out
4. All assumptions are set out plainly, together with the data and basis on which they have been made
5. Sufficient information is provided to confirm the validity of data used
6. The conclusion arrived at has integrity

A formal BAT assessment following the detail described above was not performed when monitoring options for the AP1000 were considered.

However, the investigation carried out and reported here shows that a process of due diligence was followed by the design engineers. The following have underpinned the monitoring system design process:

- The design and selection of equipment for the monitoring of liquid and aerial waste streams conforms to US Standards and Regulatory Guidance. These are essentially similar to guidance in the UK. The US Nuclear Regulatory Commission has reviewed the AP1000 design and confirmed that it conforms to its Regulatory Guidance [17].
- The selection of equipment has been based on tried and tested monitoring techniques in use elsewhere in American nuclear power stations.
- The selected monitoring techniques and their corresponding measuring ranges are all consistent with commercially available radiation detectors that are used in nuclear power plants across the world.
- Flexibility has been built into the design, i.e. the capability to extract grab samples for additional analysis is included at each sampling point.

Finally, it is important to note, that many of the considerations discussed here are not yet finalised. In particular, the operating procedures and some of the equipment including specialised laboratory equipment will be determined at later stages in the design and commissioning process. In other words, there is scope for some of the measuring procedures to be rationalized to conform closer to UK requirements, if appropriate.

In order to evaluate how the AP1000 monitoring techniques compare with current UK practice, information on discharge monitoring techniques in use at operating UK nuclear reactors was compiled [18]. The results of this comparison can be seen in Table 12 for aerial discharges and Table 13 for liquid discharges.

For both aerial and liquid discharges, the monitoring techniques are broadly equivalent. This indicates that the monitoring techniques outlined in the DCD are in line with current best practice in the UK.

5 Conclusions

The monitoring system included in the AP1000 design (based on the DCD and supporting evidence) has been investigated and compared to relevant UK regulatory guidance, namely

- European Union Commission Recommendation 2004/2/Euratom
- Environment Agency Technical Guidance Notes M11 and M12

It was found that for both aerial and liquid effluent streams AP1000 monitoring systems are in good agreement with UK regulatory guidance.

One gap identified relates to the monitoring of tritium and carbon-14 in aerial discharges, which is currently not included in the design of the continuous monitoring systems. Typically tritium and carbon-14 activity concentrations in the plant vent will be below minimum detectable levels of detectors. In order to determine their activity levels in aerial discharges from nuclear power plants off-line bubbler systems can be used to concentrate levels over several days or weeks to obtain measurable activity concentrations. If the requirement to monitor and report levels of tritium and carbon-14 in aerial discharges from the AP1000 design is endorsed by the UK regulators then the capability to provide continuous measurement data for these radionuclides can be added.

Further gaps exist where operator procedures of the AP1000 have not yet been fully defined. Appropriate requirements will be addressed during procedure development. Monitoring systems can be reviewed again against UK guidance during the site specific licensing stage when all relevant procedures and specialised laboratory equipment have been fully specified.

Although a formal Best Available Technique (BAT) assessment was not carried out when the AP1000 monitoring system was originally designed, the monitoring techniques were selected following best practice in the US and according to US National Standards and Regulatory Guidance notes. On closer examination it was found that these standards and guidelines are very similar to UK best practice guidelines. In addition, proposed AP1000 monitoring systems are broadly equivalent to monitoring systems currently used in operating UK nuclear power plants. This provides confidence that the AP1000 monitoring techniques are in line with current best practice in the UK.

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Table 1 (a) AP1000 aerial effluent monitors and detection ranges – main vent

Monit. Point (see Fig. 1)	Description	Detector	Category	Type	Isotopes	Nominal detection range Minimum (Bq/m^3)	Nominal detection range Maximum (Bq/m^3)	Purpose
8	Main plant vent	VFS-JE-RE101	Continuous, off-line	Beta-sensitive scintillation detectors viewing fixed particulate filters	Sr-90, Cs-137	3.7E-02	3.7E+03	Normal operation range
		n/a	Continuous, off-line	Manual removal of filter cartridges for analysis	Sr-90, Cs-137	Laboratory[1]	Laboratory[1]	Accident range
		VFS-JE-RE102	Continuous, off-line	Gamma-sensitive thallium-activated, sodium iodide scintillation counter	I-131	3.7E-01	3.7E+04	Normal operation range
		n/a	Continuous, off-line	Manual removal of filter cartridges for analysis	I-131	Laboratory[1]	Laboratory[1]	Accident range
		n/a	Grab sample	Manual collection of effluent sample for laboratory analysis	noble gases, iodine, particulates, tritium	Laboratory[1]	Laboratory[1]	n/a
		VFS-JE-RE103	Continuous, in-line	Beta-sensitive scintillation detector	Kr-85, Xe-133	3.7E+03	3.7E+08	Normal operation range
		VFS-JE-RE104A	Continuous, in-line	Beta/gamma-sensitive detector	Kr-85, Xe-133	3.7E+06	3.7E+12	Accident (mid) range
		VFS-JE-RE104B	Continuous, in-line	Beta/gamma-sensitive detector	Kr-85, Xe-133	3.7E+09	3.7E+15	Accident (high) range

[1]Samples will be taken to the on-site chemical laboratory for analysis. Laboratory equipment has not been specified at this stage of the design, as it will be determined by the future plant operator.

Table 1 (b) AP1000 aerial effluent monitors and detection ranges – turbine building vent

Monit. point (see Fig. 1)	Description	Detector	Category	Type	Isotopes	Nominal detection range		Purpose
						Minimum (Bq/m^3)	Maximum (Bq/m^3)	
10	Turbine building vent	TDS-JE-RE001	Continuous, in-line	Beta/gamma-sensitive Geiger-Mueller tubes	Kr-85, Xe-133	3.7E+04	3.7E+15	Accident range
	Condenser air removal system	n/a	Grab sample	Manual collection of effluent sample for laboratory analysis	noble gases, iodine, tritium	Laboratory[1]	Laboratory[1]	n/a
	Gland seal system	n/a	Grab sample	Manual collection of effluent sample for laboratory analysis	noble gases, iodine, tritium	Laboratory[1]	Laboratory[1]	n/a

[1]Samples will be taken to the on-site chemical laboratory for analysis. Laboratory equipment has not been specified at this stage of the design, as it will be determined by the future plant operator.

Table 1 (c) AP1000 aerial effluent monitors and detection ranges – internal vent monitors

Monit. point (see Fig. 1)	Description	Detector	Category	Type	Isotopes	Nominal detection range		Purpose
						Minimum (Bq/m^3)	Maximum (Bq/m^3)	
1	Radwaste building exhaust	VRS-JE-RE023	Continuous, off-line	Beta-sensitive scintillation detectors viewing fixed particulate filters	Sr-90, Cs-137	3.7E-02	3.7E+03	Normal operation range
2	Annex building exhaust	VAS-JE-RE003	Continuous, in-line	Beta-sensitive scintillation detector	Kr-85, Xe-133	3.7E+03	3.7E+08	Normal operation range
3	Health physics & hot machine shop exhaust	VHS-JE-RE001	Continuous, off-line	Beta-sensitive scintillation detectors viewing fixed particulate filters	Sr-90, Cs-137	3.7E-02	3.7E+03	Normal operation range
4	Containment air filtration & exhaust	VFS-JE-RE001	Continuous, in-line	Beta-sensitive scintillation detector	Kr-85, Xe-133	3.7E+03	3.7E+08	Normal operation range
5	Auxiliary building exhaust	VAS-JE-RE002	Continuous, in-line	Beta-sensitive scintillation detector	Kr-85, Xe-133	3.7E+03	3.7E+08	Normal operation range
6	Fuel handling area exhaust	VAS-JE-RE001	Continuous, in-line	Beta-sensitive scintillation detector	Kr-85, Xe-133	3.7E+03	3.7E+08	Normal operation range
7	Gaseous radwaste exhaust	WGS-JE-RE017	Continuous, in-line	Beta-sensitive scintillation detector	Kr-85, Xe-133	3.7E+06	3.7E+12	Normal operation range

Table 2 AP1000 annual atmospheric discharge data

Category	Radionuclide[1]	Plant vent (Bq/y)	Turbine vent (Bq/y)	Total release (Bq/y)
Tritium	Tritium	1.8E+12	-	1.8E+12
Carbon-14	Carbon-14	2.7E+11	-	2.7E+11
Noble gases	Argon-41	1.3E+12	-	1.3E+12
	Krypton-85m	1.7E+10	7.8E+09	2.4E+10
	Krypton-85	3.1E+12	2.6E+10	3.1E+12
	Krypton-87	1.7E+10	2.2E+09	1.9E+10
	Krypton-88	1.8E+10	8.5E+09	2.7E+10
	Xenon-131m	1.3E+12	8.1E+10	1.4E+12
	Xenon-133m	8.1E+10	3.5E+10	1.2E+11
	Xenon-133	9.6E+11	2.9E+11	1.2E+12
	Xenon-135m	1.3E+11	5.9E+10	1.9E+11
	Xenon-135	1.7E+11	2.6E+11	4.3E+11
	Xenon-137	3.4E+10	1.6E+10	5.0E+10
	Xenon-138	5.9E+10	2.9E+10	8.8E+10
	Total noble gases	**7.2E+12**	**8.1E+11**	**8.0E+12**
Iodines	Iodine-131	2.1E+08	3.4E+06	2.1E+08
	Iodine-133	3.5E+08	3.7E+06	3.5E+08
	Total iodines	**5.5E+08**	**7.1E+06**	**5.6E+08**
Other particulates	Chromium-51	1.9E+05	-	1.9E+05
	Manganese-54	1.1E+05	-	1.1E+05
	Cobalt-58	8.6E+06	-	8.6E+06
	Cobalt-60	3.2E+06	-	3.2E+06
	Strontium-89	1.1E+06	-	1.1E+06
	Strontium-90	4.1E+05	-	4.1E+05
	Zirconium-95	3.7E+05	-	3.7E+05
	Niobium-95	8.9E+05	-	8.9E+05
	Caesium-134	8.3E+05	-	8.3E+05
	Caesium-137	1.3E+06	-	1.3E+06
	Barium-140	1.5E+05	-	1.5E+05
	Total particulates	**1.7E+07**	**-**	**1.7E+07**

[1]radionuclides with expected discharges of less than 3.7E+04 Bq/y have been omitted

Table 3 Comparison of AP1000 aerial monitoring arrangements with Euratom/2004/2

Euratom 2004/2 key radionuclide	Euratom minimum detection limit for aerial discharges (Bq/m^3)	AP1000 minimum detection limit for main vent monitoring point (Bq/m^3)	AP1000 minimum detection limit for turbine building vent monitoring point (Bq/m^3)
Kr-85	1E+04[1]	3.7E+03	3.7E+04
Xe-133	1E+04	3.7E+03	3.7E+04
S-35	1E+01	No discharge	No discharge
Co-60	1E-02	Laboratory[2]	No discharge
Sr-90	2E-02	3.7E-02	No discharge
Cs-137	3E-02	3.7E-02	No discharge
Pu-239 & Pu-240	5E-03	No discharge	No discharge
Am-241	5E-03	No discharge	No discharge
Total Alpha	1E-02	No discharge	No discharge
I-131	2E-02	3.7E-01	Laboratory[2]
H-3	1E+03	Laboratory[2]	Laboratory[2]
C-14	1E+01	Laboratory[2]	Laboratory[2]

[1]A detection limit of 1E-04 Bq/m^3 is listed in Euratom for this isotope, it has been assumed that the entry should read 1E+04 Bq/m^3.

[2]If required these radionuclides can be monitored via grab sample collection. The samples will be taken to the on-site chemical laboratory for analysis. Laboratory equipment has not been specified at this stage of the design, as it will be determined by the future plant operator.

Table 4 Objectives of aerial monitoring programme

M11 Section 3 - Objectives of aerial monitoring programme	AP1000 monitoring arrangements	Conclusion/Comment
To ensure that potential discharges are known by the site operator to be within authorised limits	The on-line monitors on the main discharge vent have been designed to detect a range of radionuclides at normal operating levels.	Comply. Which radionuclides will be part of a future discharge authorisation will be determined at the site specific stage of the licensing process.
Provide information to demonstrate that the operations giving rise to the effluent and the use of abatement plant (if any) and all associated control; and management systems are performing as planned	On-line monitors on the main discharge vent have been designed to detect a range of radionuclides at normal operating levels, whereas others are set to trigger alarms if activity levels rise above a number of different set points. Monitoring on internal vents (MP 1-7) has also been designed to raise alarms if levels exceed normal operation ranges.	Comply
To detect rapidly, give warning and identify the nature and extent of any unplanned releases to the environment to allow suitable remedial activities to be instigated	A number of the gaseous effluent release vents have in-line monitors that are linked directly to the main control room and raise alarms should pre-determined set-points be exceeded.	Comply
To provide a record of the amount of radioactive material discharged to the environment in order to demonstrate compliance with the authorised limits on releases	Data collected by the monitoring programme have been designed for reporting to the Nuclear Regulatory Commission (NRC) in accordance with Regulatory Guidance 1.21. This guidance note requires the operator to measure, evaluate and report radioactivity on released waste on a quarterly and annual basis in a similar fashion to the requirements of EA and Euratom guidance.	Comply. Which radionuclides will be part of a future discharge authorisation will be determined at the site specific stage of the licensing process.
To identify trends in discharges, especially those which may indicate a chronic plant or process problem	The monitoring programme provides a robust set of discharge levels for each of the key plant operation indicator radionuclides. The integrated instrumentation and control system will allow the identification of trends and problems.	Comply. More specific operator procedures for logging and reporting of data will be defined at future stages of the design evaluation process.

M11 Section 3 - Objectives of aerial monitoring programme	AP1000 monitoring arrangements	Conclusion/Comment
Provide source term data and other information for modelling studies, for example, for radiological impact assessments	The monitoring programme conforms to the ANSI-42.18 standard, which states that need for a monitoring system to assist quantitative evaluation.	Comply. More specific operator procedures for logging and reporting of data will be defined at future stages of the design evaluation process.
Indicate requirements for off-site environmental measurements or a programme of environmental monitoring	A number of key radionuclides are part of the monitoring programme, e.g. I-131. It is unlikely that radionuclides discharged to atmosphere by the AP1000 would be detectable in the local environment above background levels.	Comply. Specific operator procedures for environmental monitoring can be defined at future stages of the design evaluation process.
Provide public reassurance	The final monitoring programme will be designed to comply fully with UK regulation which help ensure public protection and safety for operating nuclear power plants. The results will be available in the public domain.	Comply
Planning should define the nuclides to be included in the programme. This may include not only those nuclides specified in the discharge authorisation but others that may provide additional information on, for example, the efficiency of an abatement plant.	The sampling programme includes a representative range of radionuclides.	Comply. Which radionuclides will be part of a future discharge authorisation will be determined at the site specific stage of the licensing process.
Planning should define the timing and frequency of sampling of the discharge, and the sampling methods to be used. The aims are to ensure that the samples are representative and that sufficient data are available to determine total discharges over the discharge authorisation period and (in some cases) any trends over time.	The sampling arrangements for the AP1000 have been designed for compliance with the ANSI Standards and NRC Regulatory Guides which include comparable guidelines on representative sampling	Comply. A detailed sampling programme should be designed by the future operators of the plant.

M11 Section 3 - Objectives of aerial monitoring programme	AP1000 monitoring arrangements	Conclusion/Comment
The planning should define the laboratory analysis programme. This is required to ensure that the final data can be used to establish reliably the cumulative discharge and that trends with time are not masked by poor analytical data.	The AP1000 includes an on-site laboratory that contains spectroscopic equipment to analyse samples in a timely fashion.	Comply. A detailed analytical programme should be designed by the future operators of the plant.

Table 5 Comparison of AP1000 aerial monitoring arrangements with M11 guidance

M11 section	M11 Guidance	AP1000	Conclusion/Comment
4.1	Off-line (i.e grab) sampling provides a more accurate, albeit retrospective, estimate of discharges. These are normally used for accounting purposes to demonstrate compliance with authorisation limits. On-line (i.e. in-line or off-line continuous) sampling on the other hand are not usually used for accounting purposes. Rather, on-line systems enable rapid corrective action to be taken in the event of any deviation from the norm, by use of alarm levels. They may also be used for comparison with internal standards. Where the collection characteristics of the systems are suitable, the sample collected can be used for accounting purposes.	The monitoring system in the AP1000 provides capabilities for both sampling methods. The main plant vent includes continuous off-line (i.e. sampled air stream diverted to monitor) monitoring, for iodine and beta particulates, which is suitable for use for accountancy purposes. In addition continuous in-line (i.e. detector is situated inside main effluent stream) monitoring of noble gases is also performed. The facility to collect grab samples for further analysis is also provided at both the main plant vent and the turbine building vent.	Comply
4.2.1	Continuous sampling is normally required on major emission routes and it is important that all factors which could affect sampling are taken into account such as temperature, pressure, humidity and chemical form	Provisions have been made for continuous sampling on the main plant vent. The sampling arrangement has been designed to conform to the ANSI N13.1 standard which has the same requirement for taking into account temperature, pressure, humidity and chemical form of the waste stream.	Comply
4.2.1	Sampling must take place downstream of any abatement plants	The sampling points for discharge accountancy purposes (MP 8 and 10) are downstream of any filters or delay beds.	Comply

M11 section	M11 Guidance	AP1000	Conclusion/Comment
4.2.1	The sample must be taken at a position in the emission stack where all constituents are adequately mixed	It is noted in ANSI N13.1 that the sampling position should be selected based on measurement of its velocity distribution to determine that flow is fully developed and mixing is complete.	Comply
4.2.1	The sample must be taken well away from any ductwork features such as dampers, bends and merged streams, which may have a detrimental effect on mixing and flow patterns, or a well-mixed flow must be demonstrated at the plane where the sample is taken. The recommendation is 10-20 duct diameters downstream from any ductwork features.	A minimum sampling distance of 5, preferably 10 or more, duct diameters downstream from any duct feature is specified in ANSI N13.1.	Comply
4.2.1	The sample should ideally be taken via a probe and this must be pointing upstream	ANSI N13.1 states that the probe should expose the collector directly into the stream to be sampled, i.e. pointing upstream.	Comply
4.2.1	The emission velocity and concentration profiles adjacent to the exact plane should be reasonably uniform	Guidance for the determination of the velocity distribution across the duct cross-section, which allows for a rate of sample withdrawal that maintains isokinetic flow, is given in ANSI N13.1. It is recommended that for a uniform velocity a single sampling point can be used, however if a duct has a large cross-section it may necessitate the use of additional probes each with individual sample delivery lines. On-site flow measurements of the plant vent velocity profiles will confirm that the velocity profile is reasonably uniform.	Comply

M11 section	M11 Guidance	AP1000	Conclusion/Comment
4.2.1	To ensure representative sampling of particulate material the probe nozzle should be isokinetic i.e. the velocity at the nozzle inlet must equal that of the duct	The main plant vent monitor (MP 8) has an isokinetic sampling nozzle with flow sensors. Isokinetic sampling is not relevant for in-line measurements of noble gases.	Comply
5.1	For particulate and vapour sample extraction the length of the pipework between the probe and sample collector should be as short as possible and bends should be minimised to avoid plate out. Any bend radius should be greater than 5 times pipe diameter.	The guidance in ANSI N13.1 recommends that sampling lines should be kept to a minimum length. If any bends are needed the bend radius should be as long as possible with flow rates maintained as low as possible.	Comply
5.2	To avoid plate out for volatile species of iodine the sample line should be trace heated	It is noted in ANSI N13.1 that when heavy moisture levels are expected the sample lines should be heated to prevent condensation. The condensate could act as a trap or provide a surface for radioactive material to adhere to, thereby preventing representative sample collection.	Comply
5.3	The design and positioning of the collector must ensure that, as far as practicable, the collection medium can not be bypassed by the radioactive material being sampled	Detailed guidance on the best sampling systems for particulates in the waste stream is given in ANSI N13.1. This includes consideration of particle size, sample distortion due to chemical reactions, flow rate, sensitivity of the collection medium i.e. different filter types.	Comply
5.4	An integrated flow meter that indicates the total volume sampled should be provided. Low flow and high flow sensors should be fitted which bring up an alarm in the control room.	The AP1000 design includes flow meters which raise an alarm in the control room if low or high flows are detected.	Comply

M11 section	M11 Guidance	AP1000	Conclusion/Comment
5.5	One pump and one standby pump should be provided on all systems where high reliability of the sampling system is required, particularly where continuous sampling systems are being used to monitor emissions to show compliance with limits	The AP1000 monitoring systems are selected based on experience of successful plant systems and vendor data. A detailed reliability analysis will also be performed prior to installation. Back-up pumps will be stored in the event of a pump failure, however standby pumps may be provided, depending on the outcome of the reliability analysis.	Comply. Pending site specific design finalisation.
5.5	Materials used for construction of the sampling system should be chosen to minimise deposition of radioactive material	ANSI N13.1 gives guidance on materials that should be avoided such as rubber, copper and some plastics.	Comply
5.6	The monitoring systems should be protected against unauthorised tampering and damage from water, oil, excessive heat, etc.	The AP1000 monitoring system consist of an open-framed design. It complies with requirements to be e.g. water/dust proof, depending on the intended environment. The plant operating parameters are controlled electronically and access is restricted via passwords and keys.	Comply
5.7	Most sampling systems require high reliability thus routine maintenance and backing up of essential components must be in place. Outage time on continuous sampling systems should be less than 9 h per year.	One of the system design requirements is that the time taken for the detection of a failure, repair and verification of the repair shall be a minimum of 4 hours and a maximum of 8 hours.	Comply

M11 section	M11 Guidance	AP1000	Conclusion/Comment
7	Where specific radionuclide measurement is part of a continuous on-line measuring system, account must be taken of the possibility of errors arising from the presence of other radionuclides on the sample medium	Each of the monitoring systems is designed for specific radionuclides, as listed in Table 1. The analysis allows for detection ranges over an energy window designed to encompass these radionuclides. If a more detailed analysis needs to be performed to confirm the relative contribution of any specific radionuclide a grab sample can be taken.	Comply
7	On-line systems should incorporate alarm thresholds which are triggered by levels at just above the normal operating range (to indicate changing operation conditions) and at higher emission levels, e.g. which relate to maximum emission limits. A threshold set at below the expected measuring range should be provided. If the instrument registers below this threshold it should activate and alarm to alert the operators that it may be faulty.	All of the continuous monitoring systems at internal vents and vents to atmosphere have alarms fitted which are triggered when emissions exceed pre-set levels. These also fulfil the role of out of range monitors and can be set to trigger an alarm if activity levels fall to below the expected measuring range.	Comply

Table 6 AP1000 liquid monitors and detection ranges

Monit. point (see Fig. 2)	Description	Detector	Category	Type	Isotopes	Nominal Detection Range		Purpose
						Minimum (Bq/m^3)	Maximum (Bq/m^3)	
1	Radwaste building plant outfall	WLS-JS-RE229	Continuous in-line	Gamma-sensitive thallium-activated, sodium iodide scintillation counter	Cs-137	3.7E+04	3.7E+08	Normal and accident operation range
	Holding tanks	n/a	Grab sample	Manual collection of effluent sample for laboratory analysis	H-3, Cs-137	Laboratory[1]	Laboratory[1]	n/a
4	Turbine building waste water plant outfall	WWS-JE-RE021	Continuous, off-line	Gamma-sensitive thallium-activated, sodium iodide scintillation counter	Cs-137	3.7E+03	3.7E+09	Normal and accident operation range
		n/a	Grab sample	Manual collection of effluent sample for laboratory analysis	H-3, Cs-137	Laboratory[1]	Laboratory[1]	n/a
5	Turbine building service water system	SWS-JE-RE008	Continuous, off-line	Gamma-sensitive thallium-activated, sodium iodide scintillation counter	Cs-137	3.7E+03	3.7E+09	Normal and accident operation range
		n/a	Grab sample	Manual collection of effluent sample for laboratory analysis	H-3, Cs-137	Laboratory[1]	Laboratory[1]	n/a

[1]Samples will be taken to the on-site chemical laboratory for analysis. Laboratory equipment has not been specified at this stage of the design, as it will be determined by the future plant operator.

Table 7 AP1000 annual liquid discharge data

Category	Radionuclides[1]	Total release (Bq/y)
Tritium	Tritium	3.3E+13
Other radionuclides	Carbon-14	7.0E+04
	Sodium-24	3.8E+07
	Chromium-51	4.6E+07
	Manganese-54	3.2E+07
	Iron-55	4.9E+08
	Iron-59	5.0E+06
	Cobalt-58	4.1E+08
	Cobalt-60	2.3E+08
	Nickel-63	5.4E+08
	Zinc-65	1.0E+07
	Rubidium-88	3.9E+05
	Strontium-89	2.4E+06
	Strontium-90	2.5E+05
	Yttrium-91	9.1E+04
	Zirconium-95	6.9E+06
	Niobium-95	6.1E+06
	Molybdenum-99	1.9E+07
	Technetium-99m	1.8E+07
	Ruthenium-103	1.2E+08
	Silver-110m	2.6E+07
	Iodine-131	1.5E+07
	Iodine-132	2.0E+07
	Iodine-133	2.9E+07
	Iodine-134	5.9E+06
	Caesium-134	7.6E+06
	Iodine-135	2.4E+07
	Caesium-136	9.3E+06
	Caesium-137	2.3E+07
	Barium-140	1.4E+07
	Lanthanum-140	1.8E+07
	Cerium-144	8.0E+07
	Praseodymium-144	8.0E+07
	Tungsten-187	3.0E+06
	Plutonium-241	8.0E+04
	Total other radionuclides	**2.3E+09**

[1]radionuclides with expected discharges of less than 3.7E+04 Bq/y have been omitted

Table 8 Comparison of AP1000 liquid monitoring arrangements with Euratom/2004/2

Euratom 2004/2 key radionuclide	Euratom minimum detection limit for liquid discharges (Bq/m^3)	AP1000 minimum detection limit for liquid radwaste discharge monitoring point (Bq/m^3)	AP1000 minimum detection limit for waste water discharge monitoring points (Bq/m^3)
H-3	1E+05	Laboratory[1]	Laboratory[1]
S-35	3E+04	No discharge	No discharge
Co-60	1E+04	Laboratory[1]	Laboratory[1]
Sr-90	1E+03	Laboratory[1]	Laboratory[1]
Cs-137	1E+04	3.7E+03	3.7E+03
Pu-239 & Pu-240	6E+03	No discharge	No discharge
Am-241	5E+01	No discharge	No discharge
Total Alpha	1E+03	No discharge	No discharge

[1]If required these radionuclides can be monitored via grab sample collection. The samples will be taken to the on-site chemical laboratory for analysis. Laboratory equipment has not been specified at this stage of the design, as it will be determined by the future plant operator.

Table 9 Objectives of liquid sampling system

M12 Section 3 - Objectives of liquid monitoring programme	AP1000 monitoring arrangements	Conclusion/Comment
To ensure that potential discharges are known by the site operator to be within authorised limits.	The continuous in-line monitor on the main effluent pipe has been designed to detect Cs-137 activity concentrations. Grab samples are to be collected from the holding tanks prior to discharge. The laboratory specification for the grab sample analysis can encompass any radionuclide.	Comply. The laboratory specification for the grab sample will be specified at a later stage of the design process.
Provide information to demonstrate that the operations giving rise to the effluent and the use of abatement plant (if any) and all associated control; and management systems are performing as planned.	All of the monitors on the main discharge outfalls have been designed to detect Cs-137 at normal operating levels and trigger alarms if activity levels rise above a number of set points.	Comply. Administrative procedures to be set into place at a later stage will be used to control effluent release from the holding tanks based on grab sample analysis.
To detect rapidly, give warning and identify the nature and extent of any unplanned releases to the environment to allow suitable remedial activities to be instigated.	Liquid effluents are discharged in batches from holding tanks. Each batch release is preceded by grab sample analysis. In addition, the liquid effluent pipe contains an in-line monitor that is linked directly to the main control room and this would raise an alarm should pre-determined set-points be exceeded during the discharge.	Comply
To provide a record of the amount of radioactive, material discharged to the environment in order to demonstrate compliance with the authorised limits on releases.	Data collected by the monitoring programme have been designed for reporting to the NRC in accordance with their Regulatory Guidance Notes 1.21. These guidance notes require the operator to measure, evaluate and report radioactivity on released waste on a quarterly and annual basis in a similar fashion to EA and Euratom guidance.	Comply. Which radionuclides will be part of a future discharge authorisation will be determined at the site specific stage of the licensing process.

M12 Section 3 - Objectives of liquid monitoring programme	AP1000 monitoring arrangements	Conclusion/Comment
To identify trends in discharges, especially those which may indicate a chronic plant or process problem.	The monitoring programme provides a robust set of discharge data for Cs-137. The integrated instrumentation and control system will allow the identification of trends and problems.	Comply. More specific operator procedures for logging and reporting of data will be defined at future stages of the design evaluation process.
Provide source term data and other information for modelling studies, for example, for radiological impact assessments	The monitoring programme conforms to the ANSI-42.18 standard, which states the need for a monitoring system to assist quantitative evaluation.	Comply
Indicate requirements for off-site environmental measurements or a programme of environmental monitoring.	One key radionuclide is part of the monitoring programme, Cs-137. It is unlikely that radionuclides discharged to the sea by the AP1000 would be detectable in the local environment above background levels.	Comply. Specific operator procedures for environmental monitoring can be defined at future stages of the design evaluation process.
Provide public reassurance	The final monitoring programme will be designed to comply fully with UK regulation which help ensure public protection and safety for operating nuclear power plants. The results will be available in the public domain.	Comply
Planning should define the nuclides to be included in the programme. This may include not only those nuclides specified in the discharge authorisation but others that may provide additional information on, for example, the efficiency of an abatement plant.	The sampling programme already includes a key indicator radionuclide.	Comply. Which radionuclides will be part of a future discharge authorisation will be determined at the site specific stage of the licensing process.

M12 Section 3 - Objectives of liquid monitoring programme	AP1000 monitoring arrangements	Conclusion/Comment
Planning should define the timing and frequency of sampling of the discharge, and the sampling methods to be used. The aims are to ensure that the samples are representative and that sufficient data are available to determine total discharges over the discharge authorisation period and (in some cases) any trends over time.	The sampling arrangements for the AP1000 have been designed for compliance with the ANSI Standards and NRC Regulatory Guides which include comparable guidelines on representative sampling.	Comply. A detailed sampling programme should be designed by the future operators of the plant.
The planning should define the laboratory analysis programme. This is required to ensure that the final data can be used to establish reliably the cumulative discharge and that trends with time are not masked by poor analytical data.	The AP1000 includes an on-site laboratory that contains spectroscopic equipment to analyse samples prior to discharge.	Comply. A detailed analytical programme should be designed by the future operators of the plant.

Table 10 Comparison of AP1000 liquid monitoring arrangements with M12 guidance

M12 section	M12 Guidance	AP1000	Conclusion/Comment
4.1	In addition to the key radionuclides to be monitored, there may also be a range of non-radioactive substances present which have implications for the monitoring programme. These include suspended solids, organic matter, detergents etc.	Provision has been made should a particular waste stream not be compatible with the liquid waste system. The radwaste building contains truck bays which allow temporary processing equipment to be connected into the waste system. Thus, the AP1000 has the ability to accommodate most wastes whatever their chemical/physical form.	Comply
4.1	The composition of nuclides in a waste stream, in terms of their chemical/physical state needs to be considered in the planning of a monitoring programme.	It is noted in ANSI N42.18 that the physical and chemical state of the waste stream should be understood including temperature, pressure, humidity, size and number of suspended particles and flow rate.	Comply
4.2	For batches discharges the liquid waste should be stored temporarily in one or more hold-up sentencing tanks. Once full, the contents of the tanks should be normally mixed, sampled and analysed prior to being discharged.	As part of the liquid waste system, hold up monitor tanks are used in which the liquid waste is mixed by pumping. These hold up tanks also allow demineralization and a time delay for radioactive decay of some short-lived isotopes. The facility to treat the waste through degasifers or ion exchangers if needed is also included.	Comply
4.2	Additional sampling during the discharge itself should also be considered, with retrospective (and usually more detailed) analysis of these samples.	Prior to discharge a grab sample is taken to allow a detailed analysis to be performed. During release to the environment an in-line monitor in the discharge line will continuously monitor radionuclide levels.	Comply

M12 section	M12 Guidance	AP1000	Conclusion/Comment
4.3	For batch discharges from tanks there is a need to: Avoid inadvertent discharge from the filled tanks prior to sampling and analysis. Avoid discharge of the tank simultaneous to filling of the tank or other operations such as transfers, retreatment or recirculation. These events can be prevented by administrative procedures and/or interlocks.	The liquid waste is pumped from the hold up tanks to separate monitoring tanks prior to discharge. Interlocks are incorporated into the design to prevent inadvertent discharges. Design construction of the hold up tanks aims to minimise any system leakage. Additionally sensors and alarms prevent tank overflow.	Comply. At future design stages further operator procedures for the discharging of liquid waste should be defined.
4.3	Recently, discharge systems have been subject to updating in accord with revised safety cases. For example, diaphragm valves on tank outlets have been replaced by ball valves, which have better leak resistance.	The design for the AP1000 includes the use of ball valves at the tank outlets.	Comply
5.1	On-line instrumental measurement systems operate in real time but are limited in the range of nuclides that can be analysed and accuracy can be low. They may not be sufficient by themselves to indicate compliance with site discharge limits	On the main liquid radwaste discharge line (MP 1) each batch is sampled and the sample analysed in the onsite laboratory prior to discharge. Monitors at monitoring points 5 and 4 are continuous monitors. In addition, grab sample capability is provided in the design for further analysis by the on-site laboratory.	Comply

M12 section	M12 Guidance	AP1000	Conclusion/Comment
5.2.1	Sampling of batch discharges may be carried out by two methods. 1- A pump can be used to mix the contents via a recirculation line. A single grab sample should be taken, usually in the pump recirculation line. 2- A composite sample of the contents of the tank can be taken from the discharge line using a proportional sampler.	In the hold up tanks on the main discharge line a pump is used to mix the contents and sampling is carried out in the pump's recirculation line.	Comply
5.3	There is a need to monitor for instantaneous activity in a waste stream. It is noted that this is most easily achieved with on-line measurement sampling systems	The monitoring systems on all discharge lines use continuous in-line or off-line monitors that trigger alarms in the main control room. As a result, the discharges can be stopped and treated before reaching the environment should preset high activity levels in the waste stream be detected.	Comply
6.2	The time taken to instigate the sampling after a discharge starts represents a period when variations in waste streams quality cannot be detected e.g. immediately after a batch discharge starts, there may be a burst of particulates that have settled in the exit pipe of the tank, which would be missed if only a single grab sample is taken later in the discharge. This problem can be minimised by mixing of the hold up tanks and the use of proportional samplers.	The discharge stream is mixed before sampling.	Comply

M12 section	M12 Guidance	AP1000	Conclusion/Comment
6.3	Sampling must be carried out downstream of any abatement plant but upstream of any point of further dilution of the waste stream.	The waste is sampled from the monitor tanks after it has been routed through deep bed filters/ion exchange resins. Once discharged from the monitoring tanks the radwaste stream is diluted with re-circulated cooling water.	Comply
6.3	Prior to taking single grab samples the contents of the hold up tank must be mixed and sampling must take place prior to any period of particulate settling.	The liquid waste is mixed by pumping prior to sampling in the hold up monitor tanks.	Comply
6.3	Once mixed it is unlikely that particulate material will be homogenously mixed. Areas of low flow/adsorption to walls of the container/aggregation may occur. This should be considered when designing sampling probes. Representative samples can be taken by using isokinetic probes or frequent grab samples over the discharge period.	The guidance given in ANSI-N42.18 highlights the problems of representative sampling of particulates. This can be addressed by selecting a suitable monitoring system and a suitable sampling position. On the main discharge line the effluent stream is monitored by an in-line monitor and so no sample extraction is carried out.	Comply

Table 11 Comparison between AP1000 aerial monitoring and current UK practice

Radionuclide	Proposed AP1000 monitoring		Examples of current UK practice (EARWG)	
	Sampling technique	Analytical technique	Sampling technique	Analytical technique
Tritium	-	-	Bubbler trap	Liquid scintillation counter
Carbon-14	-	-	Bubbler trap	Liquid scintillation counter
Krypton-85	In-line sampler	Beta-sensitive liquid scintillation counter	Real time in-line sampler or representative spot sampling	Gas proportional counting
Xenon-133	In-line sampler	Beta-sensitive liquid scintillation counter	Real time monitoring	Real time monitor measures and calculates discharges
Iodine-131	Fixed charcoal filter Silver zeolite filter	Gamma-sensitive thallium-activated, sodium iodide scintillation counter	Carbon/silver zeolite filters	Germanium detector/low energy photon detector
Caesium-137	Particulate filter	Beta-sensitive liquid scintillation counter	Particulate filter	Germanium detector/low energy photon detector
Strontium-90	Particulate filter	Beta-sensitive liquid scintillation counter	Particulate filter	Cerenkov counter

Table 12 Comparison between AP1000 liquid monitoring and current UK practice

Radionuclide	Proposed AP1000 monitoring		Examples of current UK practice (EARWG)	
	Sampling Technique	Analytical Technique	Sampling Technique	Analytical Technique
Tritium	-	-	Chemical separation of beta emitters	Liquid scintillation Counter
Caesium-137	-	Gamma-sensitive thallium-activated, sodium iodide scintillation counter	Stabilisation	Germanium detector/high resolution spectroscopy

	LOCATION
1.	Radwaste Building Exhaust
2.	Annex Building Exhaust
3.	Health Physics & Hot Machine Shop Exhaust
4.	Containment Air Filtration & Exhaust
5.	Auxiliary Building Exhaust
6.	Fuel Handling Area Exhaust
7.	Gaseous Radwaste Exhaust
8.	Plant Vent
9.	Main Steam Line (Reg. Guide 1.97 and Primary-to-Secondary Leakage N-16)
10.	Turbine Building Vent Discharge

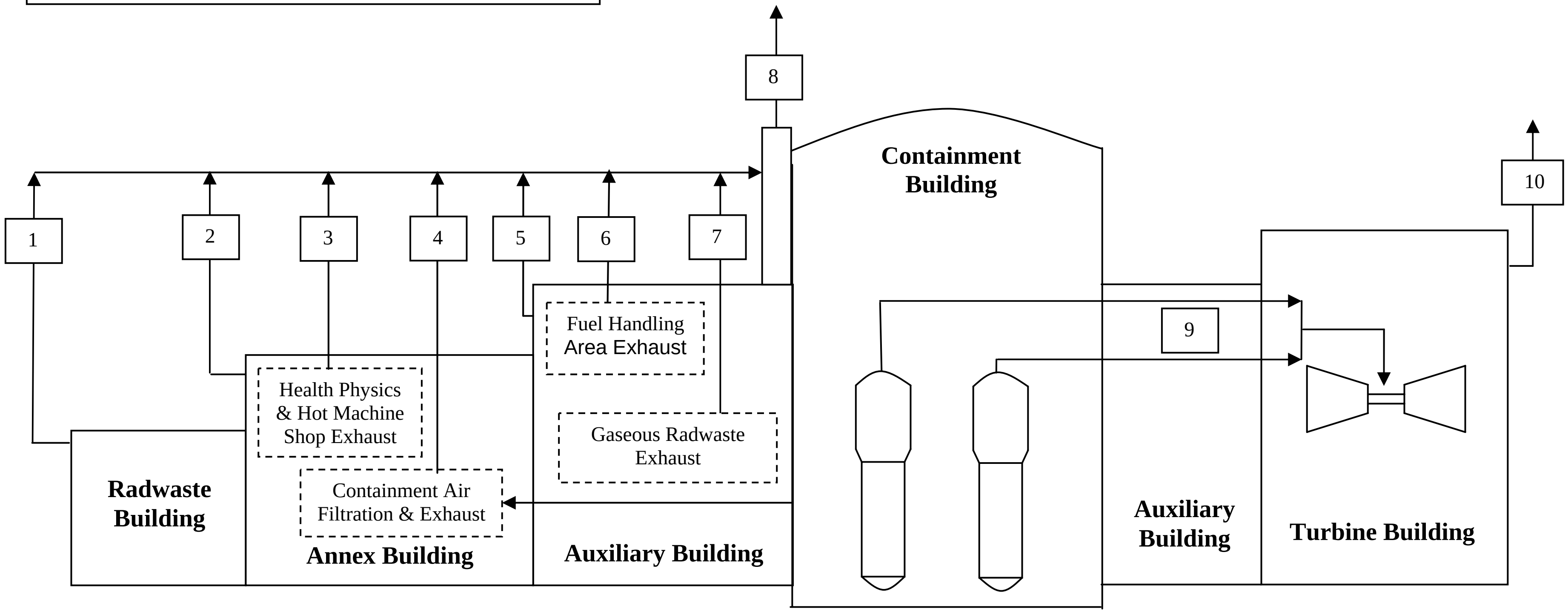

Figure 1 Schematic illustrating aerial release vents of the AP1000 plant and associated monitors

LOCATION
1. Liquid Radwaste Discharge
2. Steam Generator Blowdown Electrodeionization Effluent
3. Steam Generator Blowdown Electrodeionization Brine
4. Waste Water Discharge
5. Service Water Blowdown

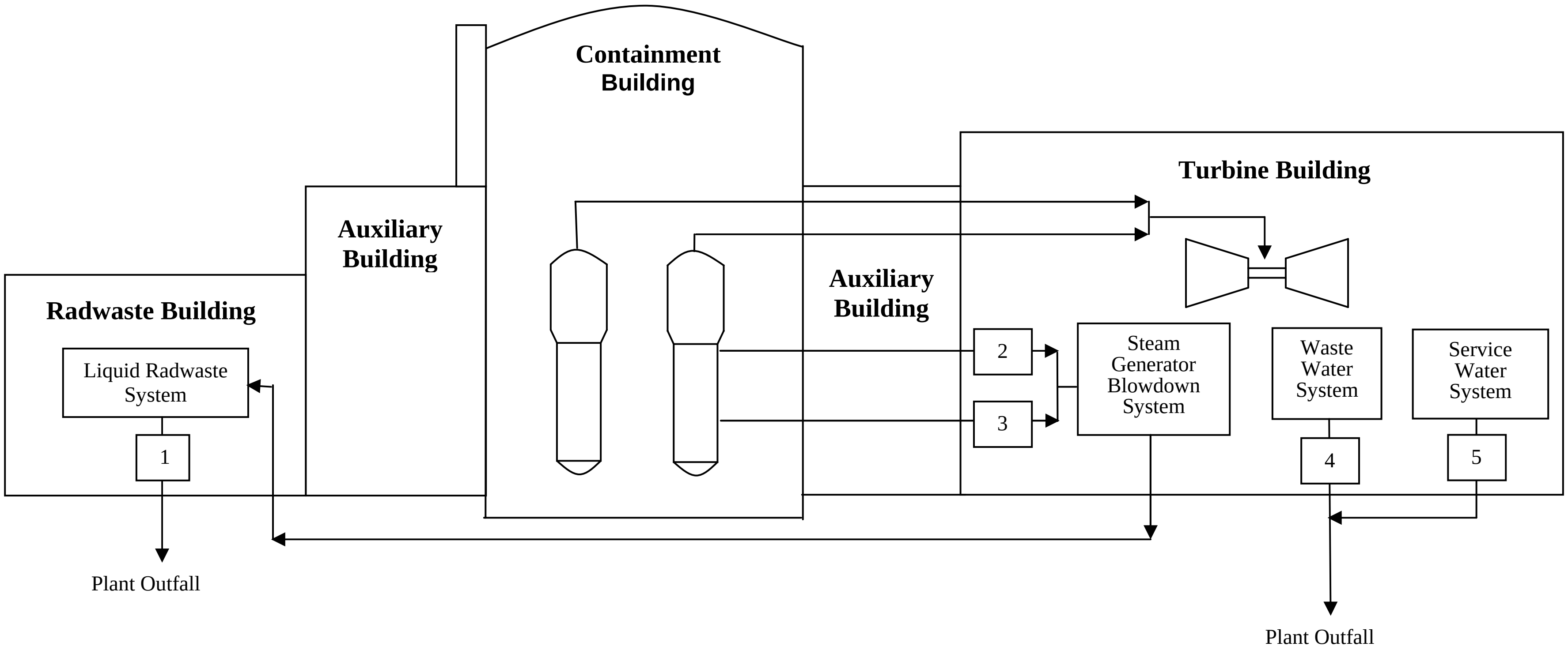

Figure 2 **Schematic illustrating liquid release points of the AP1000 plant and associated monitors**