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****Plant Applicability:** ☐ All AP1000 plants except:
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Reference 2-18

AP1000 Generic Design Prospective Individual Dose Assessment

This reference provided in Section 2.7 contains Technical Report SERCO/TAS/002730/002 Issue 02 (UKP-GW-GL-030, Revision 0), "AP1000 Generic Design Prospective Individual Dose Assessment," prepared by SERCO for the Westinghouse "UK AP1000 Environment Report," UKP-GW-GL-790, Revision 1.

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AP1000 Generic Design

Prospective Individual Dose Assessment

Westinghouse Electric Company

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Executive Summary

This report provides further details on the following assessments for the AP1000 design:

- annual dose to most exposed members of the public for liquid discharges;
- annual dose to the most exposed members of the public for gaseous discharges;
- annual dose to the most exposed members of the public for all discharges from the facility;
- annual dose from direct radiation to the most exposed member of the public;
- annual dose to the critical group for the facility;
- potential short-term doses;
- a comparison of the calculated doses with the relevant dose constraints; and
- an assessment of the build-up of radionuclides in the local environment.

For the purposes of this assessment the estimated liquid discharges for the AP1000 design were grouped into the following categories: tritium, carbon-14, all iodines and all other radionuclides. The estimated AP1000 aerial discharges were grouped into the following categories: tritium, carbon-14, argon-41, all other noble gases, all iodines, all other radionuclides.

The total dose from marine discharges is 4.8 µSv y^{-1}. The total dose from aerial discharges is 0.63 µSv y^{-1}. The highest dose to the critical group from a single atmospheric short-term release is 3.0 µSv. Assuming one short-term release event per year in gives a total dose for all discharges of 8.4 µSv y^{-1}. The direct shine dose has been estimated at 10 µSv y^{-1}, based on the direct shine dose at the Sizewell B site perimeter fence in 2006.

The total dose to the AP1000 design critical group is 18.4 µSv y^{-1}. This lies well below the UK dose constraint of 300 µSv y^{-1}, by a factor of about 15.

Build-up of radionuclides in the local environment has been assessed by calculating activity concentrations in soil and sediment after 50 years of continuous discharge from the AP1000 design. The interpretation of these activity concentration is not clear at present as no widely accepted guidance is available. However, the radiological impact of the build-up in the environment of discharged radionuclides is already covered in the dose assessments which have been carried out for the 50^{th} year of continuous discharge.

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Contents

List of Tables

1 Introduction

The Environment Agency (EA) and Health and Safety Executive (HSE) have developed a Generic Design Assessment (GDA) process [1] to evaluate different designs for the next generation of power stations to be built in the UK. Westinghouse Electric Company (WEC) has submitted its AP1000 nuclear power plant design for evaluation under this process [2].

The EA has evaluated the initial WEC submission and has requested further information on several aspects of the prospective dose assessment [3].

This report provides further details on the following:

- annual dose to most exposed members of the public for liquid discharges (Section 2);
- annual dose to the most exposed members of the public for gaseous discharges (Section 3);
- annual dose to the most exposed members of the public for all discharges from the facility (Section 6);
- annual dose from direct radiation to the most exposed member of the public (Section 4);
- annual dose to the critical group for the facility (Section 6);
- potential short-term doses, including via the food chain, based on the maximum anticipated short-term discharges from the facility in normal operation (Section 5);
- a comparison of the calculated doses with the relevant dose constraints (Section 6); and
- an assessment of whether the build-up of radionuclides in the local environment of the facility, based on the anticipated lifetime discharges, might have the potential to prejudice legitimate users or uses of the land or sea (Section 7).

2 Annual Individual Dose from Liquid Discharges

2.1 Introduction

WEC already submitted a preliminary assessment of doses from liquid discharges from its proposed AP1000 design to the EA [4]. Since then some additional and updated information has been developed, including new generic site information [5] and updated liquid discharge rates [6]. For these reasons the assessments has been updated here.

2.2 Method

At this stage of the Generic Design Assessment it is appropriate to assess potential doses from the proposed power station designs using the EA's initial assessment methodology [7].

Liquid discharges to the marine environment were taken from reference [6]. For the purposes of this assessment the discharges were grouped into the following categories, in line with advice from the EA [8]:

- Tritium (assumed to be tritiated water)
- Carbon-14
- All iodines – to be assessed as iodine-131
- All other radionuclides – to be assessed as cobalt-60

Liquid discharge data used in the assessment are listed in Table 1

Dose per unit discharge data from the initial assessment methodology are shown in Table 2. They have been extracted for the radionuclides in the discharge list and for the relevant exposure group. For liquid discharges into the sea the relevant exposure group is ‘fisherman family’. This group is assumed to be exposed to radioactive releases from the proposed AP1000 plant through the following pathways:

- internal irradiation from the consumption of seafood contaminated with radionuclides;
- external irradiation from radionuclides in beach and shore sediments during bait digging.

Detailed information on these pathways and associated habit data such as seafood consumption rates and sediment occupancy rates are listed in reference [6]. Doses are assessed in the 50th year of discharge; the only available integration time option.

Two assessments were carried out, firstly a conservative default ‘Stage 1’ initial assessment, using a volumetric exchange rate of water between the local and regional marine compartments of 100 m^3 s^{-1}. This was followed by a more refined ‘Stage 2’ initial assessment, adjusting the volumetric exchange rate to 130 m^3 s^{-1}, in accordance with the generic site information [5].

2.3 Results

Initial assessment individual doses due to marine discharges from the AP1000 design are shown in Table 3 for the default Stage 1 assessment and Table 4 for the more refined Stage 2 assessment.

The total dose from marine discharges for the refined assessment is 4.8 µSv y^{-1}. The total dose is dominated by the contribution of the ‘other radionuclides’ which were assessed as cobalt-60.

Applying cobalt-60 as a surrogate radionuclide for the ‘other radionuclides’ category leads to conservative doses as cobalt-60 has a high dose per unit release factor. To illustrate the effect of grouping these radionuclides together rather than assessing them separately a scoping assessment has been carried out. For this the Stage 2 initial dose for the five radionuclides with the highest discharges were assessed individually. Table 5 shows the discharge data used, dose per unit release factors (DPUR) and results. The total marine dose from this scoping calculation is 0.58 µSv y^{-1}, about ten times less than the original dose. This should be borne in mind when evaluating the grouping of radionuclides between categories as part of future more detailed assessments.

3 Annual Individual Dose from Atmospheric Discharges

3.1 Introduction

WEC have previously submitted a preliminary assessment of doses from atmospheric discharges from its proposed AP1000 design to the EA [4]. Since then some additional and updated information has been developed, including new generic site information [5], new effective stack heights and updated aerial discharge rates [6]. For these reasons the assessments have been updated here.

3.2 Method

At this stage of the Generic Design Assessment it is appropriate to assess potential doses from the AP1000 design using the EA's initial assessment methodology [7].

Discharges to the atmosphere were taken from reference [6]. For the purposes of this assessment the discharges were grouped into the following categories [8]:

- Tritium (assumed to be tritiated water)
- Carbon-14
- Argon-41
- All other noble gasses – to be assessed as krypton-85
- All iodines – to be assessed as iodine-131
- All other radionuclides – to be assessed as cobalt-60

Most of the release takes place from the main plant vent. The main plant vent has an effective stack height of 62.4 m, which was rounded to 60 m for assessment purposes. About 12 % of the total release takes place from the turbine building vent which has an effective stack height of 39.8 m (rounded to 40 m). Aerial discharge data used in the assessment are listed in Table 6

Dose per unit discharge data from the initial assessment methodology are shown in Table 7. They have been extracted for the radionuclides in the discharge list and for the relevant exposure group. For aerial discharges the relevant exposure group is 'local resident family'. This group is assumed to be exposed to radioactive releases from the proposed AP1000 plant through the following pathways:

- inhalation of radionuclides in the effluent plume at a distance of 100 m;
- internal irradiation from the consumption of terrestrial foodstuffs incorporating radionuclides deposited to the ground at a distance of 500 m; and
- external irradiation from radionuclides in the effluent plume and deposited to the ground at a distance of 100 m.

Detailed information on these pathways and associated habit data such as terrestrial food consumption rates, inhalation rates, building shielding factors and occupancy times are listed in reference [6]. Doses are assessed in the 50th year of discharge; the only integration time option available. Similarly, the location distance of 100 m for the local resident family is the only distance available as part of the EA's initial assessment methodology [7].

Two assessments were carried out, firstly a conservative default 'Stage 1' initial assessment, assuming a ground level release. This was followed by a more refined 'Stage 2' initial assessment. Both release points, the main vent and the turbine building vent, were assessed separately with their respective effective stack heights. The following release height scaling factors were applied (taken from Figure 2 in Reference [7]):

- food dose scaling factors of 0.05 and 0.1 for the main vent and turbine vent respectively; and
- inhalation and external dose scaling factors of 0.003 and 0.007 for the main vent and turbine vent respectively.

3.3 Results

Initial assessment individual doses due to atmospheric discharges from the AP1000 design are shown in Table 8 for the default Stage 1 assessment and Tables 9 to 11 for the more refined Stage 2 assessment.

The total dose from aerial discharges for the refined assessment is 0.63 µSv y^{-1}. The total dose is dominated by carbon-14 (75%) followed by the contribution from total iodines, assessed as iodine-131 (18%).

4 Dose from Direct Radiation

Exposure to external radiation due to direct radiation from the AP1000 design will result in a very small dose to members of the public. The closest comparable design currently in operation in the UK is the Sizewell B PWR (Pressurised Water Reactor), which is based on an older WEC design.

The direct shine dose at the Sizewell B perimeter fence was 10 µSv in 2006 [3]. This is an overall direct shine dose from both the Magnox nuclear reactor Sizewell A and the Pressurized Water Reactor Sizewell B. It is likely that the Sizewell direct radiation dose will be smaller in 2007 and subsequent years as the Magnox station Sizewell A ceased operation in December 2006.

Based on the existing Sizewell data an annual dose contribution to the AP1000 design critical group of 10 µSv y^{-1} has been applied here. It is likely that this represents a conservative estimate.

5 Potential Short-Term Doses

5.1 Introduction

When doses from routine discharges are assessed it is normally assumed that these discharges occur continuously and uniformly over a year. However, during normal operations at nuclear sites, it is possible to have short-term enhanced releases, e.g. during routine maintenance operations of the plant.

Discharging radioactive material to atmosphere over the short-term may lead to doses that are higher than would be expected if it were assumed that the same discharge takes place uniformly over a year. This is mainly due to the fact that short-term releases can lead to peak activity concentrations in air and foodstuffs, which, combined with seasonal agricultural practices and variation in habit data, can lead to higher doses.

For liquid discharges to the marine environment effects from short-term releases are deemed to be much lower. This is mainly due to limited pumping capacity from discharge tanks, making it unfeasible to assume that a month's liquid discharge volume can be released into the marine environment over a period of a few hours. Also, for marine discharges via a pipeline which discharges into the sea away from the near shore the timescale of the release is less important than for atmospheric, marine near shore or freshwater releases, as travel times to potential exposure locations are much longer. As a result only the effects from short-term aerial releases are assessed here.

At the moment there is no formal guidance on assumptions to be used when assessing short-term releases or how to integrate doses arising from short-term releases with those arising from continuous releases. NDAWG (National Dose Assessment Working Group) has set up a subgroup to look at these issues and a guidance note is expected in late 2008. Here a methodology published by the HPA (Health Protection Agency) has been adapted to assess the impact of short term atmospheric releases from the AP1000 design [9].

5.2 Method

The short-term discharges have been grouped into the same radionuclide categories used for the routine assessment (see Section 3).

The maximum short-term planned discharge is taken to be the highest planned discharge in a single month [10], shown in Table 12. The discharge period is conservatively set at 0.5 hours, the shortest period recommended in the HPA methodology. Two stack heights are used: ground level, which is the most pessimistic for nearby exposed groups, and 60 m to represent the site stack where the discharges are most likely to arise.

The meteorological conditions during the release were taken to be a single wind direction, a wind speed of 3 m s^{-1} (at a height of 10 m), neutral stability conditions, and precipitation of 0.5 mm h^{-1}. These are based on HPA's recommendation to give a cautious estimate of atmospheric concentrations and deposition on the ground close to the discharge location [9]. The concentrations were calculated using the UK accepted dispersion code for short-term releases, ADMS version 4.1 [11].

The predicted air and deposited concentrations per unit release for each radionuclide from the ADMS model run are shown in Table 13. Cloud gamma dose factors per unit release were also calculated directly using ADMS. The factors are shown in Table 14.

The dose pathways and exposure locations assumed for these short term releases were the same as for the atmospheric dose methodology for routine releases, described in Section 3.

The doses to adults, children and infants were calculated separately for each pathway. The methodology used to calculate the dose from the modelled activity concentrations for each pathway is the same as the HPA's [9], and where the parameter values were available in their report, these were used. More information on the input data is given below:

- The breathing rate was taken from Table 4 in the HPA report [9]
- The dose per unit intake values from ingestion and inhalation has been taken from reference [6]
- The crop and animal uptake concentrations per unit deposition were derived from runs of the FARMLAND module which is part of the PC CREAM modelling suite [12]. The values were adjusted for a single, instantaneous deposition; the final values are shown in Table 15. Note that the tritium and carbon-14 crop uptakes are based on air concentrations, rather than ground deposition rates.
- The critical and average food intake rates are taken from Table 2 in the HPA report [9]. Note that critical group intakes were only used for the two food groups giving the highest dose for each person; average intakes were used for other foods.
- The annual dose per unit surface deposition rates were taken from the ORNL Radiological Toolbox [13], and adjusted for radioactive decay over a year; the final dose rates are shown in Table 16.
- The shielding and occupancy factors were taken from Table 5 in the HPA report [9].

5.3 Results

The short term release doses from the AP1000 design are shown in Table 17. The breakdown by pathway for a 60 m release is shown in Table 18.

The highest dose to the local inhabitant exposure group from a single atmospheric short-term discharge release is 3.0 µSv. A theoretical maximum of 12 such releases could occur each year. Assuming that on average per year a single short-term release occurs when the wind is blowing towards the exposure group location this would result in an annual dose contribution to the local habitant exposure group of 3.0 µSv. The assumption that a single short term release contributes to the exposure group dose is valid for a generic site assessment using a uniform windrose.

6 Total Doses

6.1 Annual Dose to the Most Exposed Members of the Public for all Discharges

In order to derive the annual dose from all discharges to the most exposed members of the public the following have to be taken into account:

- Annual dose from liquid discharges (Section 2)
- Annual dose from atmospheric discharges (Section 3)
- Dose from short-term atmospheric releases (Section 5)

From the results of the dose assessments for the fisherman family exposed through liquid discharges from the proposed facility and for the local resident family exposed through aerial discharges it can be seen that the fisherman family potentially receives the highest dose. As a result the fisherman family is the individual exposure group receiving the highest dose in this assessment.

However, as it can not be ruled out at this stage that the local resident family is not exposed to the liquid discharges from the facility and vice versa for the fisherman family. As a result it is prudent to add the contribution from both discharge streams.

Thus the annual dose to the critical group for all continuous discharges from the AP1000 design is 5.4 µSv y^{-1}.

Adding the annual dose contribution from atmospheric short-term releases to the critical group gives a total dose for all discharges of 8.4 µSv y^{-1}.

6.2 Annual Dose to the Critical Group

In order to assess the total annual dose to the critical group direct radiation also needs to be taken into account. Adding the direct radiation dose of 10 µSv y^{-1} (Section 4) to the dose from all discharges (from Section 6.1) results in a total dose of 18.4 µSv y^{-1}.

This represents a maximum critical group dose as it is assumed that members of this group are exposed to both discharge streams as well as the direct radiation dose expected at the site boundary fence.

6.3 Comparison of the Calculated Doses with the Relevant Dose Constraints

The AP1000 design critical group dose of 18.4 µSv y^{-1} can be compared with the dose constraint of 300 µSv y^{-1} which is applicable to any single new source in the UK [14]. It lies well below the dose constraint, by a factor of about 15.

The total dose to the Sizewell critical group in 2006 was 91 µSv [15]. It should be noted that this dose has been derived using different methods as those applied here, for example radionuclide levels in terrestrial and marine foodstuffs are based on monitoring data rather than computer model calculations. The Sizewell critical group dose also includes a contribution from the operation of the Sizewell A Magnox reactor.

7 Build-up of Radionuclides in the Local Environment

7.1 Introduction

In order to ensure that as a result of operating the proposed AP1000 design power station in the UK there will be no potential to prejudice legitimate users or uses of the land or sea, the prospective build-up of radionuclides discharged from the facility in the local environment needs to be assessed.

7.2 Method

For the assessment two representative environmental media have been selected, one for each discharge route. For liquid discharges into the marine environment the build-up in marine coastal sediments has been assessed. For aerial discharges the build-up in undisturbed soil has been assessed.

In order to take account of accumulation of radionuclides over the plant's operational life span the plant's anticipated licensing period should be taken into account [14]. The anticipated licensing period of the AP1000 is 60 years. However the model used to carry out the calculations does not provide the option of integrating over 60 years. As a result the nearest available integration time of 50 years was chosen.

For discharges to the atmosphere, predicted environmental concentrations of radionuclides in soil were obtained with the PLUME and FARMLAND modules of the PC CREAM model [12]. PC CREAM is based on a methodology for assessing the radiological consequences of routine releases to the environment published by the European Commission [16]. For the build-up in the environment assessment radionuclides present in the discharge list have been assessed individually, rather than grouped into categories. The build-up of noble gases in soil and sediments was assumed to be negligible.

Tritium and carbon-14 are not included in FARMLAND. The transfer of tritium and carbon-14 between the atmosphere and the terrestrial environment is more complex than that for other radionuclides, since hydrogen and carbon are fundamental to biological systems. A relatively simple 'specific activity' approach is widely used in terrestrial foodchain modelling for these radionuclides [16]. It is assumed that all foodstuffs come into rapid equilibrium with atmospheric carbon-14 and tritium in atmospheric water vapour and thus it is implicitly assumed that build-up does not occur.

Discharge data used are based on data in reference [6] and are shown in Table 19.

The following assumptions were made for calculating soil concentrations as a result of aerial releases:

- Effective stack height of 60 m
- Distance from source 300 m (minimum distance available in PLUME dispersion model)
- Uniform windrose
- Atmospheric stability category distribution of 50% D

For discharges to the marine environment, predicted environmental activity concentrations of radionuclides in coastal sediments were obtained with the DORIS module of the PC CREAM model [12]. As far as possible radionuclides present in the discharge list have been assessed individually. Discharge data are based on data in reference [6] and are shown in Table 20. Any radionuclides in the discharge list that were not included in the model's default database have not been assessed. These are listed at the bottom of Table 20.

The following assumptions were made for calculating coastal sediment concentrations as a result of liquid discharges:

- Volumetric exchange rate of water between the local and adjacent regional compartments: 130 m^3 s^{-1}

7.3 Results

Activity concentrations in undisturbed soil after 50 years of atmospheric discharges from the AP1000 design are shown in Table 21 for various soil depths. Activity concentrations in the top 1 cm of soil range from 0.0003 Bq g^{-1} for barium-140 to 0.8 Bq g^{-1} for iodine-131.

Activity concentrations in coastal sediment after 50 years of liquid discharges from the AP1000 design are shown in Table 22. The activity concentration for tritium is 2800 Bq g^{-1} and that of carbon-14 9.5E-04 Bq g^{-1}. The activity concentrations for all other radionuclides in the sediment range from 5E-09 Bq g^{-1} for praseodymium-144 to 22 Bq g^{-1} for nickel-63.

Interpretation of these activity concentration is not clear at present as no widely accepted guidance is available. But the radiological impact of these is already covered in the dose assessments in Sections 2 and 3. The dose assessments also incorporate the build-up of the radionuclides in the environment as the doses have been assessed in the 50^{th} year of discharge.

8 References

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Tables

Table 1 Estimated liquid discharges from the AP1000 design

Radionuclide	Total annual discharge
	Bq/y
Tritium	3.34E+13
Carbon-14	7.00E+04
All iodides (I-131)	9.33E+07
All others (Co-60)	2.24E+09

Table 2 Dose per unit release factors for fisherman family exposure group

Radionuclide	External DPUR	Seafood DPUR	Total DPUR
	μSv/y per Bq/y		
Tritium	0.0E+00	8.9E-16	8.9E-16
Carbon-14	1.6E-16	4.6E-10	4.6E-10
Cobalt-60	2.7E-09	7.5E-11	2.8E-09
Iodine-131	2.5E-15	2.5E-12	2.5E-12

Table 3 Results for Stage 1 marine assessment

Radionuclide	External dose	Seafood dose	Total dose
	μSv/y		
Tritium	0.0E+00	3.0E-02	3.0E-02
Carbon-14	1.1E-11	3.2E-05	3.2E-05
Cobalt-60	6.0E+00	1.7E-01	6.2E+00
Iodine-131	2.3E-07	2.3E-04	2.3E-04
Total Dose	**6.0E+00**	**2.0E-01**	**6.2E+00**

Table 4 Results for Stage 2 marine assessment

Radionuclide	External dose	Seafood dose	Total dose
	µSv/y		
Tritium	0.0E+00	2.3E-02	2.3E-02
Carbon-14	8.6E-12	2.5E-05	2.5E-05
Cobalt-60	4.6E+00	1.3E-01	4.8E+00
Iodine-131	1.8E-07	1.8E-04	1.8E-04
Total Dose	**4.6E+00**	**1.5E-01**	**4.8E+00**

Table 5 Results of marine dose scoping calculations

Radionuclide	Discharge	Total DPUR	Total dose
	Bq/y	µSv/y per Bq/y	µSv/y
Tritium	3.3E+13	8.9E-16	2.3E-02
Carbon-14	7.0E+04	4.6E-10	2.5E-05
Iron-55	4.8E+08	3.0E-13	1.1E-04
Cobalt-58	4.1E+08	6.9E-11	2.2E-02
Cobalt-60	2.2E+08	2.8E-09	4.8E-01
Nickel-63	5.3E+08	3.6E-12	1.5E-03
Ruthenium-103	1.2E+08	8.8E-12	8.2E-04
Iodine-131[1]	9.3E+07	2.5E-12	1.8E-04
Caesium-137[2]	4.4E+08	1.5E-10	5.1E-02
Total dose			**5.8E-01**

[1] Includes all iodines
[2] Includes all other radionuclides

Table 6 Estimated atmospheric discharges from the AP1000 design

Radionuclide	Discharges from main plant vent	Discharges from turbine plant vent	Total annual discharge
	Bq/y		
Tritium	1.80E+12	0.00E+00	1.80E+12
Carbon-14	2.70E+11	0.00E+00	2.70E+11
Argon-41	1.30E+12	0.00E+00	1.30E+12
All remaining noble gases (Kr-85)	5.86E+12	8.15E+11	6.68E+12
All iodides (I-131)	5.51E+08	7.10E+06	5.59E+08
All remaining particulates (Co-60)	1.71E+07	0.00E+00	1.71E+07

Table 7 Dose per unit release factors for local resident family exposure group

Radionuclide	Food DPUR	External DPUR	Inhalalation DPUR	Total DPUR
	µSv/y per Bq/y			
Tritium	2.7E-13	0.0E+00	6.9E-13	9.6E-13
Carbon-14	3.3E-11	6.4E-17	3.5E-11	6.8E-11
Argon-41	0.0E+00	3.2E-12	0.0E+00	3.2E-12
Cobalt-60	5.3E-11	1.1E-08	2.2E-10	1.2E-08
Krypton-85	0.0E+00	1.3E-14	0.0E+00	1.3E-14
Iodine-131	4.1E-09	3.8E-11	3.9E-10	4.5E-09

Table 8 Results for Stage 1 aerial assessment

Radionuclide	Food dose	External dose	Inhalalation dose	Total dose
	µSv/y			
Tritium	4.9E-01	0.0E+00	1.2E+00	1.7E+00
Carbon-14	8.9E+00	1.7E-05	9.5E+00	1.8E+01
Argon-41	0.0E+00	4.2E+00	0.0E+00	4.2E+00
Cobalt-60	9.1E-04	1.9E-01	3.8E-03	2.1E-01
Krypton-85	0.0E+00	8.7E-02	0.0E+00	8.7E-02
Iodine-131	2.3E+00	2.1E-02	2.2E-01	2.5E+00
Total Dose	**1.2E+01**	**4.5E+00**	**1.1E+01**	**2.7E+01**

Table 9 Results for Stage 2 aerial assessments: main plant vent

Radionuclide	Food dose	External dose	Inhalalation dose	Total dose
	µSv/y			
Tritium	2.4E-02	0.0E+00	3.7E-03	2.8E-02
Carbon-14	4.5E-01	5.2E-08	2.8E-02	4.7E-01
Argon-41	0.0E+00	1.2E-02	0.0E+00	1.2E-02
Cobalt-60	4.5E-05	5.6E-04	1.1E-05	6.2E-04
Krypton-85	0.0E+00	2.3E-04	0.0E+00	2.3E-04
Iodine-131	1.1E-01	6.3E-05	6.5E-04	1.1E-01
Total Dose	**5.8E-01**	**1.3E-02**	**3.3E-02**	**6.3E-01**

Table 10 Results for Stage 2 aerial assessments: turbine building vent

Radionuclide	Food dose	External dose	Inhalalation dose	Total dose
	µSv/y			
Tritium	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Carbon-14	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Argon-41	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Cobalt-60	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Krypton-85	0.0E+00	3.2E-05	0.0E+00	3.2E-05
Iodine-131	1.5E-03	8.1E-07	8.3E-06	1.5E-03
Total Dose	**1.5E-03**	**3.3E-05**	**8.3E-06**	**1.5E-03**

Table 11 Results for Stage 2 aerial assessments: total dose

Radionuclide	Food dose	External dose	Inhalalation dose	Total dose
	µSv/y			
Tritium	2.4E-02	0.0E+00	3.7E-03	2.8E-02
Carbon-14	4.5E-01	5.2E-08	2.8E-02	4.7E-01
Argon-41	0.0E+00	1.2E-02	0.0E+00	1.2E-02
Cobalt-60	4.5E-05	5.6E-04	1.1E-05	6.2E-04
Krypton-85	0.0E+00	2.6E-04	0.0E+00	2.6E-04
Iodine-131	1.1E-01	6.4E-05	6.5E-04	1.2E-01
Total Dose	**5.8E-01**	**1.3E-02**	**3.3E-02**	**6.3E-01**

Table 12 Maximum estimated monthly aerial discharges from the AP1000 design

Radionuclide	Maximum monthly discharge (Bq)
Tritium	2.42E+11
Carbon-14	3.68E+10
Argon-41	1.71E+11
Other noble gases	2.03E+12
Iodines	4.96E+07
Other particulates	1.42E+06

Table 13 Dispersion factors for short-term release

Discharge Height	Radionuclide	Integrated air concentration (Bq s/m^3 per Bq release)		Deposition (Bq/m^2 per Bq release)	
		100 metres	500 metres	100 metres	500 metres
Ground Level	Iodine-131	3.36E-04	2.05E-05	3.76E-06	2.87E-07
	Krypton-85	4.00E-04	2.62E-05	0.00E+00	0.00E+00
	Tritium	4.00E-04	2.62E-05	0.00E+00	0.00E+00
	Carbon-14	4.00E-04	2.62E-05	0.00E+00	0.00E+00
	Argon-41	3.98E-04	2.57E-05	0.00E+00	0.00E+00
	Cobalt-60	3.91E-04	2.52E-05	8.33E-07	1.20E-07
Elevated (60 m)	Iodine-131	3.91E-13	7.26E-06	5.64E-07	1.88E-07
	Krypton-85	4.51E-13	7.89E-06	0.00E+00	0.00E+00
	Tritium	4.51E-13	7.89E-06	0.00E+00	0.00E+00
	Carbon-14	4.51E-13	7.89E-06	0.00E+00	0.00E+00
	Argon-41	4.50E-13	7.80E-06	0.00E+00	0.00E+00
	Cobalt-60	4.43E-13	7.74E-06	5.64E-07	1.23E-07

Table 14 Cloud gamma dose factors at 100 m

	Radionuclide	Dose factor at 100 m (Sv per Bq discharged)
Ground Level 0.5 hours	Iodine-131	7.78E-19
	Krypton-85	5.01E-21
	Tritium	0.00E+00
	Carbon-14	0.00E+00
	Argon-41	2.96E-18
	Cobalt-60	5.62E-18
Elevated (60 m) 0.5 hours	Iodine-131	1.15E-19
	Krypton-85	6.53E-22
	Tritium	0.00E+00
	Carbon-14	0.00E+00
	Argon-41	5.27E-19
	Cobalt-60	9.75E-19

Table 15 Food uptake factors for short-term release

Factor	Iodine-131	Cobalt-60	Tritium	Carbon-14
	Bq/kg per Bq/m^2		Bq/kg per Bq s/m^3	
Green Veg	1.31E-03	3.81E-03	3.58E-06	8.47E-06
Carrots	2.73E-04	1.62E-04	3.17E-06	1.69E-05
Potatoes	2.73E-04	1.62E-04	3.17E-06	1.69E-05
Sheep Meat	1.01E-03	9.67E-04	2.77E-06	2.54E-05
Sheep Offal	1.01E-03	9.68E-02	2.77E-06	2.54E-05
Cow Meat	7.84E-04	6.08E-04	2.77E-06	2.54E-05
Cow Offal	7.84E-04	6.08E-02	2.77E-06	2.54E-05
Cow Milk	1.84E-03	1.88E-03	3.58E-06	8.47E-06
Soft Fruit	9.80E-04	1.40E-03	3.17E-06	1.69E-05

Table 16 Gamma dose factors from surface deposition

Radionuclide	Dose (Sv/y per Bq/m^2)
Iodine-131	3.81E-10
Cobalt-60	6.80E-08

Table 17 Doses from a single short-term release

Discharge height	Dose (μSv)		
	Adult	Child	Infant
Ground level	1.29E+01	8.15E+00	1.10E+01
Elevated (60 m)	1.21E+00	1.46E+00	3.03E+00

Table 18 Doses from a single short-term 60 m stack release by pathway

Pathway	Dose (μSv)		
	Adult	Child	Infant
Inhalation	1.00E-08	4.01E-09	3.01E-09
Ingestion	1.11E+00	1.36E+00	2.93E+00
Deposited gamma	1.24E-02	1.24E-02	1.24E-02
Cloud gamma	9.17E-02	9.17E-02	9.17E-02
Total	**1.21E+00**	**1.46E+00**	**3.03E+00**

Table 19 AP1000 atmospheric discharge data used in build-up assessment

Radionuclides	Total release (Bq/y)
Tritium	1.80E+12
Carbon-14	2.70E+11
Chromium-51	2.30E+05
Manganese-54	1.60E+05
Cobalt-58	8.50E+06
Cobalt-60	3.20E+06
Strontium-89	1.10E+06
Strontium-90	4.40E+05
Zirconium-95	3.70E+05
Niobium-95	9.30E+05
Iodine-131	2.10E+08
Iodine-133	3.50E+08
Caesium-134	8.50E+05
Caesium-137	1.30E+06
Barium-40	1.60E+05

Table 20 AP1000 marine discharge data used in build-up assessment

Radionuclides	Total release (Bq/y)
Tritium	3.3E+13
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
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
Technetium-99m	1.8E+07
Ruthenium-103	1.2E+08
Silver-110m	2.6E+07
Iodine-131	1.5E+07
Iodine-133	2.9E+07
Plutonium-241	8.0E+04
Caesium-134	7.6E+06
Caesium-136	9.3E+06
Caeium-137	2.3E+07
Barium-140	1.4E+07
Lanthanum-140	1.8E+07
Cerium-144	8.0E+07
Praseodymium-144	8.0E+07
Radionuclides not included in build-up assessment	
Rubidium-88	3.9E+05
Molybdenum-99	1.9E+07
Iodine-132	2.0E+07
Iodine-134	5.9E+06
Iodine-135	2.4E+07
Tungsten-187	3.0E+06

Table 21 Activity in undisturbed soil layers in 50th year of atmospheric discharges

Radionuclides	0-1 cm	1-5 cm	5-15 cm	15-30 cm	30-100 cm
	Activity concentration at 300 m (Bq/kg)				
Chromium-51	1.1E-06	8.1E-09	2.4E-11	7.4E-14	2.5E-17
Manganese-54	7.8E-06	5.0E-07	1.3E-08	4.1E-10	1.5E-12
Cobalt-58	1.1E-04	2.1E-06	1.5E-08	1.0E-10	7.9E-14
Cobalt-60	4.0E-04	1.1E-04	1.6E-05	2.8E-06	6.0E-08
Strontium-89	9.6E-06	2.6E-07	1.3E-09	7.3E-12	4.1E-15
Strontium-90	4.2E-05	4.9E-05	1.7E-05	6.8E-06	2.7E-07
Zirconium-95	4.4E-06	7.5E-08	4.8E-10	3.1E-12	2.2E-15
Niobium-95	5.8E-06	5.4E-08	2.0E-10	8.0E-13	3.4E-16
Iodine-131	8.2E-04	1.6E-06	1.3E-09	1.2E-12	1.1E-16
Iodine-133	1.4E-04	3.0E-08	2.6E-12	2.4E-16	3.2E-21
Caesium-134	3.3E-05	1.6E-06	9.2E-08	6.8E-09	5.9E-11
Caesium-137	6.5E-05	4.2E-06	1.4E-06	6.7E-07	3.2E-08
Barium-40	3.4E-07	1.1E-09	1.4E-12	2.0E-15	3.2E-19

Table 22 Activity concentrations in coastal sediments in 50th year of liquid discharges

Radionuclides	Activity concentration in local compart. (Bq/kg)
Tritium	2.8E+00
Carbon-14	9.5E-07
Sodium-24	1.1E-09
Chromium-51	5.0E-06
Manganese-54	5.8E-05
Iron-55	2.5E-03
Iron-59	1.0E-06
Cobalt-58	1.5E-04
Cobalt-60	2.3E-03
Nickel-63	2.2E-02
Zinc-65	1.2E-05
Strontium-89	1.0E-07
Strontium-90	1.2E-06
Yttrium-91	2.7E-08
Zirconium-95	2.3E-06
Niobium-95	9.8E-07
Technetium-99m	1.4E-11
Ruthenium-103	1.3E-06
Silver-110m	6.4E-06
Iodine-131	8.9E-09
Iodine-133	3.1E-10
Plutonium-241	1.7E-06
Caesium-134	1.3E-05
Caesium-136	1.5E-07
Caesium-137	2.7E-04
Barium-40	2.8E-07
Lanthanum-140	0.0E+00
Cerium-144	1.3E-04
Praseodymium-144	5.8E-12