Generic design assessment

AP1000 nuclear power plant design by Westinghouse Electric Company LLC

Assessment report
Independent dose assessment

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Executive summary

The Health and Safety Executive and the Environment Agency (the nuclear regulators) are working together to ensure that any new nuclear power stations built in the UK meet the highest standard of safety, security, environmental protection and waste management. Together we have established a generic design assessment process to consider the acceptability of the new nuclear power station plants. One of the stages in the processes is consideration of the environmental acceptability of the design.

In the first stage of the GDA process, we are carrying out detailed assessments of the environmental effects of each design, which will lead to a statement about the acceptability of the design. The statement on acceptability will be non-binding but will give a strong indication of whether a design is likely to be acceptable in principle in the UK with respect to matters that the Environment Agency regulates.

Westinghouse Electric Company (WEC) has submitted its AP1000 Generic Design for evaluation under the GDA arrangements. In their submission, WEC provided assessments of potential doses to members of the public from discharges of radioactive waste to atmosphere and to the marine environment.

As part of the GDA process, an independent assessment of the potential impact of liquid and gaseous discharges of radioactive wastes from the AP1000 design has been carried out, on behalf of the Environment Agency, in accordance with the generic design assessment approach outlined in our Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs [Ref. 1]. This assessment takes account of the discharge information, design and the generic site description, provided by WEC.

The aim of the independent assessment was to:

- Validate and verify the assumptions made by WEC in their dose assessments;
- Validate and verify the outcomes of the dose assessments carried out by WEC;
- Carry out independent dose assessments to demonstrate that the dose assessments carried out by WEC are realistic.

In the WEC submission, it assumed that the AP1000 would be located on the coast. WEC applied the Environment Agency's initial radiological assessment approach. Using this approach, a dose of 7.6 μSv/y and 12 μSv/y are assessed to local residents from the annual representative and annual limit discharges to atmosphere respectively. The highest dose to an adult fisherman from marine discharges was assessed as 2.3 μSv/y for representative discharges and 3.8 μSv/y for annual limit discharges. It was possible to repeat these assessments using the WEC assumptions.

The WEC assessment of direct radiation was based on measured values for Sizewell B which is the only PWR operating in the UK. The direct radiation dose rate measured at the site perimeter fence during 2007 of 4 μSv/y was used in the WEC assessment. WEC also assessed the impact of short duration releases to

atmosphere at higher discharge rates as 12 µSv/y. The total dose assessed by WEC to the representative person from the site was therefore 14 µSv/y for representative discharges and 20 µSv/y for discharges at possible annual limits, including a contribution from short-term releases. This is based on a conservative summation of doses from atmospheric discharges, liquid discharges and direct radiation.

WEC did not undertake a detailed assessment which is sometimes made following on from the initial radiological assessment. A more detailed independent assessment was undertaken on behalf of the Environment Agency. This assessment took into account good practice and published assessment guidance and used PC CREAM 98, a long recognised system for dose assessment developed for the EC. At the discharges to atmosphere assumed by WEC, a dose of around 4 µSv/y to the most exposed local residents consuming locally produced terrestrial foods has been estimated. This assumes an effective stack height that takes account of the effects of adjacent buildings. On the basis of the expected liquid discharges estimated by WEC, effective doses of around 1 µSv/y to an adult fisherman have been assessed. The assessment of direct radiation was based on measured values for Sizewell B for 2007, for which a value of 4 µSv/y has been published. The representative person dose from the site assessed in the more detailed independent assessment has been predicted to be 8 µSv/y, including a contribution from direct radiation but without the inclusion of a contribution from short-term releases. Doses from short duration releases are presented separately.

WEC assessment outcomes were higher than the independent assessment because it is based on conservative assumptions from the initial assessment system and more conservative assumptions about combinations of exposures than those applied in the independent assessment.

Doses predicted from WEC assessment and from the independent assessment were very low and well below the dose constraint of 300 µSv/y or the proposed constraint for new nuclear power stations of 150 µSv/y.

The independent assessment of collective doses was essentially equivalent to that presented in the WEC submission.

A dose of 11-13 µSv (depending on age group) has been predicted to arise from a single short-term release to atmosphere – where one month's discharge is assumed to occur over a short time scale. This compares to 12 µSv predicted by WEC. There are some small differences in the application of the atmospheric dispersion model for this scenario however the outcomes are similar.

Contents

Introduction

1 The Environment Agency has established a Generic Design Assessment (GDA) process, together with the Health and Safety Executive (HSE), to consider the acceptability of candidate designs for new nuclear power plant designs, proposed by Requesting Parties (RPs). The Westinghouse Electric Company LLC (WEC), as a RP, has submitted its AP1000 nuclear power plant design for evaluation under these GDA arrangements.

2 As required by the Environment Agency's Process and Information Document [Ref. 1], the WEC submission included an assessment of annual individual and collective doses arising from potential liquid and gaseous discharges, and of potential short-term doses from the maximum short-term planned discharges in a single month [Ref. 2]. These assessments were based on generic design and hypothetical site characteristics [Ref. 2, 3, 4].

3 The WEC submission assumed that the AP1000 would be located at the coast. WEC proposed characteristics of the generic coastal site to encompass the range of conditions likely to occur at any coastal nuclear site in England and Wales [Ref. 2, 4]. Generic information on the location of the closest habitation, farms and population centres were also derived on the basis of information from a range of existing nuclear sites in England and Wales [Ref. 2, 4].

4 The WEC submission has been critically reviewed and verified and an independent assessment of the impact of liquid and gaseous discharges has been undertaken.

Assessments made

5 An independent assessment has been undertaken of the WEC submission, on behalf of the Environment Agency, in order to:

- Validate and verify the assumptions made by WEC in their dose assessments;
- Validate and verify the outcomes of the dose assessments carried out by WEC;
- Carry out independent dose assessments to determine whether the dose assessments carried out by WEC are realistic.

6 The first stage of this independent approach was application of the Environment Agency's Initial Radiological Assessment approach [Ref. 5], followed by a more detailed assessment using PC CREAM 98 [Ref. 6] and comparison with the corresponding assessment undertaken by WEC [Ref. 2].

7 The WEC initial radiological assessment was verified by repeating it using the same assumptions and models. Similar results were obtained for both atmospheric and liquid discharges, as described in more detail in Appendix 1.

8 A review of assumptions and parameters used in approach adopted by WEC, has been undertaken. This review also informed the approach taken in the independent re-assessment made on behalf of the Environment Agency. The results of this review and a comparison of the bases for the WEC and independent assessments are presented in Appendix 2. The differences are also highlighted in that appendix.

9 An independent assessment has been made of the annual doses to the public from the representative annual discharges and annual limit radioactive discharges to the atmosphere and to the marine environment and from direct radiation. An assessment has also been made of the potential short-term dose from the maximum short-term discharge, based on the highest planned discharge in a single month. The collective doses arising from the representative annual releases to atmosphere and of radioactive liquid discharge have also been assessed.

Discharge data for assessments

10 The expected annual releases to the atmosphere from different buildings and stack heights were provided [Ref. 2, 3] by WEC and are summarised in Table 1. These data were used in the independent detailed assessment. Alternative discharge assumptions were also provided and used by WEC in their initial radiological assessment [Ref. 2]. These discharges and the assessments are discussed in more detail in Appendix 1. WEC indicate [Ref. 2] that the effective stack heights of the main vent and turbine building vent are both around 22.5 m, allowing for the effect of the adjacent reactor buildings. Around 12% of the total atmospheric release was considered to take place from the turbine building vent. For the purposes of the initial radiological and collective dose assessments, WEC assumed all atmospheric releases to be discharged from a single stack with an effective stack height of 22.5 m [Ref. 2, 3].

11 The maximum short-term discharges to atmosphere, envisaged to occur under normal operational conditions [Ref. 2], are presented in Table 2; the expected annual liquid discharges [Ref. 2, 3] are shown in Table 3. The limited pumping capacity from liquid discharge tanks is considered by WEC to preclude the potential for significant short-term liquid discharges from this route [Ref. 2].

12 The discharge assumptions used by WEC in their initial radiological assessment are presented in Appendix 1. The more detailed data presented in Tables 1 and 3 were used in the independent verification assessment. The effects of an adjacent building (of height 70 m) on dispersion were also taken into account in the independent initial and more detailed assessments by modifying the effective stack height to 23 m, as described in more detail in Appendices 1 and 2, respectively.

Assessment Methodology

13 The first stage of the independent assessment was to apply the Environment Agency's Initial Radiological Assessment approach [Ref. 5]. This provides radionuclide specific dose per unit release factors derived from generic parameters, which allows conservative estimates of dose to be made in a transparent and consistent manner. WEC undertook an initial assessment of their expected discharges using this system. This report presents a verification of this initial assessment stage by repeating the WEC assessment, as described in Appendix 1.

14 The next stage of this work was a critical review of the WEC assessment and supporting reports, in order to:

- identify the assessment approach, assumptions and parameters used;
- comment on the applicability of the approach; and,
- determine the basis for an independent assessment.

15 The review was undertaken using consistency matrices that identified each of the key assessment stages. These matrices are provided in Appendix 2 for ease of reference.

16 The final stage of the work was to undertake an independent detailed assessment taking into account the review of the WEC initial radiological assessment. The review is summarised in the matrices in Appendix 2. The independent assessment also took account of guidance provided by the UK National Dose Assessment Working Group (NDAWG). The NDAWG provides a technical forum dealing with dose assessment matters for the UK and involves the Environment Agency and other regulatory and advisory organisations.

17 WEC did not undertake a more detailed assessment because their estimated doses from representative discharges were less than 20 μSv/y, and therefore further assessments would not be required for discharge authorisation purposes [Ref. 5]

18 An assessment spreadsheet was created, using dispersion, environmental transfer and other relevant information from the PC CREAM 98 programme [Ref. 6]. Allowance for the effects of adjacent buildings on plume dispersion was made and an effective stack height of 23 m was

applied. The independent assessment was designed to allow the Environment Agency to take an independent view of the outcome of the discharges.

19 The methodology used for the more detailed independent assessment of the radiological impact of radioactive discharges, is described in more detail in the appendices, as follows:

- Appendix 3: Radiological assessment of discharges of gaseous radioactive waste to atmosphere using predicted environmental concentrations; obtained from modelling carried out using the PC CREAM 98 model [Ref. 6];
- Appendix 4: Radiological assessment of discharges of liquid radioactive to the marine environment using predicted environmental concentrations; obtained from modelling carried out using the PC CREAM 98 model [Ref. 6];
- Appendix 5: Radiological assessment of collective doses from atmospheric and liquid discharges;
- Appendix 6: Potential doses from anticipated short-term atmospheric releases;
- Appendix 7: A discussion about some of the main uncertainties associated with the dose assessments;.
- Appendix 8: The methodology used for the assessment of the potential contribution from direct radiation
- Appendix 9: Estimated site doses and total doses.

20 It is assumed that no radioactive discharges will be made directly to the freshwater environment from the AP1000 therefore no assessment of doses from the freshwater environment has been made. Furthermore, no release information was provided for site incinerators and it has also been assumed that there are no discharges from this route.

21 Given the generic nature of the site, it has been assumed that there are no current and future discharges from adjacent sources, or from historic discharges from previous operations. The total doses arising from the AP1000 have therefore been used for comparison with the site dose constraint and the annual effective dose limit for members of the public of 1000 μSv/y. If the AP1000 power plant were to be positioned in the vicinity of a present or previous nuclear site, these dose assessments would need to be modified to take account of any additional contributions to radiation dose that might arise from these sources.

Exposure pathways

22 Members of the public can be exposed to radionuclides discharged to atmosphere or to the marine environment by a range of exposure pathways. The exposure pathways considered in the independent assessment were based on information provided by WEC on the nature of the generic site [Ref. 3], along with Environment Agency knowledge of the typical nature of nuclear sites gained through radiological assessments of discharges from other sites.

23 For discharges to atmosphere, the WEC initial radiological assessment and the more detailed independent assessment consider:

- ***Internal irradiation*** following inhalation of radionuclides discharged to atmosphere;
- ***Internal irradiation*** from the ingestion of radionuclides incorporated into locally produced foods following deposition of radionuclides discharged to atmosphere;
- ***External irradiation*** from radionuclides in the atmosphere and deposited on the ground following discharge to atmosphere.

24 For discharges of liquids to coastal waters the WEC initial radiological assessment and the independent assessment consider:

- ***External irradiation*** following incorporation of radionuclides into coastal sediment;

- ***Internal irradiation*** following the ingestion of radionuclides in marine fish and shellfish caught along the coast. Inhalation of sea spray incorporating radionuclides;

The following additional minor pathways were included in the more detailed independent assessment, which were not included in that undertaken by WEC:

- ***External irradiation*** from exposure to the skin from handling of fishing gear which has come into contact with the sediment;

- ***Internal irradiation*** from inhalation of sea spray incorporating radionuclides and following the inadvertent intake of coastal sediment incorporating radionuclides along the coast.

25 Both the WEC and independent assessments consider:

- ***External irradiation*** due to direct radiation from the site.

The approaches adopted were similar.

Candidates for the representative person

26 Given the nature of this assessment, specific information on the land use and location of members of the public around the generic site are not available. As a consequence, it has been necessary to make some general assumptions about the environment around the generic site. In their submission, WEC assumed that the AP1000 nuclear power plant is located at a coastal site and proposed generic assumptions regarding the characteristics of the terrestrial and marine environments that were intended to be conservative and to envelop those of existing UK nuclear sites. Both assessments assume that commercial fish and shellfish may be sourced at or near to the generic site.

27 For the independent assessment, the mode of radioactive waste discharge, information on generic habits and previous radiological assessments for other sites have been used to identify candidates for the representative person. The candidates for the representative person were chosen to reflect the residential and other communities in the area closest to a generic coastal site. The approach taken in the independent assessment is described more fully in Appendices 3 and 4. Candidates for the representative person most exposed to liquid discharges may also be exposed via consumption of terrestrial foods and other atmospheric pathways and vice versa. However, one or the other discharge tends to dominate and the dominant exposure routes have been used to categorise appropriate candidates for the representative person into: local residents, who are primarily exposed to atmospheric discharge pathways; and a local fisherman and family, who are primarily exposed to liquid discharges.

Candidates for the representative person

28 The WEC assessment is based on the Environment Agency Initial Radiological Assessment approach [Ref. 5], and the assumptions underlying this approach are presented in more detail in Appendix 2. WEC did not undertake a more detailed assessment.

29 For the independent assessment which is more detailed there was consideration of:

- ***CRP1 Local residents*** For the purposes of this generic assessment, it is assumed that a family (adults, children and infants) live in the nearest habitation (assumed to be 100 m from the atmospheric discharge point), are exposed to atmospheric discharges, direct radiation and to liquid discharges in the marine environment. It is assumed that members of this family spend most of their time at home, some of which is spent outside. They get their green vegetables, root vegetables and fruit from their garden or other local source (within 100 m from the atmospheric discharge point) and milk and meat from local farms close to the site (assumed to be located at 500 m from the atmospheric discharge point). They also eat small amounts of local fish and shellfish. Generic habit data were used as the basis for the occupancy and food intakes of the members of this family or families as outlined in Appendix 3. The estimated direct radiation dose is described in Appendix 8.

- ***CRP2 Fisherman and family*** For the purposes of this assessment, it is assumed that the fishermen and their families are exposed to liquid discharges from the site by spending some time on the intertidal sediments in the area and consuming high levels of locally caught fish and shellfish in addition to small amounts of locally produced foodstuffs (fruit and vegetables), originating from local sources (100 and 500 m from the atmospheric discharge point). This group are assumed to live at sufficient distance from the site to not receive exposure from direct radiation or inhalation of atmospheric releases. Generic habit data were used to define the occupancy and food intakes of the members of this family or families, as outlined in more detail in Appendix 4.

30 Generic habit data, based on NRPB-W41 [Ref. 7] have been used together with standard dose coefficients for internal and external exposure [Ref. 8, 9]. The sources of other assessment parameters are presented in Appendices 3 and 4.

Results

Verification of the assessment of doses supplied by WEC.

31 The results of the initial radiological assessment, undertaken by the WEC, are summarised in Table 4. The effective doses from discharges to atmosphere from the AP1000 plant were predicted to be 7.6 μSv/y for representative discharges and 12 μSv/y for annual limit discharges. The effective doses from liquid discharges from the AP1000 power plant were predicted to be 2.3 μSv/y for representative discharges and 3.8 μSv/y for annual limit discharges. It was possible to reproduce these doses using the same assumptions and model.

32 The WEC assessment of collective doses could be reproduced.

33 The WEC assessment of effective doses arising from short-term releases could be broadly reproduced, as discussed in more detail in Appendix 1. WEC have predicted an effective dose of 12 μSv to arise from a single release, while doses of between 11 and 13 μSv have been predicted in the independent assessment depending on age group.

Independent assessment of doses undertaken in this work

34 The individual doses to the candidates for the representative person calculated independently in more detail using generic site and habits data, are summarised in Table 5 for representative annual discharges. At these levels, the effective doses from discharges to atmosphere from the AP1000 power plant to a potential terrestrial candidate representative person of local residents have been predicted to be around 4.4 μSv/y (infants), and 2.9 μSv/y (children) and 2.6 μSv/y (adults). The dose resulting from all discharges to infant candidates for the representative person, broken down by radionuclide and by pathway, is included in Appendix 3. The main pathway contributing to the highest of these doses (to infants) was consumption of C-14 in milk.

35 At the expected annual radioactive liquid discharge level, the effective doses candidates for the representative person (local fisherman family) from representative discharges from the AP1000 have been predicted to be around 0.1 μSv/y (infants), 0.3 μSv/y (children) and 1 μSv/y (adults). The main pathways were consumption of carbon-14 in fish and shellfish. A

breakdown of the dose by radionuclide and by pathway (arising from all discharges) to adult candidates for the representative person are provided in Appendix 4.

Individual doses to candidates for the representative person arising from direct radiation

36 Exposure of the public from direct radiation from nuclear sites in the UK is the responsibility of the HSE. HSE require site operators to measure direct radiation at the site perimeter and estimate exposure to a reference group on an annual basis. The total dose from direct radiation from the AP1000 power plant was assessed as 4 μSv/y as outlined in Appendix 8. It is based on measured gamma dose rates for Sizewell B in 2007 [Ref. 10], the only PWR in the UK.

Representative person for the AP1000 power plant

37 The representative person for discharges at the predicted levels and direct radiation from the AP1000 power plant are infant local residents, who received a total dose of 8.4 μSv/y, of which 4.4 μSv/y is from discharges and 4 μSv/y from direct radiation.

38 WEC estimated direct radiation doses of around 4 μSv/y, based on measurements at the Sizewell B perimeter fence in 2007. This estimate is consistent with that used for the independent assessment. WEC estimated the total dose for the representative discharges from AP1000 to be 14 μSv/y, based on the sum of the atmospheric and marine components of dose and the direct radiation estimate of 4 μSv/y.

Site dose from proposed discharges

39 Site dose is calculated by taking into account the potential combined doses arising from the radioactive source in question (in this case the AP1000 nuclear plant) and from any other sources with which it is co-located. Given the generic nature of the site considered in this assessment, it has been assumed that the AP1000 is the only source located at this site. The site dose is, in this case, equivalent to that from the AP1000.

Total dose

40 Total dose is generally calculated by taking into account doses from predicted discharges from the site along with doses resulting from any residues from previous discharges from this site, and doses from other sites (nearby or more distant).. The calculation of these contributions to total dose is highly site specific. At this stage, it has been assumed that the AP1000 is located, in isolation, at a site which has not previously been occupied by a source of radioactive discharges and at some distance from any other such sources. In this case, the total dose may therefore be assumed to be equivalent to the total dose from discharges and direct radiation from the AP1000. If the AP1000 were to be located on a current nuclear licensed site, for example, these assumptions would need to be reviewed.

Collective doses to UK, Europe and the World

41 The average collective doses per year of discharge (truncated to 500 years) arising from discharges to atmosphere and discharges to the sea were calculated as detailed in Appendix 5 and are as follows:

- ***Discharges to atmosphere from the AP1000 power plant at predicted levels –*** 0.26 manSv for the UK population, 1.97 manSv for European population, and 12.4 manSv for the World population for representative discharges; and 0.40 manSv for UK population, 3.08manSv for European population and 19.5 manSv for World population for annual limit discharges.

- ***Discharges to the sea from the AP1000 power plant at predicted levels*** – 0.0008 manSv for the UK population, 0.0039 manSv for European population, and 0.053 manSv for the World population for representative discharges; and 0.0013 manSv for UK population, 0.0061 manSv for European population and 0.084 manSv for World population for annual limit discharges.

42 The majority of the collective dose from discharges to atmosphere arises from carbon-14. The majority of the collective dose from discharges to sea varies depending upon the location of the site considered. The highest radionuclide contribution is from carbon-14.

Doses from potential short-term releases

43 The doses arising to members of the public as a consequence of potential short-term releases to atmosphere have been calculated as set out in Appendix 6. The dose from a single short term release to atmosphere has been estimated to be 13 μSv to adults and 11 μSv to other age groups. This arises primarily from the inhalation of carbon-14.

Discussion

44 At the estimated annual discharge levels, provided by WEC, the independent assessment has predicted an effective dose to the representative person, from the AP1000 power plant including direct radiation of 8.43 μSv/y. This value is less than the dose constraint of 300 μSv/y, or the proposed dose constraint for new nuclear power stations of 150 μSv/y [Ref. 11, 12].

45 In order to make an assessment of the site and total dose to the representative person for comparison with either the site constraint (of 500 μSv/y) or the dose limit for members of the public of 1000 μSv/y [Ref. 11], it is necessary to take account of discharges from all operations on the same site or from all practices. This information would ideally require specific information about the location of the power plant. In the absence of such information, it has been assumed that the AP1000 is located at a new site and at some distance from any other radioactive sources. Under these circumstances the representative person doses above may be compared with the site constraint and dose limit. This would not be the case if the AP1000 were co-located on a current nuclear licensed site.

46 The independent assessment predicted a collective dose of around 12 manSv due to atmospheric discharges per year of discharge to the world population (truncated at 500 years). Discharges to the marine environment were predicted to give rise to much lower collective doses of less than 0.1 manSv per year of discharge. There is no legal dose limit on collective doses.

47 Collective doses may be used to derive the average individual dose to members of different population groups, known as per caput doses. The UK regulatory and advisory agencies have stated that discharges giving rise to per caput doses in the range of nanosieverts per year of discharge can be regarded as miniscule [Ref 11]. The average per caput dose for representative discharges to atmosphere from the AP1000 power plant are highest for the UK population at 4.7 nSv per year of discharge. The average per caput doses from the AP1000 power plant for discharges to the sea at the predicted levels are 0.024 nSv. These average per caput doses may be regarded as trivial.

48 The potential dose to a representative member of the public from a single short-term release to atmosphere was estimated to be 11-13 μSv depending on age group. Although the dose from a single short-term release is low, there is the potential for multiple releases during the course of the year and, at this level, the contribution of short-term releases would be of a similar level as those predicted for continuous discharge.

Comparison of the WEC and independent assessments

49 At the estimated annual discharge levels, WEC assessed the effective dose to the representative person from the AP1000 power plant to be 14 μSv/y for representative discharges and 20 μSv/y for discharges at proposed annual limits. It is based on the assumption that the predicted doses from the atmospheric and liquid discharges and direct radiation can be added. It includes a 4 μSv/y contribution from direct radiation. The dose from atmospheric discharges accounts for more than 50% of the effective representative person dose at 7.6 μSv/y for representative discharges.

50 The detailed independent assessment gives a representative person dose of 8.4 μSv/y. This includes a 4 μSv/y contribution from direct radiation. The dose from discharges to atmosphere was 4.4 μSv/y from an assumed effective stack of 23 m. Less pessimistic assumptions about combinations of exposures have been made in calculating effective doses from the source.

51 WEC has estimated the collective doses to the world population (truncated at 500 years) from representative atmospheric discharges to be of the order of 12 to 13 manSv per year of discharge to atmosphere and 0.05 to 0.055 from representative liquid discharges. The independent assessment results of 12.2 to 12.6 manSv per year for atmospheric discharges and 0.052 to 0.054 manSv per year for liquid discharge are effectively equivalent.

Uncertainty in results

52 The assessments show that individual doses from representative discharges (excluding short duration releases) are well below the dose constraints of 300 μSv/y and also below lower dose criterion for the 'threshold of optimisation' of 20 μSv/y. Given the relatively low doses, a limited assessment of uncertainty in the results has been made.

53 For example, the potential for a variability of around a factor of 2 in atmospheric concentrations may be associated with the assumptions about wind direction, as discussed in more detail in Appendix 7. The dose assessment will also be influenced by the choice of distance of the receptor from the release point. In the independent assessment, standard assumptions regarding the habitation and domestic fruit and vegetable production (100 m) and agricultural produce (500 m). The air concentrations at these locations are around 70% and 50% of those estimated at the location with the maximum air concentration, as discussed in more detail in Appendix 7.

54 The doses have also been presented separately for internal and external exposure, in Appendix 7 to allow that uncertainties in the calculations of each to be considered in more detail if required.

Doses to the foetus and breast fed infants

55 The independent assessment also considered the possibility that pregnant women and breast-feeding infants could be present in the candidates for the representative person, and an estimate of doses to the foetus and breast-fed infant during the first few months of life was made. The predicted doses were slightly higher than those to the adult. This assessment is reported in more detail in Appendix 7.

Conclusions

56 An independent assessment was undertaken, on behalf of the Environment Agency, in order to:

- Validate and verify the assumptions made by WEC in their dose assessments;
- Validate and verify the outcomes of the dose assessments carried out by WEC;
- Carry out independent dose assessments to demonstrate that the dose assessments carried out by WEC are realistic.

57 WEC undertook an assessment using the Environment Agency Initial Radiological Assessment approach. The approach was repeated with the same results.

58 The WEC and independent approaches to assess the dose from direct radiation are similar. In both cases, measurements of the dose rates around the perimeter of the only operating PWR in the UK (Sizewell B) have been used to represent those likely to arise from the operation of the AP1000. The value of 4 μSv/y measured in 2007 has been used in both assessments.

59 A more detailed independent prospective radiological assessment has been undertaken for expected annual radioactive discharges for the AP1000 nuclear power plant, using the generic site characteristics and parameters agreed with the Environment Agency, identified in Appendix 2. The assessment has considered releases from atmospheric discharges from the PWR plant, liquid discharges and direct radiation.

60 The representative person for the expected discharges and direct radiation from the AP1000 nuclear power plant, using the generic site information and the expected annual discharges provided by WEC, is an infant member of the local population (CRP1), who has been predicted to receive a dose of 8.4 μSv/y with the majority of the dose arising from atmospheric discharges and direct radiation.

61 The doses associated with the expected annual discharges from the AP1000 nuclear power plant are therefore less than the existing source dose constraint of 300 μSv/y and the proposed dose constraint for new nuclear power stations of 150 μSv/y.

62 In order to make an assessment of the site and total dose to the representative person for comparison with either the site constraint (of 500 Sv/y) or the dose limit for members of the public of 1000 μSv/y [Ref. 10], it is necessary to take account of discharges from all operations on the same site or from all practices. For the purposes of this assessment, it has been assumed that the AP1000 is located on a site at some distance from any existing or previous sources of radioactive discharges. As a consequence, the contribution of historic sources or from discharges of other practices on the same or other sites would be negligible. Under these circumstances the representative person doses above may be compared with the site constraint and dose limit. This would not be the case if the AP1000 were co-located on a current nuclear licensed site.

63 Collective doses to the UK, Europe and the world population, truncated at 500 years, have been assessed on the basis of representative annual discharges. The assessment made by WEC and that made independently are in agreement. The highest dose is around 13 manSv per year of discharge to atmosphere to the world population. Doses to European population were around 2 manSv and the UK were less than 1 manSv per year of discharge. Doses to the world population were around 0.05 manSv for liquid discharges. The highest average per caput doses (to the UK population) are of the order of 5 nSv per year of discharge. Per caput doses at this level may be regarded as trivial [Ref 10].

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Table 1 Expected Annual Discharges to Atmosphere

Radionuclide	Predicted Atmospheric Discharges (TBq/y)	
	Reactor Building (Stack 1)	Turbine Hall (Stack 2)
Ar-41	1.30E+00	-
Ba-140	1.50E-07	-
C-14	6.06E-01	-
Co-58	8.60E-06	-
Co-60	3.20E-06	-
Cr-51	1.90E-07	-
Cs-134	8.30E-07	-
Cs-137	1.30E-06	-
H-3	1.80E+00	-
I-131	2.10E-04	3.40E-06
I-133	3.50E-04	3.70E-06
Kr-85	3.10E+00	2.60E-02
Kr-85m	1.70E-02	7.80E-03
Kr-87	1.70E-02	2.20E-03
Kr-88	1.80E-02	8.50E-03
Mn-54	1.10E-07	-
Nb-95	8.90E-07	-
Sr-89	1.10E-06	-
Sr-90	4.10E-07	-
Xe-131m	1.30E+00	8.10E-02
Xe-133	9.60E-01	2.90E-01
Xe-133m	8.10E-02	3.50E-02
Xe-135	1.70E-01	2.60E-01
Xe-135m	1.30E-01	5.90E-02
Xe-137	3.40E-02	1.60E-02
Xe-138	5.90E-02	2.90E-02
Zr-95	3.70E-07	-

Table 2 Predicted Short term Discharges to Atmosphere

Radionuclide	Total release in 30 minutes Bq	Emission Rate over 30 minutes (Bq/s)
H-3	2.42E+11	1.34E+08
C-14	8.30+10	4.61E+07
Ar-41	1.71E+11	9.50E+07
Co-58*	1.02E+06	5.67E+02
Co-60	2.69E+05	1.49E02
Kr-85**	3.30E+12	1.84E+09
Sr-90	3.70E+04	2.06E+01
I-131	1.73E+07	9.61E+03
I-133***	4.96E+07	2.76E+04
Xe-133	1.87E+11	1.04E+08
Cs-137	1.11E+05	6.17E+01

* C0-58 is surrogate for all particulate discharges other than Co-60, Sr-90 and Cs-137;
** Kr-85 is surrogate for all noble gasses other than Ar-4 and Xe-133;
*** I-133 is surrogate for all radio-iodides other than I-131

Table 3 Expected Annual Liquid Discharges to the Sea

Radionuclide	Predicted Marine Discharges (TBq/y)
Ag-110m	2.60E-05
Ba-140	1.30E-05
C-14	3.3E-03
Ce-144	9.00E-05
Co-58	4.10E-04
Co-60	2.30E-04
Cr-51	4.60E-05
Cs-134	7.60E-06
Cs-136	9.30E-06
Cs-137	2.30E-05
Fe-55	4.90E-04
Fe-59	5.00E-06
H-3	3.34E+01
I-131	1.50E-05
I-133	2.90E-05
La-140	1.80E-05
Mn-54	3.20E-05
Na-24	3.80E-05
Nb-95	6.10E-06
Ni-63	5.40E-04
Pr-144	8.00E-05
Pu-241	8.00E-08
Ru-103	1.20E-04
Sr-89	2.40E-06
Sr-90	2.50E-07
Tc-99m	1.80E-05
Y-91	9.10E-08
Zn-65	1.00E-05
Zr-95	6.90E-06

Table 4 Summary of Individual Doses from the WEC Initial Radiological Assessment based on Representative Annual Discharges and Short Term Releases (μSv/y)

Candidate for the Representative Person	AP1000 Power Plant Discharges and Short Term Releases				
	Stack 1 (22.5 m)	Liquid (130 m/s exchange rate)	Direct Radiation	Short Term releases	Total
Local resident based on combined results of initial radiological assessment	7.6	2.3	4.0	5.1	19.0

Table 5 Summary of Individual Doses to Candidates for the Representative person arising from Discharges and Direct Radiation based on Predicted Maximum Discharges (μSv/y)*

Candidates for the Representative person	Age Group	AP1000 Power plant Discharges				
		Stack 1	Stack 2	Liquid	Direct Radiation	Total
CRP1 - local resident (high rate terrestrial food consumer)	Adult	2.6	0.01	0.1	4.0	6.7
	Child	2.9	0.01	0.04	4.0	6.9
	Infant	**4.4**	**0.01**	**0.04**	**4.0**	**8.4**
CRP2 - local fishing family (high marine exposure)	**Adult**	**1.6**	**0.01**	**1.0**	**0.0**	**2.6**
	Child	1.9	0.01	0.3	0.0	2.2
	Infant	2.1	0.01	0.1	0.0	2.2

*** Rounded 2 two significant figures**

Appendix 1 – Verification of radiological assessment and short term assessment for Westinghouse AP1000 Design

Introduction

A1.1 In accordance with the established principles and guidance for prospective assessment of public doses, a staged approach has been applied in the independent assessment of representative person dose.. The first stage, also applied by WEC, was the application of the simple and cautious approach provided by the Environment Agency's Initial Radiological Assessment (IRA) [Ref. A1.1]. This provides dose per unit release values which allow a simple, single step conservative assessment of doses from discharges to be made. It is recommended that if effective doses from this approach are less than 20 μSv/y that no further assessment would be warranted for the purpose of authorising discharge of radioactive waste to the environment.

A1.2 The IRA approach has been applied for the representative and annual limit atmospheric and liquid discharges, provided in the WEC submission [Ref. A1.2] and the results compared with those provided by WEC [Ref. A1.2]. The results of verification activities on the WEC assessments of short term releases from the AP1000 design collective dose are also presented in this appendix.

Stage 1 Initial Radiological Assessment

A1.3 No information on a Stage 1 initial radiological assessment was provided by WEC in their Environment Report [Ref. A1.2]

Stage 2 Initial Radiological Assessment

A1.4 The assumed atmospheric and liquid discharges presented by WEC are provided in Tables A1.1 and A1.2 respectively [Ref. A1.2]. In Stage 2 of the Environment Agency's Initial Radiological Assessment, an effective stack height of 22.5 m was applied to take account of the building wake effects of the nearby building (of 70 m), in accordance with the approach adopted by WEC [Ref. A1.2]. A volumetric exchange rate of 130 m^3/s is considered to be more representative of the local marine compartment. The results from the application of the relevant dose per unit release values are presented in Tables A1.3, A1.4, A1.5 and A1.6 respectively.

A1.5 A dose of 7.6 μSv/y and 12 μSv/y were assessed to local residents from the annual representative and annual limit discharges to atmosphere respectively. The highest dose to an adult fisherman from marine discharges was assessed as 2.3 μSv/y for representative discharges and 3.8 μSv/y for annual limit discharges.

A1.6 The direct radiation dose rate was 4 μSv/y as used in the WEC assessment. The doses from liquid and gaseous discharges at representative and annual limit discharges including direct radiation are 14 μSv/y and 20 μSv/y respectively.

A1.7 The effective doses estimated in Stage 2 presented by WEC could be repeated.

Stage 3 More Detailed Radiological Assessment

A1.8 WEC did not undertake a detailed (Tier 3) assessment of doses to candidates for the representative person from either atmospheric or marine discharges; the results of Stage 2 initial radiological assessments, for representative discharges, were below the threshold dose (20 μSv/y) for further assessment [Ref.A1.2].

Short duration releases to atmosphere

A1.9 WEC also undertook an assessment of short duration releases to atmosphere. This made use of the ADMS model code for dispersion [Ref. A1.3]. It was possible to verify the short term dispersion modelling assessment undertaken by WEC to a reasonably good degree, as demonstrated in the summary of the validated parameters in Table A1.7. The modelled ground level concentrations, deposition rates and gamma doses were similar to the results reported in UKP-GW-GL-790 Revision 2 [Ref. A1.2].

A1.10 WEC estimated the highest effective dose from short-term releases to be 12 μSv per discharge to the local inhabitant exposure group. A more detailed breakdown of doses from different pathways and to different age groups was not provided. It was not therefore possible to verify the WEC assessment. Instead an independent assessment was made which gave similar results.

Collective Dose

A1.11 The collective dose results included in the WEC submission are presented in Table A1.8 The highest total collective dose to the UK was estimated to be 0.27 manSv, while the corresponding values for the European and World populations were estimated to be 2.1 and 13 manSv respectively.

A1.12 For atmospheric discharges, collective dose per unit release (DPUR) were calculated using PC CREAM for UK, EU and World populations, and for releases from the Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell sites in accordance with WEC methodology. The results were then combined with discharge data to obtain the actual doses to the population groups. The results for the individual sites were then statistically combined, in line with the WEC approach. Some minor differences in the percentage contributions to different population arose, which might be attributed to rounding differences.

Summary

A1.13 Stage 2 of the Environment Agency Initial Radiological Assessment (IRA) [Ref. A1.1] approach was applied for the atmospheric and liquid discharges, for default assumptions and for the stack heights and volumetric exchange rates presented in the WEC submission. The total doses were essentially equivalent to those presented by WEC.

A1.14 It was possible to validate WEC modelling of the dispersion and cloud gamma doses arising from short-term releases to the atmosphere.

A1.15 The collective dose estimates presented by WEC could be repeated with the same values, although there were some minor differences in the percentage contributions to different radionuclides.

References

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A1.2 Eisenstatt, L, Environment Report, WEC, UKP-GW-GL-790, Revision 3 (April 2010)

A1.3 ADMS 4, Industrial Air Pollution Model, http://www.cerc.co.uk/software/adms4.htm

Table A1.1: Atmospheric Discharges used in Initial Radiological Assessment

Radionuclide	Representative 12-Month Plant Discharge (D) (TBq/y)	Calculated Annual Limit (TBq/y)
Radioiodines[1](I-133)	3.88E-04	7.00E-04
Noble Gases[2](Kr-85)	9.34E-01	1.00E+00
Tritium	1.87E+00	3.00E+00
Carbon-14	6.38E-01	1.00E+00
Argon-41	1.32E+00	2.00E+00
Cobalt-60	3.22E-06	5.00E-06
Krypton-85	4.07E+00	7.00E+00
Strontium-90	4.44E-07	7.00E-07
Iodine-131	2.07E-04	3.00E-04
Xenon-131m	1.76E+00	3.00E+00
Xenon-133	1.34E+00	2.00E+00
Caesium-137	1.33E-06	2.00E-06
Other particulates (Co-58)	1.22E-05	2.00E-05
Total Beta particulate[3]	6.00E-09	2.30E-06
Total	**11.93**	**19.00**

1. Radioiodines - taken to be all radioiodines apart from iodine-131. I-133 has been used as the representative radionuclide.

2. Noble gases - taken to be all isotopes of krypton and xenon apart from krypton-85 and xenon-133. Kr-85 used as the representative radionuclide.

3. Total beta particulate - taken to be all particulates apart from cobalt-60, strontium-90, and ceasium-137. Co-58 used as the representative radionuclide.

Table A1.2: Liquid Discharges used in Initial Radiological Assessment

Radionuclide	Representative 12-Month Plant Discharge (D) (TBq/y)	Calculated Annual Limit (TBq/y)
Tritium	3.51E+01	6.00E+01
Non-tritium	7.70E-03	1.00E-02
Carbon-14	4.42E-03	7.00E-03
Iron-55	6.42E-04	1.00E-03
Cobalt-58	5.44E-04	9.00E-04
Cobalt-60	3.01E-04	5.00E-04
Nickel-63	6.91E-04	1.00E-03
Strontium-90	3.24E-07	5.00E-07
Caesium-137	3.01E-05	5.00E-05
Plutonium-241	1.08E-07	2.00E-07
Other isotopes[1]	1.07E-03	2.00E-03
Total	35.104	60

Note: 1. Other isotopes = Non-tritium isotopes – (C-14+ Fe-55+Co-58+Co-60+Ni-63+Sr-90+Cs-137+Pu-241).

Table A1.3 Estimated Doses from Stage 2 IRA from AP1000 from WEC Representative Annual Atmospheric Radioactive Discharge (effective stack height 22.5 m)*

Radionuclide	Surrogate radionuclide	Local Habitant Dose μSv/y	% Contribution
Tritium	-	1.9E-01	2.51%
Carbon-14	-	7.0E+00	92.21%
Argon-41	-	1.3E-01	1.68%
Other particulate radionuclides (excl. Co-60, Sr-90 & Cs-137)	Co-58	1.3E-04	0.00%
Cobalt-60	-	1.1E-03	0.01%
Other noble gasses (excl. Ar-41 & Xe-133)	Krypton-85	4.7E-03	0.03%
Strontium-90	-	9.6E-05	0.00%
Iodine-131	-	2.6E-01	3.40%
Other radio-iodides	I-133	1.5E-02	0.13%
Xenon-133	-	2.8E-03	0.04%
Caesium-137	-	4.1E-04	0.01%
Total dose		**7.6 μSv/y**	

Table A1.4 Estimated Doses from Stage 2 IRA from AP1000 from WEC Annual Limit Atmospheric Radioactive Discharge (effective stack height 22.5 m)*

Radionuclide	Surrogate radionuclide	Local Habitant Dose μSv /y	% Contribution
Tritium	-	3.1E-01	2.58%
Carbon-14	-	1.1E+01	92.42%
Argon-41	-	1.9E-01	1.62%
Other particulate radionuclides (excl. Co-60, Sr-90 & Cs-137)	Co-58	2.1E-04	0.00%
Cobalt-60	-	1.8E-03	0.01%
Other noble gasses (excl. Ar-41 & Xe-133)	Krypton-85	7.8E-03	0.03%
Strontium-90	-	1.5E-04	0.00%
Iodine-131	-	3.7E-01	3.15%
Other radio-iodides	I-133	2.5E-02	0.15%
Xenon-133	-	4.2E-03	0.04%
Caesium-137	-	6.2E-04	0.01%
Total dose		**12 μSv/y**	

* Scaling factors: 0.03 (inhalation and external dose); 0.3 (food).

Table A1.5 Estimated Doses from Stage 2 IRA from AP1000 from WEC Representative Annual Liquid Radioactive Discharge (130 m^3/s volumetric exchange rate)

Radionuclide	Surrogate radionuclide	Fisherman dose µSv/y	% Contribution
Tritium	-	2.4E-02	1.05%
Carbon-14	-	1.6E+00	68.50%
Iron-55	-	1.5E-04	0.01%
Cobalt-58	-	2.9E-02	1.26%
Cobalt-60	-	6.5E-01	28.40%
Nickel-63	-	1.9E-03	0.08%
Strontium-90	-	1.5E-06	0.00%
Caesium-137	-	3.5E-03	0.15%
Other radionuclides	Cerium-144	1.2E-02	0.54%
Total dose		**2.3 µSv/y**	

Table A1.6 Estimated Doses from Stage 2 IRA from AP1000 from WEC Representative Annual Liquid Radioactive Discharge (130 m^3/s volumetric exchange rate)

Radionuclide	Surrogate radionuclide	Fisherman dose µSv/y	% Contribution
Tritium	-	4.1E-02	1.12%
Carbon-14	-	2.5E+00	67.41%
Iron-55	-	2.3E-04	0.01%
Cobalt-58	-	4.8E-02	1.30%
Cobalt-60	-	1.1E+00	29.31%
Nickel-63	-	2.8E-03	0.08%
Strontium-90	-	2.3E-06	0.00%
Caesium-137	-	5.8E-03	0.16%
Other radionuclides	Cerium-144	2.3E-02	0.63%
Total dose		**3.7 µSv/y**	

Table A1.7 Verification of Dispersion Modelling for Short Term Dose Assessment

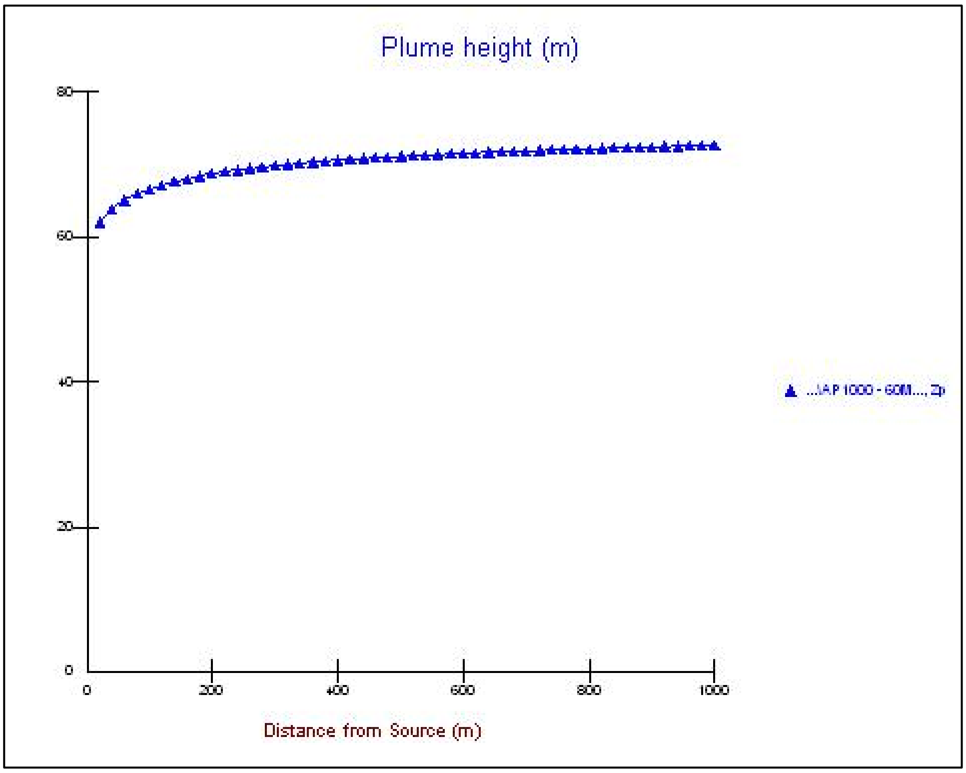
Criteria	RP (WEC Approach)	This work	Comment
Model used	ADMS 4.1	ADMS 4.1	No comment
Radionuclides modelled using ADMS	H-3 C-14 Ar-41 Co-60 Kr-85 Sr-90 I-131 Xe-133 Cs-137 Other Radioiodoines (as I-133) Other noble gases (as Kr-85) Other particulates (as Co-58)	H-3 C-14 Ar-41 Co-60 Kr-85 Sr-90 I-131 Xe-133 Cs-137 Other Radioiodoines (as I-133) Other noble gases (as Kr-85) Other particulates (as Co-58)	
Dry deposition velocity	Noble gases = 0m/s Iodines = 0.1m/s All other radionuclide's = 0.001m/s	Noble gases = 0m/s Iodines = 0.1m/s All other radionuclide's = 0.001m/s	No comment
Wet deposition	Calculated using washout co-efficient of $0.0001s^{-1}$	Calculated using washout co-efficient of $0.0001s^{-1}$	No comment
Meteorology	Wind from 270º and wind speed 3m/s, 800m boundary layer height	Wind from 270º and wind speed 3m/s, 800m boundary layer height, reciprocal of the monin-obukhov length 0m	Other parameters defining neutral conditions (heat flux, cloud cover or reciprocal of the monin-obukhov length) not recorded
Surface roughness	0.3m	0.3m	No comment
Stack location	0,0	0,0	No comment
Receptor locations	100m (100, 0) and 500m (500, 0) downwind	100m (100, 0) and 500m (500, 0) downwind	No comment

Criteria	RP (WEC Approach)	This work	Comment
Temperature	15º C	15º C	No comment
Stack emission parameters (elevated release)	height = 60m diameter = 1m volumetric flow = $0m^3/s$ efflux velocity = 0m/s	height = 60m diameter = 1m volumetric flow = $0m^3/s$ efflux velocity = 0m/s	RP used a release height of 60m. This is based on a physical stack height of 55.7m plus a calculated plume rise of 6.7m = 62.4m. The emission height of 62.4m was rounded down to 60m. Emission parameters to set to assume a zero plume rise (e.g. 0 m/s efflux velocity and 0 m^3/s volumetric flow) by RP. This effectively lead to separate calculation of plume rise; (stack height equivalent to the physical stack plus plume rise; modelling the emissions assuming there is no plume rise). Assuming a zero plume rise will increase the ground level air concentrations for the following reasons: - Plume rise varies with distance from the source due to velocity and temperature (see Figure A1.1). The value used by the RP is likely to represent the plume rise immediately downwind of the source and assumes that this remains constant. This leads to less plume rise than allowing the ADMS plume rise module to the ADMS value and would lead to higher predicted concentrations - Assuming a zero volumetric flow does not allow for initial dilution of the stack gases. This would lead to higher predicted concentrations than modelling the actual volumetric flow of stack gases. - Although a plume rise of 6.7m was calculated, the RP used a value of 4.3m. This would lead to higher predicted concentrations than using the calculated value. The RP rounded the stack height down to 60m for consistency with the long term assessment approach.
Gamma dose (elevated release)	Modelled using the ADMS Gamma Dose module without building at a stack height of 22.5m	Modelled using the ADMS Gamma Dose module without building at a stack height of 22.5m	ADMS cannot calculate gamma dose with the buildings module on - an equivalent stack height without a building was determined by the RP which resulted in similar concentrations than the with building scenario). No further comment
Building	H 70m, L 43m, W 43m	H 70m, L 43m, W 43m	No comment
Building location	upwind of stack	upwind of stack	No comment

Table A1.8: Highest Collective Doses for Representative Discharges from AP1000 (WEC Assessment)

		UK	Europe	World
Collective dose (manSv)	Atmospheric Discharges	0.27	2.1	13
	Liquid Discharges	0.0012	0.0046	0.055
	Total	0.27	2.1	13.1

Figure A1.1: Calculated plume centreline for a 55.7m stack using the Enviros emissions parameters



Appendix 2 – Review of assessment of Westinghouse AP1000 design; assessment approach and summary of key independent parameters

A2.1 Following the initial radiological assessment (the results of which are presented in Appendix 1), the next stage of this work was to undertake a detailed critical review of the approach and parameters used in the assessments presented for consideration by WEC [Ref. A2.1]. This review was undertaken using matrices for each assessment process. The criteria and approaches used were compared with the latest regulatory and advisory body guidance. Supporting notes and comments and decisions regarding the approaches to be adopted during the subsequent independent assessment outlined in this report are noted in Tables A2.1 to A2.7 and key points noted below.

A2.2 This work has not assessed the validity of expected annual discharges provided by WEC.

Review Findings

A2.3 The review of the assumptions and data used by WEC was carried out against previous assessments and advisory body guidance. The WEC approach primarily involved the use of the Environment Agency's initial radiological assessment [Ref. A2.2]. The assumptions and parameters used to derive the dose per unit discharge values, on which this approach is based, are necessarily conservative. For example, assumptions made in the combination of habits are generally pessimistic. By adopting a generic approach it is possible to be more realistic in some key areas.

A2.4 The following difference in key input data between the WEC initial and the independent more detailed assessment has also been identified:

- The initial assessment approach is based on an atmospheric stability category of 50% D. On the coasts of England and Wales the stability category varies from 55% D to 80% D. Category of 60% D was used a the most representative value for the potential coastal sites.

A2.5 The location of the candidate representative person from atmospheric releases (100 m from release) and the origin of terrestrial foods (500 m) applied in Reference A2.2 and the WEC initial assessment. The same general approach was also applied for the independent assessment, although green and root vegetables and domestic fruit were assumed to be derived from 100 m.

A2.6 All terrestrial foods are assumed to be locally derived and consumed at high rates in the derivation of the Dose per unit Release (DPUR) values in Reference A2.2, modified by a factor to allow for a 22.5 m effective stack height were used by WEC [Ref. A2.1]. For the independent assessment, habit data for the candidate representative person from atmospheric pathways were based on the 'top two' approach, in which the two terrestrial foods giving rise to the highest doses are assumed to be consumed at high rates while other foods are consumed at average rates.

A2.7 For the assessment of marine discharges, the relevant DPUR values from Reference A2.2 were applied in the WEC assessment, based on a volumetric exchange rate of 130 m^3/s. For the purposes of the independent assessment, the marine compartment characteristics for the potential coastal site with the lowest volumetric exchange rate have been applied. The independent assessment also includes the following additional minor pathways: inhalation of seaspray, external exposure from handling fishing nets, and inadvertent ingestion of sediment and seawater during leisure activities.

A2.8 In the WEC assessment, the direct radiation dose was calculated on the basis of the dose rates measured in the vicinity of Sizewell B in 2007 (of 4 μSv/y). The same value has been applied for the purpose of the independent assessment.

A2.9 WEC also undertook an assessment of short duration releases to atmosphere [Ref. A2.1]. This made use of the ADMS model code for dispersion [Ref. A2.3]. The discharge assessment could not be verified completely. A key matter in the assessment of impacts from short-term releases that remains to be resolved is the application of a stack height of 60 m, when there is an adjacent building of 70 m. The lower relative height of the stack to the adjacent building is contrary to established practice. Further, the assumptions regarding any potential releases from the Condenser Air Removal Stack warrant further consideration. Cloud gamma doses were modelled using ADMS and an equivalent stack height of 22.5 m, while the independent assessment was based on FGR12 [Ref. A2.4] to assess gamma dose rates from the cloud and deposited material.

A2.10 PC CREAM 98 [A2.5] has been used to assess collective doses in the WEC and independent assessments. The basis for these assessments were similar (to the UK, European and World populations, truncated at 500 years), and in accordance with guidance from UK regulatory and advisory bodies [Ref. A2.6]. For both assessment, the range of collective doses from atmospheric and liquid discharges were assessed for the range of potential sites. The assumptions on effective stack height and stability categories were consistent with those used for the individual assessments and were therefore the same for the WEC and independent assessment, as outlined above. For marine discharges, the marine compartment characteristics of each potential site were implicitly applied.

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Table A2.1: Summary and Review of WEC Approach for Assessment of Individual Dose - Discharges to Atmosphere

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
Discharges	Discharge assumptions	Discharges grouped as follows: tritium (tritiated water); C-14; Ar-41; Xe-133; All other noble gases (Kr-85); I-131 All other iodines (I-133); C0-60; Sr-90; Cs-137; All other radionuclides (Co-58).	Based on DPUR values from Environment Agency Initial Assessment Methodology [Ref. A2.2]; 50th year discharge.	**The same list of radionuclides as those used by WEC used for the inital assessment. The full list of radionuclides was applied in the more detailed assessment, in line with the data in Reference A2.1.**
	Release Points	Main vent (88% discharge): 60 m Turbine vent (12%): 40 m An effective stack height of 22.5 m was used for the assessment. Discharges were modelled as being released from a single stack for the purpose of the assessment.	Assumed data for dose assessments indicates that stack height 55.7 m with plume rise 6.7 m, nearby building height 70 m. 22.5 m has been used as effective stack height. This stack height takes account of the building wake effects of a nearby building of 70 m height. According to guidance from the Working Group Atmospheric Dispersion, an effective stack height of 1/3rd of the building may be applied [A2. 8].	**Following discussion of Environment Agency Guidance for Environmental Permitting (H1 Guidance) [Ref A2.7] the effective height for a release would be 0 m where the height of a stack is less than the height of any nearby building. It was agreed with the Environment Agency that 1/3 physical stack height be used [Ref A2. 8].**
	Incineration release	No incineration		**Capability included in spreadsheet**
Receptor Points and pathways	Representative person Habits	Habitation	Locations and habits – as defined by the DPUR in the Environment Agency Initial Assessment Methodology [Ref A2.2]. Habitation 100 m (in effluent plume). From generic site characteristics; nearest	**Environment Agency requested that habitation be assumed at 100 m and agricultural food production at 500 m, in line with initial assessment methodology [Ref A2.2].**

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
			habitation at 80 m (closest of 5 representative sites); 50 and 100 m isolated properties and farms within 1 and 2 km respectively (also most restrictive of representative sites).	
		Food origin	Terrestrial foods derived from 500 m from plume; DPUR approach; all local origin and all consumed at critical rates.	**Agricultural production location 500 m. Green and root vegetables and fruit from 100 m other foods from 500 m.**
Exposure Pathways	Internal and external exposure	External	External dose from cloud immersion and ground deposition at habitation (100 m).	**Similar approach**
		Inhalation	DPUR values from Environment Agency Initial Assessment methodology [Ref A2.2] applied for 'local resident family'. Based on inhalation of activity in the plume at 100 m; indoor and outdoor air concentrations assumed to be equal.	**Similar approach**
		Ingestion	Terrestrial foods originating from 500 m from discharge.	**Similar approach for agricultural products; vegetables and domestic fruits derived from 100 m.**
Modelling of Environmental Concentrations	Meteorology	50% Pasquill Stability Category assumed	Alternative assumptions may lead to higher doses to the candidate representative person.	**Environment Agency requested that most conservative coastal atmospheric case of 55-60% Category D.**
	Deposition	Dry deposition velocity: 0.001 m/s with the exception of inorganic forms of iodine (0.01 m/s); zero m/s for noble gases (no deposition). Deposition of H-3 and C-14 based on specific activity approach	Standard assumptions.	**Same approach**
	Surface	0.3 m	Corresponds to rural	**Same approach**

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
	roughness		environment.	
	Terrestrial food concentrations	FARMLAND used to derive activity concentrations in foods integrated over 50-year interval for unit deposition rate (Bq/kg per Bq m^{-2} s^{-1})	C-14: assuming specific activity in food equal to that in atmosphere (1.5 E-04 kg/m^3); H-3 activity in foods based on atmospheric water vapour concentration (8 E-03 kg/m^3). Values consistent with those derived from PC CREAM/FARMLAND [Ref A2.5].	**Similar approach**
Habits Data	Occupancy	At location	100% occupancy at the habitation.	**Similar approach**
		Indoor/outdoor	Fraction of time indoors: 0.9 (infant), 0.8 (child), 0.5 (adult).	**Similar approach**
	Inhalation	Reference A79 inhalation rates used	0.22, 0.64 and 0.92 m^3/h for infants, children and adults respectively. Consistent with Reference A2.9.	**Similar approach**
	Ingestion	Terrestrial foods	Technical reports on generic site and information for dose assessment – habits data consistent with Reference A2.9. All foods of local origin and all consumed at critical rates.	**Environment Agency confirmed use of top 2 approach using ingestion rates from Reference A2.9, with exclusion of grain and milk products.**
Dose to Terrestrial Candidate Representative person	External dose coefficients	Cloud emersion from Reference A2.4	Source consistent with that used for external dose rate factors in Reference A2.4 and Ref A2.2.	**Similar source of dose coefficients; Environment Agency noted preference for use of data from Reference A2.4.** **Standard location factor of 0.2 applied.**
		External dose from deposit	GRANIS [Ref. A2.5] – dose rates above wet generic soil (5 compartments to depth of 1 m). This approach includes full decay chains and daughters.	**Environment Agency noted preference for use of Reference A2.4. Standard location factors used**

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
	Internal dose per unit intake values	**Derived from Reference A2.11 or Reference A2.12**	**Data for all radionuclides available.**	**Environment Agency confirmed that standard values from Reference A2.11 or Ref A2.12 are appropriate.**

Table A2.2: Summary and Review of WEC Approach for Assessment of Individual Dose – Liquid Discharges to the Marine Environment

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
Local Compartment Characteristics		Based on initial radiological assessment approach [Ref.A2.2 method]	Parameters provided p. 162 (Table E3) in Part 2 of the methodology report [Ref. A2.2]. NB various assumptions were used in scoping the Ref A2.2 approach. The volumetric exchange rate has the greatest effect on subsequent dose.	**The characteristics of the local marine box with the lowest volumetric exchange rate chosen (North Sea Central).**
Discharges	Discharge assumptions	Stage 2: grouped discharges: H-3 (tritiated water); C-14; Fe-55; C0-58; C0-60; Ni-63; Sr-90; Cs-137; Pu-241 all other radionuclides (Ce-144).	Supporting Technical Report on Assumed Data for Dose Assessments [Ref A2.13] provides more detailed breakdown of discharges by radionuclide. The reasoning for the use of Ce-144 to represent the 'other radionuclides' is not clear.	**Independent assessment: the same list of radionuclides used for the initial assessment and the full list of radionuclides discharged used for the detailed assessment.**
	Release point characteristics	Stage 2: 130 m^3/s assumed	Supporting Technical Report on the characteristics of a generic site [Ref. A2.13] indicates that the generic site exchange rate of 130 m^3/s was chosen as the most conservative (lowest) of the 5 coastal nuclear sites considered to be typical of the range of coastal sites in the UK.	**The marine compartment characteristics related to the potential site with the lowest volumetric exchange rate was used.**
Receptor Points and	Representative	DPUR for fisherman	Additional data presented in technical reports on generic	**100% local fish, crustaceans and molluscs**

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
pathways	person Habits	family applied	site and information for dose assessment – habits data consistent with Reference A2.9. DPUR approach based on all pathways at critical rates.	**assumed at Reference A2.9 critical intake rates.**
	Occupancy	Local compartment	100% of beach occupancy assigned to local rather than regional compartment	**Similar approach**
		Beach occupancy– Reference A2.9 rates used	Beach occupancy: 30, 300 and 2000 h/y for infant, child and adult respectively. Consistent with Reference A2.9.	**Similar approach**
	Intakes	Inhalation – Reference A2.7 rates used	Standard inhalation rates used for terrestrial and coastal occupancy (see above).	**Similar approach**
		Ingestion - Reference A2.9 rates used	Standard consumption rates for marine foods assumed;	**Similar approach**
		Sewage workers	Habit data are provided in the technical report on generic site but not used.	**Not included.**
		Children playing in brook	Habit data are provided in the technical report on generic site but not used.	**Not included (although inadvertent ingestion of sediment and seawater during beach occupancy included).**
Exposure Pathways	Internal and external exposure	DPUR approach includes internal and external irradiation pathways	Internal irradiation from consumption of seafood	**Includes same pathways and additional internal doses from seaspray and inadvertent ingestion and external dose from net handling**
			External irradiation from beach occupancy (bait digging).	

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
Modelling of Environmental Concentrations	Water Concentrations	DORIS used to determine activity concentrations in filtered seawater	Initial Radiological Assessment includes up to one progeny and models parent and progeny separately	**Standard DORIS output used directly.**
	Sediment Concentrations		Partitioning based on coastal sediment partition coefficients Beach sediment assumed to consist of top seabed sediment layer with depth 0.1 m.	**Partition coefficients from the EA Initial Radiological Assessment Methodology**
	Marine Food concentrations	Molluscs and crustaceans derived from local compartment; fish 50% local and 50% regional compartment	Based on concentration in filtered seawater and Concentration Factor (CF) for seafood in question. CF values are derived from Reference A2.15 or Reference A2.10, where data not available in the Reference A2.16 is the most recent source currently available.	**100% from local compartment assumed**
Dose to Marine Candidate Representative person	Dose Calculations	**Dose Coefficients for external exposure to sediment based on Reference A2.4.**	**Data for soil of depth 0.15 m applied and converted from volume to per unit mass by using soil density of 1,600 kg/m^3.** **External dose factors include decay and ingrowth of progeny – assumed to be in secular equilibrium with parent to derive dose rates [Ref. A2.2]**	**Dose coefficients taken from Reference A 2.4 for infinite depth, modified for a factor of 2 to allow deviation from semi-infinite source**

Table A2.3: Summary and Review of WEC Approach for Assessment of Individual Dose – Direct Dose Assessment

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
		Assumed to be comparable with closest comparable design in UK: Sizewell B PWR. **Measured dose of 4 μSv/y from 2007 used.**	**Applied value is appropriate.**	**Environment Agency agreed use of most recent or averaged data for Sizewell B.**

Table A2.4: Summary and Review of WEC Approach for Assessment of Individual Dose – Short-term Releases

Section	Criteria	RP (WEC Approach)	Comments on the WEC Approach	Independent Approach
General approach	Discharges	Gaseous atmospheric discharges assessed only for the radionuclide groups defined for annual discharge. No short-term liquid discharges considered on basis that the discharge tanks cannot release a month's liquid discharge over a period of a few hours. Also, as the discharges are some distance from the near shore, the travel times to exposure locations are much longer than short term atmospheric discharges	Liquid discharges assessed using continuous method (see Table A2.2). Approach reasonable. Consultation with HPA indicated that potential for significantly non-homogeneous impacts from liquid discharges less than for atmospheric	**Same approach used for independent assessment.**
	Radionuclide's	Same as for the long term assessment	No comment on overall approach	**Same approach applied for independent assessment.**
	Methodology	Based on NRPB-W54 [Ref A2.17]. Modelling using ADMS 4 [Ref. A2.2]	Suitable methodology for assessing short term discharges to atmosphere	**NRPB-W54 method applied where possible for independent assessment**
Dispersion modelling of environmental concentrations	Stack height	See Table A1.9 for details of the WEC approach	See Table A1.9 for detailed comments on the WEC approach It is not clear if there are any short term emissions from the Condenser Air Removal Stack. If there is likely to be short term releases, we would recommend that this source is specifically included in the short term modelling.	**Independent assessment utilised a stack height of 55.7m and assumed all short term releases from this emission point (i.e. all short term emissions from the Main Plant Vent). Common practice for industrial installations is that the stack should be higher than any nearby buildings to reduce building wake effects and protect on-site personnel working at ground level. For this assessment, we would normally recommend**

Section	Criteria	RP (WEC Approach)	Comments on the WEC Approach	Independent Approach
				a stack slightly higher than the 70m reactor building it is adjacent to (i.e. approximately 73m). However, as this is markedly different from the proposed stack height, the independent assessment used the physical stack height of 55.7m
	Stack diameter	See Table A1.9 for details of the WEC approach	See Table A1.9 for detailed comments on the WEC approach	**2.025 x 2.311m rectangular stack modelled as circular stack of 2.44m diameter**
	Stack location in relation to building	Stack assumed to be adjacent to building (building upwind and downwind of the stack modelled to determine worst case). Highest values used for the assessment	Suitable approach to determine worst case. Stack downwind of the building provided the highest results for WEC (Enviros predicted highest results for the stack upwind of the building) in the independent assessment	**Same overall approach used for independent assessment (stack upwind of building location).**
	Building dimensions	L=43 m W=43 m H =70 m	No comment	**Same data applied for independent assessment**
	Volumetric flow rate	See Table A1.9 for details of the WEC approach	See Table A1.9 for detailed comments on the WEC approach	**Volumetric flow of 38.13 m^3/s used for independent assessment**
	Exit velocity	See Table A1.9 for details of the WEC approach	See Table A1.9 for detailed comments on the WEC approach	**Efflux velocity of 8.2 m/s used for independent assessment**
	Emission rates	Assessment based on maximum monthly discharge occurring over a 30 minute period	30-minute period is within the range of short-term release scenarios presented in NRPB-W54 (30 minutes – 12 hours). Assumption that monthly discharge occurs in a period of 30 minutes is conservative. It is not clear what averaging time was used in ADMS – it is assumed that as the release occurs over 30 minutes, the averaging	**Similar approach used for independent assessment.**

Section	Criteria	RP (WEC Approach)	Comments on the WEC Approach	Independent Approach
			time was set to 30 minutes	
	Stability	Stability category D, boundary layer depth 800m See Table A1.9 for details of the WEC approach	Use of neutral stability follows approach in NRPB-W54 [Ref. A2.17] See Table A1.9 for detailed comments on the WEC approach	**Same approach applied for independent assessment. Boundary layer height of 800m and reciprocal of the monin-obukhov length of $0m^{-1}$ as per the approach in NRPB-W54**
	Wind speed	Wind speed of 3 m/s	Within the range of wind speeds listed in NRPB-W54 (3 – 5m/s). 3 m/s corresponds to Realistically Cautious Case [Ref.A2.17]	**Same data applied for independent assessment**
	Wind direction	Towards receptors	Consistent with NRPB-W54 [Ref. A2.17] Suitable approach	**Same data applied for independent assessment**
	Rainfall	See Table A1.9 for details of the WEC approach	Washout co-efficient of $0.0001s^{-1}$ is equivalent to a rainfall rate of 1mm/hour which is higher than the range of rainfall rates specified in NRPB-W54 (0.1 – 0.6mm/hour) [Ref. A2.17] 0.1 mm/hour is specified in NRPB-W54 for the Realistically Cautious Case [Ref. A2.17]	**Rainfall rate of 0.1 mm/hr utilised for independent assessment. Washout co-efficient calculated using rainfall rate and default ADMS parameters A and B as per the approach in NRPB-W54 [Ref. A2.17].**
	Surface roughness	Surface roughness of 0.3m	Appropriate value for rural location	**Same data applied for independent assessment**
	Deposition method	Dry and wet deposition modelled simultaneously and not independently using ADMS	Approach suitable	**Same approach applied for independent assessment**
	Deposition parameters	See Table A1.9 for details of the WEC approach	Approach suitable	**Same dry deposition velocities utilised for independent assessment** **Wet deposition: Calculated using ADMS default washout coefficients A (0.0001) and B (0.64) and using rainfall rate of 0.1mm/hour**

Section	Criteria	RP (WEC Approach)	Comments on the WEC Approach	Independent Approach
	Radioactive decay	Radioactive decay was modelled, although stated in TQ-151 response that did not have significant impact due to short distances/timescales	No comment	**No decay assumed for independent assessment due to relatively short distance and travel times and consistent with NRPB-54 [A2.17]**
	Gamma dose	Modelled explicitly using Gamma Dose module in ADMS	As the buildings module cannot be used simultaneously with the Gamma Dose module, in order to model the Gamma Dose, a stack height of 22.5m was utilised to represent the emissions from a 60m stack with the buildings module turned on. This approach seems reasonable, although no evidence was supplied to support the approach used	**Independent assessment determined Gamma Dose using factors based on air concentrations and deposition values at the receptor locations for the 55.7m stack height with buildings module turned on. Gamma Dose was not specifically modelled using ADMS.**
	Receptors	Receptor at 100m and 500 m downwind from release point	Location consistent with the continuous release assumptions and consistent with initial assessment approach.	**Receptor at 100m and 500m downwind of release point modelled for independent assessment**
Pathways	External dose	From plume and deposited material Period of passage and deposition in year following release	Reasonable approach	**Similar approach**
	Inhalation	For period of plume passage	Reasonable approach	**Similar approach**
	Ingestion of foods	In the year following release	Reasonable approach	**Similar approach**
Environmental Modelling	Food concentrations	FARMLAND (PC CREAM) Used transfer factors per unit time derived from PC CREAM output to derive crop and animal uptake per unit deposition, adjusted for single, instantaneous deposition [A2.22]. C-14 and tritium	Simple pragmatic approach – reasonable initial assumptions	**Similar approach**

Section	Criteria	RP (WEC Approach)	Comments on the WEC Approach	Independent Approach
		crop uptakes based on air concentration.		
Representative person Habits	Occupancy & Location factors	100% at location; Indoor. Occupancy factors derived from NRPB-W54 [Ref. A2.17]	Reasonable approach	**No location factors applied**
	Intakes	Inhalation rates derived from NPRB-W54 [Ref. A2.17]	Reasonable approach	**Generalised factors used**
		Terrestrial food intakes from NPRB-W54 [Ref. A2.16]	Reasonable approach	**Similar approach**
Dose calculation	External (plume)	24 hour exposure	Indoor/outdoor locations used and standard (ADMS) dose coefficients for immersion.	**Dose rate calculations repeated. For independent assessment used dose rate factors for immersion based on FGR 12 [Ref. A2.4]**
	External (deposit)	Year following release	Ground contamination from ADMS, radioactive decay. Occupancy and location factors for indoor and outdoor occupancy taken into account; dose coefficients for deposit	**Dose rate calculations repeated.**
	Dose Coefficients	**From Environment Agency Initial Radiological Assessment [A2.2]**	**Reasonable approach**	**Consistent with the source of coefficients used in the independent assessment**

Table A2.5: Summary and Review of WEC Approach for Assessment of Individual Dose – Total Dose

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
		Total annual doses from representative and annual limit liquid discharges	All doses from annual discharges from atmospheric and liquid discharges added on the basis that it cannot be ruled out that each group will not be exposed to both.	**Marine group plus average terrestrial foods from 100 and 300 m.**
		Annual dose from representative and annual limit atmospheric discharges	Representative person also assumed to be exposed from single short-term release and site fence direct radiation.	**Terrestrial group and average marine occupancy of 2000 hours on beach (for adult).**
		Dose from single short-term atmospheric release.	Likely to be conservative.	
		Direct radiation		

Table A2.6: Summary and Review of WEC Approach for Assessment of Collective Dose – Discharges to Atmosphere

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
Discharges	Discharge assumptions	Grouped as follows: tritium (tritiated water), C-14, Ar-41, Co-60; Sr-90; I-131; Xe-133; Cs-137 other noble gases (Kr-85), other iodines (I-131); other particulates (Co-58)	Ref: Eisenstatt, L, Environment Report, WEC, UKP-GW-GL-790, Revision 2 [Ref. A2.1].	**The same list of radionuclides applied.**
	Release Points	22.5 m effective stack height	Assumed that all discharges from main stack. There is no effect on results since the same effective stack is used for both release points.	**The same effective stack height used**
	Meteorology	50% atmospheric stability category D	Reasonable for coastal site, although other stability category assumptions may lead to higher doses.	**Similar approach**
Receptor Points and pathways	Collective Dose assessment	UK, Europe and World, truncated at 500 y	Population groups and truncation period in accordance with Reference A2.6 Collective dose from global circulation for tritium, C-14 and Kr-85.	**Similar approach**
	Population and agricultural grids	For representative sites	Dependence of calculations on grids requires specific rather than generic site assumptions to be made; representative sites for which calculations undertaken: Dungeness, Hartlepool, Heysham, Hinkley Point, Sizewell.	**Similar approach adopted.**
Interpretation of results		**Maximum, average and minimum values**	**Demonstration of the range of values for 5 sites.**	**The same approach applied**

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
		presented		

Table A2.7: Summary and Review of WEC Approach for Assessment of Collective Dose – Liquid Discharges to the Marine Environment

Section	Criteria	WEC Approach	Comments on WEC Approach	Independent Approach
Discharges	Discharge assumptions	Grouped as follows: tritium (tritiated water); C-14; Fe-55; C0-58; Co-60; Ni-63; Sr-90; Cs-137; Pu-241; other isotopes (Ce-144)	Ref: Technical Report on Assumed Data for Dose Assessments [Ref. A2.13].	**The same list of radionuclides applied.**
Receptor Points and pathways	Collective Dose assessment	DPUR using PC CREAM	Based on PC CREAM sea food catch information	**Similar approach**
Interpretation of results		Maximum, average and minimum values presented	**The range of doses arising from 5 sites presented.**	**Similar approach**

Appendix 3 – Independent radiological assessment of discharges to atmosphere

Introduction

A3.1 The assessment undertaken by Westinghouse Electric Company (WEC) of discharges of radioactive wastes to atmosphere from the AP1000 Generic Design power plant was reviewed in Appendix 1 and 2. This review showed that some key assumptions may not be appropriate to a more detailed radiological assessment.

A3.1 An independent radiological assessment has been made on the basis of the expected annual discharges of the full list of radionuclides presented in the WEC submissions [Ref. A3.1].

A3.2 This work is based on predicted discharges to atmosphere as presented by WEC. The validity of these predictions has not been assessed.

Discharges to Atmosphere

A3.2 The information provided by WEC showed that the main discharges would be made from 2 main release points: the plant vent and the turbine building vent.

A3.3 The radiological assessment has been made on the basis of the predicted discharges of the full list of radionuclides presented in the WEC report [Ref. A3.1] and summarised in Table 1.

A3.4 Details of the atmospheric discharge points on the AP1000 Generic Design power plant are provided in Table A3.1 and predicted levels of activity discharged in Table A3.2. The plant vent is the release point for approaching 90% of the activity discharged to atmosphere, and represents the release path for containment venting, auxiliary building ventilation, annex building releases and radioactive waste building releases. The turbine building vent is the release path for condenser air removal, gland seal condenser exhaust and turbine building ventilation releases. Both stacks are assumed to be located close to a building of 70 m in height. For the purposes of this assessment, both release points have been assessed and the effective stack height of 1/3rd of the building height (23 metres) has been assumed for both release points, in accordance with the approach outlined in NPRB-R157 [Ref. A3.2].

Receptor Points and Candidates for the representative person

A3.5 For the purposes of this assessment, candidates for the representative person affected by atmospheric discharges (CRP1) has been identified to be potential local residents living close to the proposed power plant. Generic habit profiles were developed, on the basis of the Environment Agency Initial Radiological Assessment Methodology [Ref. A3.3] and NRPB-W41 [Ref. A3.4], to represent those likely to be the most exposed individuals to atmospheric discharges from the AP1000 power plant.

A3.6 On the basis of information provided by WEC, the AP1000 power plant has been assumed to be located at a coastal site. It is therefore assumed that commercial fishing is in operation, for fish and shellfish along the coast, where the liquid discharges from the site are made. Fishing families may also receive exposures from atmospheric discharges from locally derived terrestrial foods.

A3.7 The following candidates for the representative person have been identified to reflect the residential, farming and working communities in the area closest to the AP1000 power plant.

- ***CRP1 Local residents.*** For the purposes of this assessment, it is assumed that families (adults, children (10 years) and infants (1 year)) living in the nearest habitation (assumed to be located at approximately 100 m from the discharge point), are exposed to atmospheric discharges, direct radiation and, to a lesser extent, to liquid discharges in the marine environment. It is assumed that members of this family spend most of their time at home, some of which is spent outside. They get their green vegetables, root vegetables and fruit from their garden or other local source (100 m from the discharge point) and milk and meat from local farms close to the site whose livestock graze approximately 500 m from the site. Some local fish and shellfish are also consumed. Generic habit data for this group were derived from NRPB-W41 [Ref. A3.4].

A3.8 Each age group in CRP1 has been assumed to consume 2 terrestrial foods at critical rates, in accordance with the approach recommended guidance from the National Dose Assessment Working Group (NDAWG) [Ref. A3.5], for use where no site-specific information is available. Generic assumptions regarding the proportion of time spent indoors and outdoors were assumed, from NRPB-W41 [Ref. A3.4]; higher than average outdoor occupancy rates for adults and children have been considered appropriate for a farming family.

Exposure Pathways

A3.9 The exposure pathways considered were:

- internal exposure to radionuclides from ingestion of local fruit and vegetable produce (green vegetable and root vegetable), cow and sheep meat and cow milk;
- internal exposure via inhalation of radionuclides from the plume and secondary inhalation of radionuclides deposited on the ground and resuspended; and,
- external doses from exposure to the plume (‘cloudshine’) and beta and gamma radiation from radionuclides deposited on the ground (‘groundshine’).

A3.10 Assessment of exposure to direct radiation from the site was taken into account where appropriate (Appendix 8).

Modelling of Environmental Concentrations

A3.11 Air concentrations and deposition at 100 m (local residence) and 500 m (local farmland) from the site relevant to the assessment of exposure of local terrestrial representative person members have been assessed.

A3.12 The Gaussian plume atmospheric dispersion model, Plume, in PC-CREAM [Ref A3.6] have been used to calculate air activity concentrations (dispersion factors) and ground deposition values for each radionuclide [Table A3.3]. A uniform wind rose has been assumed and the average weather category for the Gaussian plume model has been assumed to be 60% (category D). This category is considered to represent the conditions at potential sites that would be likely to give rise to the highest doses to CRP1.

A3.13 For radionuclides discharged to atmosphere, which deposit on the ground (all radionuclides except tritium and noble gases), a deposition velocity of 0.001 m/s has been used to calculate the deposition rate for use in the calculation of food activity concentrations and external dose rates for all the depositing radionuclides except iodine, where a deposition velocity of 0.01 m/s was used [Ref A3.7]. A washout coefficient of 10^{-4} s^{-1} was used to calculate wet deposition.

A3.14 Concentrations in terrestrial foodstuffs and animal products at the nearest allotments and gardens around residences (100 m) and farmland (500 m) have been predicted from the air concentrations. For all nuclides except tritium and carbon-14 food concentrations have been derived using deposition velocity and food activity concentration per unit deposition rate factors. For tritium and carbon-14, food concentrations have been calculated from food activity concentration per unit air activity concentration factors [Ref A3.7]. The food activity concentration factors are shown in Table A3.4.

Habits Data

A3.15 Doses to candidates for the representative person have been calculated using the predicted environmental concentrations and generic habits data: information concerning food intakes and occupancy of the environment at the nearest habitation and the nearest farm; occupancy at the locations; time spent indoors and outdoors; and, breathing rates. The assessment has used information derived from the Environment Agency's Initial Radiological Assessment Methodology [Ref. A3.3] and NRPB-W41 [Ref. A3.4]. The corresponding adult, child and infant habit data is provided in Table A3.5.

A3.16 Generic breathing rates have been used throughout the assessment, these are presented in Table A3.6 [Ref. A3.4]. It has been assumed that CRP1 spent 90% of their time at their homes, but that the time spent indoors is assumed to vary with age group. Adults have been assumed to spend 50% of their time indoors while children and infants have been assumed to spend 80% and 90% respectively [Ref. 3.4].

A3.17 Generic shielding factors have been used to modify the external dose to take account of time spent indoors. A location factor of 0.1 was used for shielding from material deposited in the ground [Ref A3.7]. A shielding factor of 0.2 was used for shielding of external radiation from material in the plume [Ref A3.7].

Doses to the Terrestrial Candidates for the Representative person

A3.18 The generic habits data which were chosen were considered to considered to provide a conservative estimate of doses to candidates for representative person for gaseous releases (CRP1) from the AP1000 power plant.

A3.19 Doses to infant, child and adult candidates for the representative person have been calculated using assessment spreadsheets customised for the AP1000 power plant.

A3.20 For internal exposure, inhalation and ingestion dose coefficients [Table A3.7] from the Euratom Basic Safety Standards Directive [Ref A3.8] and the predicted concentrations of radionuclides in the environment and foods have been used. For external exposure cloudshine and groundshine factors have been used and were derived from the updated version of FGR-12 [Ref A3.9] available on the US EPA web site (Table A3.8).

A3.21 The doses associated with the discharges predicted by WEC [Ref. A3.1] have been calculated from the dose per unit release data and the source term for each stack modelled for each radionuclide using generic habits data.

A3.22 The doses from atmospheric discharges from the AP1000 power plant based predicted discharges, plus the contribution to dose from predicted marine discharges (see Appendix 4), are shown in Table A3.9. The doses to all the terrestrial candidate for the representative person from discharges have been found to be less than 5 μSv/y.

A3.23 A breakdown of the representative person dose arising from the AP1000 power plant for the infant CRP1, at the predicted discharges by radionuclide and pathway is provided in Table A3.10.

A3.24 The dose from aerial discharges from the AP1000 power plant accounts for over 99% of the dose to the terrestrial representative person from discharges (aerial and marine).

References

A3.1 Eisenstatt, L, Environment Report, WEC, UKP-GW-GL-790 Revision 3 April 2010.

A3.2 Jones, J A, The Fifth Report of the Working Group on Atmospheric Dispersion: Models to Allow for the Effects of Coastal Sites, Plume Rise and Buildings on Dispersion of Radionuclides and Guidance on the Value of Deposition Velocity and Washout Coefficients, , NRPB-R157, NRPB, Chilton, 1983.

A3.3 Environment Agency, Initial Radiological Assessment Methodology (Parts 1 and 2), Science Report SC030162/SR1 (2006)

A3.4 Smith, K R and Jones A L, Generalised Habit Data for Radiological Assessments, NRPB-W41, NRPB, Chilton (2003).

A3.5 NDAWG, Acquisition and Use of Habits Data for Prospective Assessments, NDAWG/2/2009, http://www.ndawg.org/NDAWGpapers.htm

A3.6 Mayall A, Cabianca T, Attwood C, Fayers CA, Smith JG, Penfold J, Steadman D, Martin G, Morris TP and Simmonds JR. PC CREAM-97 (PC CREAM-98 code update) NRPB, Chilton NRPB-SR-296 (EUR 17791) (1997).

A3.7 European Commission (1995). Methodology for Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment. Radiation Protection 72. EUR 15760 EN.

A3.8 Council Directive 96/29 Euratom of 13 May 1996, Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionising Radiation. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

A3.9 EPA (1993). External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report No. 12, EPA-402-R-93-081(Oak Ridge National Laboratory, Oak Ridge, TN; U.S. Environmental Protection Agency, Washington, DC).

Table A3.1 Atmospheric Discharge Points from the AP1000 Power plant

Stack Name	Discharge Position	Effective Discharge Height (metres)
Main Plant Stack (Stack 1)	Reactor Building	23
Condenser Air Removal Stack (Stack 2)	Turbine Hall	23

Table A3.2 Predicted Discharges used in the Assessment for Aerial Discharges to Atmosphere

Radionuclide	Predicted Atmospheric Discharges (TBq/y)	
	Reactor Building (Stack 1)	Turbine Hall (Stack 2)
Ar-41	1.30E+00	-
Ba-140	1.50E-07	-
C-14	6.06E-01	-
Co-58	8.60E-06	-
Co-60	3.20E-06	-
Cr-51	1.90E-07	-
Cs-134	8.30E-07	-
Cs-137	1.30E-06	-
H-3	1.80E+00	-
I-131	2.10E-04	3.40E-06
I-133	3.50E-04	3.70E-06
Kr-85	3.10E+00	2.60E-02
Kr-85m	1.70E-02	7.80E-03
Kr-87	1.70E-02	2.20E-03
Kr-88	1.80E-02	8.50E-03
Mn-54	1.10E-07	-
Nb-95	8.90E-07	-
Sr-89	1.10E-06	-
Sr-90	4.10E-07	-
Xe-131m	1.30E+00	8.10E-02
Xe-133	9.60E-01	2.90E-01
Xe-133m	8.10E-02	3.50E-02
Xe-135	1.70E-01	2.60E-01
Xe-135m	1.30E-01	5.90E-02
Xe-137	3.40E-02	1.60E-02
Xe-138	5.90E-02	2.90E-02
Zr-95	3.70E-07	-

Table A3.3 Air Concentration Factors and Ground Deposition

Discharge Point	Nuclide	Air concentration Bq/m3 per TBq/y		Resuspended Air conc at home Bq s/m3 per Bq/m2/s for 1y	Ground deposition Bq/m2/s per TBq/y	
		at home	at farm		at home	at farm
Stack 1	Ar-41*	3.81E-02	2.95E-02			
	Ba-140	3.81E-02	2.98E-02	7.81E+06	5.71E-05	4.12E-05
	C-14	3.81E-02	2.98E-02			
	Co-58	3.81E-02	2.98E-02	1.33E+07	5.71E-05	4.12E-05
	Co-60	3.81E-02	2.98E-02	2.40E+07	5.71E-05	4.12E-05
	Cr-51	3.81E-02	2.98E-02	1.03E+07	5.71E-05	4.12E-05
	Cs-134	3.81E-02	2.98E-02	2.10E+07	5.71E-05	4.12E-05
	Cs-137	3.81E-02	2.98E-02	2.92E+07	5.71E-05	4.12E-05
	H-3	3.81E-02	2.98E-02			
	I-131	3.81E-02	2.95E-02	6.40E+06	3.81E-04	3.08E-04
	I-133	3.81E-02	2.95E-02	1.02E+06	3.81E-04	3.08E-04
	Kr-85*	3.81E-02	2.98E-02			
	Kr-85m*	3.81E-02	2.98E-02			
	Kr-87*	3.81E-02	2.95E-02			
	Kr-88*	3.81E-02	2.98E-02			
	Mn-54	3.81E-02	2.98E-02	1.81E+07	5.71E-05	4.12E-05
	Nb-95	3.81E-02	2.98E-02	1.10E+07	5.71E-05	4.12E-05
	Sr-89	3.81E-02	2.98E-02	1.22E+07	5.71E-05	4.12E-05
	Sr-90	3.81E-02	2.98E-02	2.91E+07	5.71E-05	4.12E-05
	Xe-131m*	3.81E-02	2.98E-02			
	Xe-133*	3.81E-02	2.98E-02			
	Xe-133m*	3.81E-02	2.98E-02			
	Xe-135*	3.81E-02	2.98E-02			
	Xe-135m*	3.49E-02	2.76E-02			
	Xe-137*	3.04E-02	2.22E-02			
	Xe-138*	3.49E-02	2.76E-02			
	Zr-95*	3.81E-02	2.98E-02	1.29E+07	5.71E-05	4.12E-05
Stack 2	I-131	3.81E-02	2.95E-02	6.40E+06	3.81E-04	3.08E-04
	I-133	3.81E-02	2.95E-02	1.02E+06	3.81E-04	3.08E-04
	Kr-85*	3.81E-02	2.98E-02			
	Kr-85m*	3.81E-02	2.98E-02			
	Kr-87*	3.81E-02	2.95E-02			
	Kr-88*	3.81E-02	2.98E-02			
	Xe-131m*	3.81E-02	2.98E-02			
	Xe-133*	3.81E-02	2.98E-02			
	Xe-133m*	3.81E-02	2.98E-02			
	Xe-135*	3.81E-02	2.98E-02			
	Xe-135m*	3.49E-02	2.76E-02			
	Xe-137*	3.04E-02	2.22E-02			
	Xe-138*	3.49E-02	2.76E-02			

* Noble gases where no deposition to ground occurs

Table A3.4 Terrestrial Food Concentration Factors

Radionuclide	Activity Concentrations in Food per Unit Deposition Rate (Bq/kg per Bq/m^2/s per year)							
	Green Veg	Root Veg	Fruit	Milk	Cow Meat	Cow Offal	Sheep Meat	Sheep Offal
Ba-140	5.08E+04	2.06E+01	9.84E+03	8.64E+03	2.15E+03	2.40E+03	3.77E+03	3.78E+03
C-14	2.67E+02	5.33E+02	5.33E+02	2.67E+02	8.00E+02	8.00E+02	8.00E+02	8.00E+02
Co-58	9.15E+04	2.56E+02	1.59E+04	5.12E+04	6.80E+03	6.93E+05	1.16E+04	1.16E+06
Co-60	1.15E+05	5.12E+03	2.13E+04	7.08E+04	2.92E+04	2.92E+06	4.34E+04	4.35E+06
Cr-51	6.97E+04	2.14E+00	6.56E+03	4.36E+04	4.71E+04	4.95E+04	8.46E+04	8.47E+04
Cs-134	1.31E+05	1.19E+05	7.24E+04	1.59E+05	7.92E+05	7.93E+05	1.54E+06	1.54E+06
Cs-137	1.45E+05	1.36E+05	7.53E+04	1.79E+05	9.14E+05	9.14E+05	1.91E+06	1.91E+06
H-3	1.13E+02	1.00E+02	1.00E+02	1.13E+02	8.75E+01	8.75E+01	8.75E+01	8.75E+01
I-131	4.13E+04	8.64E+03	3.10E+04	5.82E+04	2.08E+04	2.47E+04	3.17E+04	3.17E+04
I-133	6.19E+03	4.68E+01	5.35E+03	3.79E+03	2.24E+02	1.11E+03	6.79E+02	6.79E+02
Nb-95	7.76E+04	1.30E+02	1.40E+04	2.31E+02	5.32E+01	5.52E+01	9.29E+01	9.32E+01
Sr-89	8.93E+04	7.04E+02	1.51E+04	1.97E+04	3.89E+03	4.00E+03	5.68E+03	5.68E+03
Sr-90	6.22E+05	8.84E+04	1.30E+05	1.39E+05	2.98E+04	2.98E+04	2.24E+04	2.24E+04
Zr-95	8.97E+04	7.60E+01	1.57E+04	2.50E+02	2.18E+02	2.24E+02	4.26E+02	4.25E+02

[a] Values for tritium and carbon-14 are quoted in Bq/kg per Bq/m^3.

Table A3.5 Habits Data Profiles for CRP1*

Age Group	Profile Number	Profile Name	Consumption (kg/y or l/y)											Handling and Occupancy (h/y)			
			Green veg consumption	Potatoes & root veg	Domestic Fruit	Milk	Cattle Meat	Cow Offal	Sheep Meat	Sheep Offal	Sea Fish	Crustacea	Mollusca	Handling Fishing Gear	Over intertidal mud[a]	Internal occupancy	External occupancy
Adult	*1*	*All critical*	*80.0*	*130.0*	*75.0*	*240.0*	*45.0*	*10.0*	*25.0*	*10.0*					*300*	*4080*	*4380*
	2	*All average*	*35.0*	*60.0*	*20.0*	*95.0*	*15.0*	*2.8*	*8.0*	*2.8*	*15.0*	*1.8*	*1.8*	*300*	*300*	*4080*	*4380*
	3	**Top two approach**	**35.0**	**130.0**	**20.0**	**240.0**	**15.0**	**2.8**	**8.0**	**2.8**	9.5	0.3	0.3	300	300	4080	4380
10 y Child	*1*	*All critical*	*35.0*	*95.0*	*50.0*	*240.0*	*30.0*	*5.0*	*10.0*	*5.0*					*300*	*7008*	*1752*
	2	*All average*	*15.0*	*50.0*	*15.0*	*110.0*	*15.0*	*1.5*	*4.0*	*1.5*	*6.0*	*1.3*	*1.3*		*300*	*7008*	*1752*
	3	**Top two approach**	**15.0**	**95.0**	**15.0**	**240.0**	**15.0**	**1.5**	**4.0**	**1.5**	4.0	0.1	0.1		300	7008	1752
1y infant	*1*	*All critical*	*15.0*	*45.0*	*35.0*	*320.0*	*10.0*	*2.8*	*3.0*	*2.8*					*30*	*7008*	*1752*
	2	*All average*	*5.0*	*15.0*	*9.0*	*130.0*	*3.0*	*0.5*	*0.8*	*0.5*	*3.5*	*0.0*	*0.0*		*30*	*7008*	*1752*
	3	**Top two approach**	**5.0**	**15.0**	**9.0**	**320.0**	**3.0**	**0.5**	**0.8**	**0.5**	2.0	0.0	0.0		30	7008	1752

[a] – Time spent over intertidal areas was summed together to give a total occupancy over intertidal areas. It is number that is used in the assessment

* The values in italics are included in the assessment spreadsheet for calculation purposes only. These values are included in this table for completeness and ease of reference; they do not represent candidate representative person profiles.

Table A3.6 Other Habit Data for Candidates for the Representative Person

Factor	Representative person independent factors			
	Adult	Child	Infant	Units
Breathing rate per y	8100	5600	1900	m3/y
Breathing rate per h	0.92466	0.639	0.217	m3/h
default fraction of time indoors	0.5	0.8	0.9	-
Default Occupancy	1	1	1	-
Inadvertent ingestion of seawater	0.5	0.5	0.2	l/y
Inadvertent ingestion of sediment	8.30E-03	0.018	0.044	kg/y
Default beach occupancy	300	300	30	h/y

Table A3.7 Internal Committed Dose Rate Factors for Expose via Inhalation and Ingestion

Radionuclide	ICRP Lung Class			Inhalation Sv/Bq			Ingestion (Sv/Bq)		
	A	C	I	A	C	I	A	C	I
Ba-140	M			5.10E-09	7.60E-09	2.00E-08	2.60E-09	5.80E-09	1.80E-08
C-14	V			2.00E-09	2.80E-09	6.60E-09	5.80E-10	8.00E-10	1.60E-09
Co-58	M			1.60E-09	2.40E-09	6.50E-09	7.40E-10	1.70E-09	4.40E-09
Co-60	M			1.00E-08	1.50E-08	3.40E-08	3.40E-10	1.10E-08	2.70E-08
Cr-51	S			3.70E-11	6.60E-11	2.10E-10	3.80E-11	7.80E-11	2.30E-10
Cs-134	F			6.60E-09	5.30E-09	7.30E-09	1.90E-08	1.40E-08	1.60E-08
Cs-137	F			4.60E-09	3.70E-09	5.40E-09	1.30E-08	1.00E-08	1.20E-08
H-3	V			1.80E-11	2.30E-11	4.80E-11	1.80E-11	2.30E-11	4.80E-11
I-131	F			7.40E-09	1.90E-08	7.20E-08	2.20E-08	5.20E-08	1.80E-07
I-133	F			1.50E-09	3.80E-09	1.80E-08	4.30E-09	1.00E-08	4.40E-08
Mn-54	M			1.50E-09	2.40E-09	6.20E-09	7.10E-10	1.30E-09	3.10E-09
Nb-95	M			1.50E-09	2.20E-09	5.20E-09	5.80E-10	1.10E-09	3.20E-09
Sr-89	M			6.10E-09	9.10E-09	2.40E-08	2.60E-09	5.80E-09	1.80E-08
Sr-90	M			3.60E-08	5.10E-08	1.10E-07	2.80E-08	6.00E-08	7.30E-08
Zr-95	M			4.80E-09	6.80E-09	1.60E-08	9.50E-10	1.90E-09	5.60E-09

A = Adult, C = Child, I = Infant. Note – Inhalation factors for noble gases are zero and are not presented

Table A3.8 External Effective Dose Rate Factors for Exposure to Cloudshine and Groundshine

Radionuclide	Cloudshine	Groundshine
	Sv/h per Bq/m^3	Sv/h per Bq/m^2/s
Ar-41	2.2E-10	4.32E-12
Ba-140	2.9E-11	2.79E-13
C-14	9.4E-15	0
Co-58	1.6E-10	6.02E-13
Co-60	4.3E-10	2.63E-11
Cr-51	5E-12	7.92E-15
Cs-134	2.5E-10	8.24E-12
Cs-137	9.2E-11	1.49E-11
H-3	0	0
I-131	6.1E-11	2.82E-14
I-133	9.9E-11	5.07E-15
Kr-85	8.6E-13	9.5E-15
Kr-85m	2.5E-11	5.49E-13
Kr-87	1.48E-10	2.63E-12
Kr-88	4.88E-10	8.41E-12
Mn-54	1.4E-10	2.09E-12
Nb-95	1.3E-10	2.44E-13
Sr-89	1.6E-12	3.81E-17
Sr-90	3.5E-13	2.85E-19
Xe-131m	1.40E-12	7.42E-14
Xe-133	4.8E-12	1.66E-13
Xe-133m	1.05E-11	3.12E-13
Xe-135	4.28E-11	8.71E-13
Xe-135m	1.16E-10	2.40E-12
Xe-137	0	0
Xe-138	6.43E-10	1.16E-11
Zr-95	1.2E-10	8.56E-13

All values derived from updated version of Ref [A2.4]

Table A3.9 Doses to the Terrestrial Candidates for the Representative person (CRP1, Local Family) from gaseous releases to atmosphere for discharges at Predicted levels and Contribution from Marine Discharges (µSv/y)

Habits Profile	Age	Dose (µSv/y)			
		Atmospheric Discharges		Marine Discharges	Total
		Stack 1	Stack 2		
CRP1 - local resident (high rate terrestrial food consumer	Adult	2.63	0.01	0.07	2.71
	Child	2.86	0.01	0.04	2.91
	Infant	4.38	0.01	0.04	4.43

Notes
* Highest dose for each group, summarised in Table 4 in the main report.

Table A3.10 Dose Breakdown for the Candidate for the Representative person (Infant) most exposed to atmospheric discharges at Predicted levels[1] (µSv/y)

Radionuclide	Terrestrial Pathways											
	Inhalation	Cloud Shine	Ground Shine	Green vegetables (home/garden)	Root vegetables (home/garden)	Fruit (home/garden)	Milk (farm)	Cow Meat (farm)	Cow Liver (farm)	Sheep Meat (farm)	Sheep Liver	Total Terrestrial Pathways
Ar-41	0.00E+00	3.43E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.43E-02
Ba-140	2.17E-07	5.22E-10	5.86E-15	3.91E-08	1.43E-10	1.36E-08	3.08E-07	7.18E-10	1.34E-10	3.36E-10	2.10E-10	5.80E-07
C-14	2.89E-01	6.84E-07	0.00E+00	4.93E-02	8.85E-01	1.77E-01	2.47E+00	6.94E-02	1.16E-02	1.85E-02	1.16E-02	3.98E+00
Co-58	4.04E-06	1.65E-07	7.25E-13	9.88E-07	2.49E-08	3.09E-07	2.56E-05	3.18E-08	5.40E-07	1.45E-08	9.05E-07	3.26E-05
Co-60	7.88E-06	1.65E-07	1.18E-11	2.84E-06	1.14E-06	9.45E-07	8.07E-05	3.12E-07	5.20E-06	1.24E-07	7.75E-06	1.07E-04
Cr-51	2.89E-09	1.14E-10	2.11E-16	8.69E-10	2.40E-13	1.47E-10	2.51E-08	2.55E-10	4.46E-11	1.22E-10	7.63E-11	2.96E-08
Cs-134	4.38E-07	2.49E-08	9.58E-13	4.96E-07	4.06E-06	4.94E-07	2.79E-05	1.30E-06	2.17E-07	6.74E-07	4.22E-07	3.60E-05
Cs-137	5.08E-07	1.44E-08	2.71E-12	6.46E-07	5.45E-06	6.03E-07	3.68E-05	1.76E-06	2.94E-07	9.83E-07	6.14E-07	4.77E-05
H-3	6.25E-03	0.00E+00	0.00E+00	1.86E-03	1.48E-02	2.96E-03	9.31E-02	6.76E-04	1.13E-04	1.80E-04	1.13E-04	1.20E-01
I-131	1.11E-03	1.56E-06	5.62E-12	3.02E-03	5.68E-03	4.08E-03	2.20E-01	7.37E-04	1.46E-04	3.00E-04	1.87E-04	2.35E-01
I-133	4.60E-04	4.20E-06	1.67E-12	1.83E-04	1.25E-05	2.85E-04	5.81E-03	3.22E-06	2.66E-06	2.60E-06	1.63E-06	6.76E-03
Kr-85	0.00E+00	3.23E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.23E-04
Kr-85m	0.00E+00	7.44E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-05
Kr-87	0.00E+00	3.42E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.42E-04
Kr-88	0.00E+00	1.55E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-03
Mn-54	4.93E-08	1.85E-09	3.22E-14	1.11E-08	6.90E-09	3.17E-09	5.62E-07	8.05E-09	5.35E-08	3.70E-09	9.07E-08	7.91E-07
Nb-95	3.35E-07	1.39E-08	3.04E-14	6.31E-08	9.51E-10	2.05E-08	8.68E-09	1.87E-11	3.24E-12	8.73E-12	5.47E-12	4.42E-07
Sr-89	1.91E-06	2.11E-10	5.86E-18	5.05E-07	3.58E-08	1.54E-07	5.15E-06	9.53E-09	1.63E-09	3.71E-09	2.32E-09	7.77E-06
Sr-90	3.27E-06	1.72E-11	1.64E-20	5.31E-06	6.80E-06	2.00E-06	5.49E-05	1.10E-07	1.84E-08	2.21E-08	1.38E-08	7.24E-05

[1] No contribution from marine discharges.

Radionuclide	Terrestrial Pathways											
	Inhalation	Cloud Shine	Ground Shine	Green vegetables (home/garden)	Root vegetables (home/garden)	Fruit (home/garden)	Milk (farm)	Cow Meat (farm)	Cow Liver (farm)	Sheep Meat (farm)	Sheep Liver	Total Terrestrial Pathways
Xe-131m	0.00E+00	2.32E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.32E-04
Xe-133	0.00E+00	7.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.20E-04
Xe-133m	0.00E+00	1.47E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.47E-04
Xe-135	0.00E+00	2.21E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.21E-03
Xe-135m	0.00E+00	2.42E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.42E-03
Xe-138	0.00E+00	6.23E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.23E-03
Zr-95	4.28E-07	5.33E-09	4.43E-14	5.30E-08	4.04E-10	1.67E-08	6.83E-09	5.59E-11	9.57E-12	2.91E-11	1.82E-11	5.11E-07
Total	**2.97E-01**	**4.86E-02**	**2.36E-11**	**5.43E-02**	**9.05E-01**	**1.84E-01**	**2.79E+00**	**7.08E-02**	**1.18E-02**	**1.90E-02**	**1.19E-02**	**4.39E+00**

Appendix 4 – Independent radiological assessment of liquid discharges

Introduction

A4.1 In accordance with information provided by Westinghouse Electric Company (WEC), the AP1000 Generic Design has been assumed to be located at a coastal site and to discharge liquid radioactive wastes into the coastal environment [Ref A4.1]. The methodology used to assess doses from the predicted liquid discharges from a coastally located AP1000 power plant is described in this Appendix.

A4.2 Discharges would also be made to atmosphere from such a power plant. Assessment of the dose from predicted atmospheric discharges is described in Appendix 3.

A4.3 This work is based on predicted discharges to sea as presented by WEC. The validity of these predictions has not been assessed.

Liquid discharges to Sea

A4.4 According to information presented by WEC, a coastally located AP1000 power plant would discharge liquids at a distance of 150 m offshore into the coastal environment [Ref. A4.1]. The expected total annual activity released from all sources (including shim bleed and equipment drains, miscellaneous wastes and the turbine building) are presented [Ref. A4.1]. The expected annual releases of radionuclides are detailed in Table A4.1.

Receptor Points and Candidates for the representative person

A4.5 Assumptions about the pattern of coastal land use and commercial and leisure activities around the site were based on generic assumptions, derived from the Environment Agency Initial Radiological Assessment Methodology [Ref. A4.2] and NRPB-W41 [Ref. A4.3], to represent those likely to be the most exposed individuals to liquid discharges from the AP1000 power plant.

A4.6 In accordance with the generic site information, provided by WEC [Ref. A4.4], it has been assumed that there would be commercial fishing in the vicinity of the AP1000 power plant, such that exposure pathways associated with fisheries and marine food consumption should be assessed.

A4.7 The following candidates for the representative person have been chosen to reflect the fishing communities who could be potentially affected by liquid discharges from an AP1000 power plant which is located at the coast and discharges into the coastal environment:

- ***CRP2 Fisherman and family.*** For the purposes of this assessment, it is assumed that the fishermen and their families (adults, children (10 years) and infants (1 year)) are exposed to liquid discharges from the site by spending time on the intertidal sediments in the area and consuming locally caught fish and shellfish (crustaceans and molluscs). Doses from atmospheric discharges from the AP1000 power plant were also assessed for this group via the consumption of some local produced terrestrial foodstuffs.

A4.1 Doses to the candidates for representative person most exposed to gaseous discharge to atmosphere (CRP1) were assessed as described in Appendix 3.

Exposure Pathways

A4.8 The exposure pathways considered were:

- internal exposure to radionuclides from ingestion of sea fish and marine shellfish (crustaceans and molluscs) caught from the local coastal waters;
- external doses from exposure to radionuclides incorporated into coastal sediment; and,
- Other exposure pathways such as external exposure from handling fishing gear and inhalation of sea spray, inadvertent ingestion of sediment and inadvertent ingestion of seawater.

Modelling of Environmental Concentrations

A4.9 The assessment of environmental concentrations in the local and regional coastal area per unit release rate has been performed using the PC DORIS Model, which is part of the PC CREAM software suite of radiological assessment models [Ref A4.5].

A4.10 Activity concentrations per unit release rate of radionuclides in filtered seawater (Bq/l per TBq/y), unfiltered seawater (Bq/l per TBq/y) and marine sediment (Bq/kg per TBq/y) have been predicted using PC DORIS assuming continuous discharges for a period of 50 years.

A4.11 PC DORIS calculates the activity concentration values in local coastal waters, ('Local Box'). For this assessment, the Local Box chosen was the 'North Sea Central box, whose parameters are pre-defined [Ref A4.6], and are shown in Table A4.2. This marine compartment has been chosen on the basis that it has the lowest volumetric exchange rate of those associated with potential sites, and therefore is likely to give rise to the highest doses to CRP2. The sediment concentration factors used in PC DORIS for the calculation of the environmental concentrations are shown in Table A4.3. The environmental activity concentrations per unit release rate (per Bq/y) for the North Sea Central Local Box are shown in Table A4.4.

A4.12 Concentration factors for sea fish, marine crustacea and marine molluscs are shown in Table A4.5. The concentration factors and the filtered seawater activity concentration per unit release rate factors have been used to calculate the local sea fish, and shellfish activity concentration per unit release rate values [Table A4.6].

A4.13 The internal dose rates per unit concentration arising from internal exposure to radionuclides through ingestion of foodstuffs or inhalation are given in Table A4.7 [Ref A4.2; A4.7].

A4.14 External effective dose rates per unit concentration arising from exposure to radionuclides from occupancy on marine sediment (Sv/h per Bq/kg) have been derived from Reference A4.8 for all radionuclides. These data are based on a semi-infinite expanse of contaminated material. In this case, it is appropriate to apply a modifying factor of 0.5 [Ref A4.8] for exposure to radionuclides in marine sediment to take account of the fact that the beach is not a semi-infinite source. It was assumed that all radionuclides occupy the upper 0.3 m or more of the sediment profile. A sediment density of 1600 kg/m3 was assumed in the derivation of the values as recommended in Reference A4.9. The external effective dose rate factors used in the assessment are provided in Table A4.8.

A4.15 The inadvertent ingestion of sediment and seawater during beach activities have been included in the assessment. Critical rates of ingestion have been used [Ref A4.10]. The doses have been calculated by determining the radionuclide intake from the appropriate environmental concentration by the level of intake. The radionuclide intake has been multiplied by the ingestion dose coefficient [Ref A4.7] to determine the doses.

A4.16 The inhalation of sea-spray has also been taken into account in the assessment. PC CREAM [Ref. 4.5] has been used to determine sea spray concentrations. This output has been used to calculate inhalation doses based on the appropriate age group inhalation rates and occupancy over the inter-tidal sediments.

A4.17 External skin equivalent dose rates have also been calculated, using the external beta skin dose rate factors (Sv/h per Bq/cm^2) [Ref A4.9]. The exposure pathway was handling fishing gear, which had come into contact with marine sediment incorporating radionuclides. The majority of skin dose arises from radionuclides emitting beta radiation. Beta skin dose rates have been calculated using the simple Hunt model [Ref A4.9].

Habits Data

A4.18 Doses to the candidates for the representative person have been calculated using the predicted environmental and seafood concentrations and habits data, including generic information concerning seafood intakes and occupancy of the coastal environment in the UK.

A4.19 The high rate generic intake rates for marine fish, crustaceans and molluscs presented in NRPB-W41 [Ref. 4.10] have been used to represent the habits of CRP2. Beach occupancy, inhalation rates and inadvertent ingestion rates have also been derived from this source. Adult candidates for the representative person have been assumed to spend their working life (2000 hours per year) on inter-tidal sediments and handling fishing nets. Beach occupancy rates for other age groups are assumed to be based on leisure activities (300 and 30 hours per year for children and infants respectively). Only adults are assumed to handle fishing gear.

A4.20 Habits data applied for CRP2 are presented in Table A4.9.

A4.21 It has been assumed that all occupancy and all seafood consumption is associated with the local marine environment (North Sea Central compartment).

Doses to the Candidates for the representative person

A4.22 Effective doses to the infant, child and adult candidates for the representative person, CRP2 have been calculated using ingestion and inhalation dose coefficients from the Euratom Basic Safety Standards Directive [Ref A4.7], generic habits data representative of fishing communities in the UK, predicted dose rate data and predicted concentrations of radionuclides in foods and the environment. Doses to CRP2 from liquid discharges, plus the contribution from predicted atmospheric discharges are shown in Table A4.10.

A4.23 A breakdown of the effective dose to the candidates for the representative person arising from liquid discharges by radionuclide and pathway to the fisherman at the predicted levels is provided in Table A4.11. The majority of the dose is from carbon-14 in fish and shellfish.

References

A4.1 Eisenstatt, L., Environment Report, WEC, UKP-GW-GL-790, Revision 3 April 2010.

A4.2 Environment Agency, Initial Radiological Assessment Methodology (Parts 1 and 2), Science Report SC030162/SR1 (2006).

A4.3 Smith, K R and Jones A L, Generalised Habit Data for Radiological Assessments, NRPB-W41, NRPB, Chilton (2003).

A4.4 Eisenstatt, L R, Westinghouse Electric Company, Characteristics of a Generic Site for a Nuclear Power Station, UKP-GW-GL-025, Revision 1, 9 January 2010.

A4.5 Mayall A, Cabianca T, Attwood C, Fayers CA, Smith JG, Penfold J, Steadman D, Martin G, Morris TP and Simmonds JR. PC CREAM-97 (PC CREAM-98 code update) NRPB Chilton NRPB-SR-296 (EUR 17791) (1997).

A4.6 Simmonds. J.R., Lawson, G. and Mayall, A., Methodology For Assessing the Radiological Consequences of Routine Releases of Radionuclides to the Environment. Radiation Protection 72, Report EUR 15760, 1995.

A4.7 Council Directive 96/29 Euratom of 13 May 1996, Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionising Radiation. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

A4.8 EPA (1993). External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report No. 12, EPA-402-R-93-081 (Oak Ridge National Laboratory, Oak Ridge, TN; U.S. Environmental Protection Agency, Washington, DC).

A4.9 Hunt G, Simple models for prediction of external radiation exposure from aquatic pathways, 1984, Radiation Protection Dosimetry Vol. 8 No. 4 p 215-224

A4.10 Smith, K R and Jones, A L, Generalised Habit data for Radiological Assessment, NRPB-W41, NRPB, Chilton (2003).

Table A4.1 Predicted AP1000 Power Plant Discharges Assumed in the Assessment for Liquid Discharges to Sea

Radionuclide	Predicted Marine Discharges (TBq/y)
Ag-110m	2.60E-05
Ba-140	1.30E-05
C-14	3.30E-03
Ce-144	9.00E-05
Co-58	4.10E-04
Co-60	2.30E-04
Cr-51	4.60E-05
Cs-134	7.60E-06
Cs-136	9.30E-06
Cs-137	2.30E-05
Fe-55	4.90E-04
Fe-59	5.00E-06
H-3	3.34E+01
I-131	1.50E-05
I-133	2.90E-05
La-140	1.80E-05
Mn-54	3.20E-05
Na-24	3.80E-05
Nb-95	6.10E-06
Ni-63	5.40E-04
Pr-144	8.00E-05
Pu-241	8.00E-08
Ru-103	1.20E-04
Sr-89	2.40E-06
Sr-90	2.50E-07
Tc-99m	1.80E-05
Y-91	9.10E-08
Zn-65	1.00E-05
Zr-95	6.90E-06

Table A4.2 North Sea Central Local Box Parameters

Parameter	Value	Source of data/Comments
Release rate (TBq/y)	1.00E+00	User defined.
Volume (m^3)	2.00E+08	Default value from RP-72 [Table A4.5, Ref A4.6]
Depth (m)	10	
Volumetric Exchange Rate (with North Sea central and North Sea South East regional compartment) (m^3/y)	4.0E+9	
Suspended Sediment Load (t/m^3)	2.00E-04	
Sedimentation Rate (t/m^3/y)	1.00-E05	
Sediment density (t/m^3)	2.60	Default value from RP-72 [Table A4.7 Ref A4.6]
Bioturbation Rate (m^2/y)	3.60-E05	
Diffusion Rate (m^2/y)	3.15-E02	

Table A4.3 Marine Sediment Concentration Factors (Bq/t per Bq/m^3)

Radionuclide	Marine Sediment Concentration Factor[a]
Ag-110m	1.00E+03
Ba-140	5.00E+03
C-14	2.00E+03
Ce-144	2.00E+06
Co-58	2.00E+05
Co-60	2.00E+05
Cr-51	5.00E+04
Cs-134	3.00E+03
Cs-136	3.00E+03
Cs-137	3.00E+03
Fe-55	5.00E+04
Fe-59	5.00E+04
H-3	1.00E+00
I-131	2.00E+01
I-133	2.00E+01
La-140	0.00E+00
Mn-54	2.00E+05
Na-24	1.00E+00
Nb-95	5.00E+05
Ni-63	1.00E+05
Pr-144	2.00E+06
Pu-241	1.00E+05
Ru-103	3.00E+02
Sr-89	1.00E+03
Sr-90	1.00E+03
Tc-99m	1.00E+02
Y-91	1.00E+07
Zn-65	2.00E+04
Zr-95	1.00E+06

[a] Default values from PC DORIS input file.

Table A4.4 Environmental Concentrations per Unit Release Rate to the North Sea Central Local Box

Radionuclide	North Sea Central Local Compartment			
	Unfiltered Sea water (Bq/l per TBq/y)	Filtered Seawater (Bq/l per TBq/y)	Seaspray (Bq/m3 per TBq/y)	Sea Bed Sediment (Bq/kg per TBq/y)
Ag-110m	2.38E-01	1.98E-01	2.10E-14	2.47E-01
Ba-140	1.25E-01	6.26E-02	5.60E-15	2.02E-02
C-14	2.50E-01	1.79E-01	6.00E-17	1.36E+01
Ce-144	2.39E-01	5.96E-04	7.40E-14	1.68E+00
Co-58	2.12E-01	5.16E-03	3.00E-13	3.69E-01
Co-60	2.48E-01	6.05E-03	2.00E-13	1.02E+01
Cr-51	1.71E-01	1.56E-02	2.70E-14	1.09E-01
Cs-134	2.46E-01	1.54E-01	6.40E-15	1.65E+00
Cs-136	1.27E-01	7.95E-02	4.10E-15	1.59E-02
Cs-137	2.50E-01	1.56E-01	2.00E-14	1.19E+01
Fe-55	2.46E-01	2.24E-02	4.10E-13	5.19E+00
Fe-59	1.94E-01	1.77E-02	3.30E-15	1.99E-01
H-3	2.49E-01	2.49E-01		1.61E-01
I-131	9.71E-02	9.67E-02	5.00E-15	6.21E-04
I-133	1.60E-02	1.59E-02	1.60E-15	1.11E-05
La-140	1.40E-01	1.40E-01	8.70E-15	2.30E-02
Mn-54	2.40E-01	5.85E-03	2.60E-14	1.81E+00
Na-24	1.18E-02	1.18E-02	1.50E-15	5.51E-05
Nb-95	2.38E-01	2.36E-03	5.00E-15	5.43E-01
Ni-63	2.50E-01	1.19E-02	4.60E-13	4.13E+01
Pr-144	2.37E-04	5.91E-07	6.50E-17	7.20E-08
Pu-241	2.49E-01	1.19E-02	6.80E-17	2.15E+01
Ru-103	1.89E-01	1.79E-01	7.80E-14	1.11E-02
Sr-89	2.00E-01	1.66E-01	1.60E-15	4.26E-02
Sr-90	2.50E-01	2.08E-01	2.10E-16	4.96E+00
Tc-99m	4.86E-03	4.76E-03	3.00E-16	8.00E-07
Y-91	2.05E-01	1.02E-04	6.40E-07	3.02E-01
Zn-65	2.37E-01	4.75E-02	8.10E-15	1.15E+00
Zr-95	2.08E-01	1.04E-03	4.90E-15	3.34E-01

Table A4.5 Fish and Shellfish Concentration Factors (Bq/t per Bq/m^3)

Radionuclide	Concentration Factors (Bq/kg per Bq/l)[a]		
	Sea fish	Crustacea	Mollusca
Ag-110m	5.00E+02	5.00E+03	1.00E+04
Ba-140	1.00E+01	1.00E+00	2.00E+01
C-14	2.00E+04	2.00E+04	2.00E+04
Ce-144	5.00E+01	1.00E+03	5.00E+03
Co-58	1.00E+03	5.00E+03	5.00E+03
Co-60	1.00E+03	5.00E+03	5.00E+03
Cr-51	2.00E+02	5.00E+02	8.00E+02
Cs-134	1.00E+02	3.00E+01	3.00E+01
Cs-136	1.00E+02	3.00E+01	3.00E+01
Cs-137	1.00E+02	3.00E+01	3.00E+01
Fe-55	3.00E+03	5.00E+03	3.00E+04
Fe-59	3.00E+03	5.00E+03	3.00E+04
H-3	1.00E+00	1.00E+00	1.00E+00
I-131	1.00E+01	1.00E+01	1.00E+01
I-133	1.00E+01	1.00E+01	1.00E+01
La-140	0.00E+00	0.00E+00	0.00E+00
Mn-54	4.00E+02	5.00E+02	5.00E+03
Na-24	1.00E-01	1.00E-01	3.00E-01
Nb-95	3.00E+01	2.00E+02	1.00E+03
Ni-63	1.00E+03	1.00E+03	2.00E+03
Pr-144	3.00E+01	1.00E+03	1.00E+03
Pu-241	4.00E+01	3.00E+02	3.00E+03
Ru-103	2.00E+00	1.00E+02	2.00E+03
Sr-89	2.00E+00	2.00E+00	1.00E+00
Sr-90	2.00E+00	2.00E+00	1.00E+00
Tc-99m	3.00E+01	1.00E+03	1.00E+03
Y-91	2.00E+01	1.00E+03	1.00E+03
Zn-65	1.00E+03	5.00E+04	3.00E+04
Zr-95	2.00E+01	2.00E+02	5.00E+03

[a] Default values taken from PC CREAM and are relative to filtered seawater.

Table A4.6 Fish and Shellfish Concentrations per Unit Release to the North Sea Central Local Box (Bq/kg per TBq/y)

Radionuclide	Fish and Shellfish Concentrations per Unit Release (Bq/kg per TBq/y)[a]		
	Sea fish	Crustacea	Mollusca
Ag-110m	9.90E+01	9.90E+02	1.98E+03
Ba-140	6.26E-01	6.26E-02	1.25E+00
C-14	3.58E+03	3.58E+03	3.58E+03
Ce-144	2.98E-02	5.96E-01	2.98E+00
Co-58	5.16E+00	2.58E+01	2.58E+01
Co-60	6.05E+00	3.03E+01	3.03E+01
Cr-51	3.12E+00	7.80E+00	1.25E+01
Cs-134	1.54E+01	4.62E+00	4.62E+00
Cs-136	7.95E+00	2.39E+00	2.39E+00
Cs-137	1.56E+01	4.68E+00	4.68E+00
Fe-55	6.72E+01	1.12E+02	6.72E+02
Fe-59	5.31E+01	8.85E+01	5.31E+02
H-3	2.49E-01	2.49E-01	2.49E-01
I-131	9.67E-01	9.67E-01	9.67E-01
I-133	1.59E-01	1.59E-01	1.59E-01
La-140	0.00E+00	0.00E+00	0.00E+00
Mn-54	2.34E+00	2.93E+00	2.93E+01
Na-24	1.18E-03	1.18E-03	3.54E-03
Nb-95	7.08E-02	4.72E-01	2.36E+00
Ni-63	1.19E+01	1.19E+01	2.38E+01
Pr-144	1.77E-05	5.91E-04	5.91E-04
Pu-241	4.76E-01	3.57E+00	3.57E+01
Ru-103	3.58E-01	1.79E+01	3.58E+02
Sr-89	3.32E-01	3.32E-01	1.66E-01
Sr-90	4.16E-01	4.16E-01	2.08E-01
Tc-99m	1.43E-01	4.76E+00	4.76E+00
Y-91	2.04E-03	1.02E-01	1.02E-01
Zn-65	4.75E+01	2.38E+03	1.43E+03
Zr-95	2.08E-02	2.08E-01	5.20E+00

Table A4.7 Internal Committed Dose Factors for Exposure via Inhalation and Ingestion

Radionuclide	ICRP Lung Class			Inhalation Sv/Bq			Ingestion (Sv/Bq)		
	A	C	I	A	C	I	A	C	I
Ag-110m	M			7.60E-09	1.20E-08	2.80E-08	2.80E-09	5.20E-09	1.40E-08
Ba-140	M			5.10E-09	7.60E-09	2.00E-08	2.60E-09	5.80E-09	1.80E-08
C-14	V			2.00E-09	2.80E-09	6.60E-09	5.80E-10	8.00E-10	1.60E-09
Ce-144	M			3.60E-08	5.50E-08	1.60E-07	5.20E-09	1.10E-08	3.90E-08
Co-58	M			1.60E-09	2.40E-09	6.50E-09	7.40E-10	1.70E-09	4.40E-09
Co-60	M			1.00E-08	1.50E-08	3.40E-08	3.40E-10	1.10E-08	2.70E-08
Cr-51	S			3.70E-11	6.60E-11	2.10E-10	3.80E-11	7.80E-11	2.30E-10
Cs-134	F			6.60E-09	5.30E-09	7.30E-09	1.90E-08	1.40E-08	1.60E-08
Cs-136	F			1.20E-09	2.00E-09	5.20E-09	3.00E-09	4.40E-09	9.50E-09
Cs-137	F			4.60E-09	3.70E-09	5.40E-09	1.30E-08	1.00E-08	1.20E-08
Fe-55	M			3.80E-10	6.20E-10	1.40E-09	3.30E-10	1.10E-09	2.40E-09
Fe-59	M			3.70E-09	5.50E-09	1.30E-08	1.80E-09	4.70E-09	1.30E-08
H-3	V			1.80E-11	2.30E-11	4.80E-11	1.80E-11	2.30E-11	4.80E-11
I-131	F			7.40E-09	1.90E-08	7.20E-08	2.20E-08	5.20E-08	1.80E-07
I-133	F			1.50E-09	3.80E-09	1.80E-08	4.30E-09	1.00E-08	4.40E-08
La-140	M			1.10E-09	2.00E-09	6.30E-09	2.00E-09	4.20E-09	1.30E-08
Mn-54	M			1.50E-09	2.40E-09	6.20E-09	7.10E-10	1.30E-09	3.10E-09
Na-24	F			2.70E-10	5.70E-10	1.80E-09	4.30E-10	7.70E-10	2.30E-09
Nb-95	M			1.50E-09	2.20E-09	5.20E-09	5.80E-10	1.10E-09	3.20E-09
Ni-63	M			4.80E-10	7.00E-10	1.90E-09	1.50E-10	2.80E-10	8.40E-10
Pr-144	S			1.80E-11	3.40E-11	1.20E-10	5.10E-11	9.50E-11	3.50E-10
Pu-241	M			9.00E-07	8.30E-07	9.70E-07	4.80E-09	5.10E-09	5.70E-09
Ru-103	M			2.40E-09	3.50E-09	8.40E-09	7.30E-10	1.50E-09	4.60E-09
Sr-89	M			6.10E-09	9.10E-09	2.40E-08	2.60E-09	5.80E-09	1.80E-08
Sr-90	M			3.60E-08	5.10E-08	1.10E-07	2.80E-08	6.00E-08	7.30E-08
Tc-99m	M			1.90E-11	3.40E-11	9.90E-11	2.20E-11	4.30E-11	1.30E-10
Y-91	S			8.90E-09	1.30E-08	3.40E-08	2.40E-09	5.20E-09	1.80E-08
Zn-65	M			1.60E-09	2.40E-09	6.50E-09	3.90E-09	6.40E-09	1.60E-08
Zr-95	M			4.80E-09	6.80E-09	1.60E-08	9.50E-10	1.90E-09	5.60E-09

A = Adult, C = Child, I = Infant

Table A4.8 External Effective Dose Rate Factors for Occupancy Over Marine Sediment

Radionuclide	External Effective Dose Rate Factor for Exposure over Sediment[b,c]		Gamma fishing gear	Beta skin dose from handling gear
	[a]Sv/s per Bq/m^3	uSv/h per TBq/y	uSv/h per TBq/y	uSv/h per TBq/y
Ag-110m	9.19E-17	6.54E-05	1.72E-06	0.00E+00
Ba-140	5.52E-18	3.21E-07	9.37E-09	5.46E-07
C-14	7.20E-23	2.82E-09	0.00E+00	0.00E+00
Ce-144	3.84E-19	1.86E-06	2.23E-07	6.19E-05
Co-58	3.19E-17	3.39E-05	9.13E-07	0.00E+00
Co-60	8.68E-17	2.55E-03	6.46E-05	0.00E+00
Cr-51	9.34E-19	2.93E-07	8.73E-09	0.00E+00
Cs-134	5.07E-17	2.41E-04	6.48E-06	2.32E-05
Cs-136	7.12E-17	3.26E-06	8.74E-08	1.92E-07
Cs-137	4.02E-21	1.38E-07	1.70E-05	2.56E-04
Fe-55	0.00E+00	0.00E+00	2.22E-08	0.00E+00
Fe-59	4.09E-17	2.34E-05	6.00E-07	2.01E-06
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I-131	1.16E-17	2.07E-08	6.01E-10	1.03E-08
I-133	1.95E-17	6.23E-10	1.71E-11	3.93E-10
La-140	8.06E-17	5.34E-06	1.35E-07	1.07E-06
Mn-54	2.76E-17	1.44E-04	3.83E-06	0.00E+00
Na-24	1.52E-16	2.41E-08	5.75E-10	2.63E-09
Nb-95	2.51E-17	3.93E-05	1.05E-06	0.00E+00
Ni-63	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pr-144	1.35E-18	2.80E-13	5.82E-15	2.51E-12
Pu-241	3.16E-23	1.96E-09	3.30E-10	0.00E+00
Ru-103	1.47E-17	4.70E-07	1.33E-08	1.08E-07
Sr-89	4.86E-20	5.96E-09	9.12E-12	2.15E-06
Sr-90	3.77E-21	5.39E-08	2.11E-11	1.61E-04
Tc-99m	2.95E-18	6.80E-12	2.55E-13	0.00E+00
Y-91	1.74E-19	1.51E-07	2.77E-09	1.57E-05
Zn-65	1.98E-17	6.56E-05	1.70E-06	0.00E+00
Zr-95	2.42E-17	2.33E-05	6.25E-07	3.35E-06

[a] Derived from data in FGR-12 [Ref A4.8]

[b] Assuming a sediment density of 1600 kg/m^3,

[C] After applying a modifying factor of 0.5 to take account for time spent on the shoreline or top of beach

Table A4.9 Habit Data Profiles for the Candidates for the Representative Person for Liquid Discharges to the Marine Environment

	Terrestrial Food Consumption Rates (kg/y or l/y)								Marine Food Consumption Rates (kg/y)			Handling and Occupancy (h/y)				
Age Group	Green veg total	Root veg total	Fruit total	Milk	Cow meat*	Cow liver*	Sheep meat	Sheep Liver	Fish (sea)	Crustaceans	Molluscs	Handling fishing gear	Handling sediment	Intertidal occupancy over mud	External occupancy	Internal occupancy (used)
Adult	35.0	60.0	20.0	95.0	15.0	2.8	8.0	2.8	100.0	20.0	20.0	2000	2000	2000	876	2380.0
Child	15.0	50.0	15.0	110.0	15.0	1.5	4.0	1.5	20.0	5.0	5.0			300	876	7008.0
Infant	5.0	15.0	9.0	130.0	3.0	0.5	0.8	0.5	5.0	0.0	0.0			30	876	7008.0

Table A4.10 Doses to the Candidates for the Representative Person (CRP2, from Fisherman Family) for Liquid Discharges at Predicted levels and Contribution From Atmospheric Discharges (µSv/y)

Habits Profile	Age	Dose (µSv/y)			
		Atmospheric Discharges		Marine Discharges	Total
		Stack 1	Stack 2		
CRP2 - local fisherman (high marine exposure)	Adult	1.60	0.01	0.98	2.59
	Child	1.87	0.01	0.29	2.17
	Infant	2.13	0.01	0.10	2.23

Table A4.11 Dose by Radionuclide and Pathway for Adult Candidates for the Representative Person (CRP2) based on Predicted Liquid Discharges to the Marine Environment from the UK EPR Nuclear Power Plant and Generic Habits Data (μSv/y)

Radionuclide	Marine Pathways Dose (μSv/y)					
	Sum of Ingestion of Fish	Sum of Ingestion of Crustaceans	Sum of Ingestion of Molluscs	Sum of External sediments	Sum of Other marine pathways	Total Marine Pathways
Ag-110m	7.21E-04	1.44E-03	2.88E-03	3.40E-06	9.83E-08	**5.05E-03**
Ba-140	2.12E-06	4.23E-08	8.46E-07	8.35E-09	1.66E-08	**3.03E-06**
C-14	6.85E-01	1.37E-01	1.37E-01	1.86E-08	4.55E-07	**9.59E-01**
Ce-144	1.39E-06	5.58E-06	2.79E-05	3.34E-07	1.13E-05	**4.65E-05**
Co-58	1.57E-04	1.57E-04	1.57E-04	2.78E-05	7.82E-07	**4.98E-04**
Co-60	4.73E-05	4.73E-05	4.73E-05	1.17E-03	2.97E-05	**1.34E-03**
Cr-51	5.45E-07	2.73E-07	4.36E-07	2.70E-08	9.54E-10	**1.28E-06**
Cs-134	2.22E-04	1.33E-05	1.33E-05	3.66E-06	4.71E-07	**2.53E-04**
Cs-136	2.22E-05	1.33E-06	1.33E-06	6.06E-08	6.98E-09	**2.49E-05**
Cs-137	4.66E-04	2.80E-05	2.80E-05	6.34E-09	1.26E-05	**5.35E-04**
Fe-55	1.09E-03	3.62E-04	2.17E-03	0.00E+00	4.86E-08	**3.62E-03**
Fe-59	4.78E-05	1.59E-05	9.56E-05	2.34E-07	2.70E-08	**1.60E-04**
H-3	1.50E-03	2.99E-04	2.99E-04	0.00E+00	7.57E-06	**2.10E-03**
I-131	3.19E-05	6.38E-06	6.38E-06	6.22E-10	1.64E-08	**4.47E-05**
I-133	1.98E-06	3.97E-07	3.97E-07	3.62E-11	1.02E-09	**2.78E-06**
La-140	0.00E+00	0.00E+00	0.00E+00	1.92E-07	4.58E-08	**2.38E-07**
Mn-54	5.32E-06	1.33E-06	1.33E-05	9.21E-06	2.49E-07	**2.94E-05**
Na-24	1.93E-09	3.86E-10	1.16E-09	1.83E-09	3.40E-10	**5.64E-09**
Nb-95	2.50E-08	3.34E-08	1.67E-07	4.79E-07	1.33E-08	**7.18E-07**
Ni-63	9.64E-05	1.93E-05	3.86E-05	0.00E+00	3.79E-08	**1.54E-04**
Pr-144	7.23E-12	4.82E-11	4.82E-11	4.48E-14	8.86E-13	**1.05E-10**
Pu-241	1.83E-08	2.74E-08	2.74E-07	3.13E-13	1.16E-10	**3.20E-07**
Ru-103	3.14E-06	3.14E-05	6.27E-04	1.13E-07	3.75E-08	**6.62E-04**
Sr-89	2.07E-07	4.14E-08	2.07E-08	2.86E-11	1.09E-08	**2.80E-07**
Sr-90	2.91E-07	5.82E-08	2.91E-08	2.69E-11	8.19E-08	**4.60E-07**
Tc-99m	5.65E-09	3.77E-08	3.77E-08	2.45E-13	9.71E-13	**8.11E-08**
Y-91	4.46E-11	4.46E-10	4.46E-10	2.75E-11	2.88E-09	**3.85E-09**
Zn-65	1.85E-04	1.85E-03	1.11E-03	1.31E-06	3.90E-08	**3.15E-03**
Zr-95	1.36E-08	2.73E-08	6.82E-07	3.21E-07	5.55E-08	**1.10E-06**
Total	**6.90E-01**	**1.41E-01**	**1.45E-01**	**1.22E-03**	**6.37E-05**	**9.77E-01**

Appendix 5 – Independent radiological assessment of collective doses

A5.1 Collective dose provides an assessment of the radiation exposure in a population. It is the time integral of the distribution of individual doses within a population. The collective dose may be calculated for different populations and time periods. It has been agreed that the collective doses to the populations of the UK, Europe (the EC population included in PC CREAM 98 population grids) and the World, truncated at 500 years, should be estimated for authorisation purposes [Ref. A5.1]. Such an estimate of collective dose has also been identified as a requirement in the Environment Agency's Process and Information Document for Generic Assessment of Candidate Nuclear Power Plants [Ref. A5.2]

Calculation of Collective Doses

A5.1 Collective doses were calculated for the UK, European and World populations, truncated at 500 years, in accordance with the guidance identified above from Defra [Ref A5.3] for discharges to atmosphere and from discharges to the marine environment.

A5.2 Collective doses to the UK, Europe and World populations were estimated for the expected discharges and for a range of potential sites, using PC CREAM [Ref. A5.4]. Collective doses are dependent on the release point. The assessment was made at 5 UK coastal nuclear sites (Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell). A range of collective doses arising from atmospheric and liquid discharges for representative annual discharges and annual limit discharges were calculated. This is the same approach as adopted by Westinghouse.

A5.3 The annual expected discharges to atmosphere and to the marine environment used in the calculations are shown in Table 1 and Table 3.

Assessed Collective Doses

A5.4 A summary of collective doses are given in Tables A5.1 to A5.4. The tables contain the distribution of doses (min, average and max values) to UK, Europe and World populations due to atmospheric and liquid discharges calculated from 5 UK coastal nuclear sites (Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell).

A5.5 The average collective doses from the representative atmospheric discharges from an AP1000 power plant have been estimated to be: 0.26 manSv/y to the UK, 1.97 manSv/y to Europe, and 12.4 manSv/y to the World. The average collective doses due to annual limit discharges are estimated to be 0.41 manSv, 3.07 manSv and 19.4 manSv to UK, Europe and the World respectively. The majority of the atmospheric collective doses have been predicted to arise from carbon-14.

A5.6 The average collective doses from representative discharges to sea from a coastally located AP1000 power plant have been estimated to be 0.0008 manSv/y to the UK, 0.0039 manSv/y to Europe, and 0.053 manSv/y to the World. The average collective doses due to limit discharges are 0.0013 manSv/y, 0.0061 manSv/y and 0.84 manSv/y for UK, Europe and the World respectively. The majority of the marine collective dose arises from a range of radionuclides, depending on the site assumptions considered. These estimates of collective dose were very close to those reported by Westinghouse in their assessment – with small differences due to rounding.

A5.7 Average per caput doses (i.e. average individual doses derived from collective dose) were calculated for UK, European and World populations, using the calculated collective doses and the population data for UK, Europe and the World (Table A5.5).

A5.8 Average per caput doses are presented in Table A5.6 (truncated at 500 years). At predicted levels, the average per caput dose to the UK from the AP1000 power plant was 4.7 nSv, those to Europe were less than 3nSv and to the World were around 1 nSv. Most of this arose from atmospheric discharges.

A5.9 The UK regulatory and advisory agencies have agreed that the risks associated with annual average per caput doses in the nanosieverts range may considered to be miniscule and should be ignored in the authorisation decision making processes [Ref A5.1]. The results of this study show that the per-caput doses are a few nanosieverts or less, and may therefore be considered as trivial.

References

A5.1 Joint Environment Agencies, Principles for the Assessment of Prospective Public Doses (Interim Guidance), (December 2002).

A5.2 Environment Agency. The Environment Agency's Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs version 1 (http://publications.environment-agency.gov.uk/pdf/GEHO0107BLTN-e-e.pdf) (2007

A5.3 Defra, The Radioactive Substances (Basic Safety Standards) (England and Wales) Direction 2000. Defra (May 2000).

A5.4 Mayall A, Cabianca T, Attwood C, Fayers CA, Smith JG, Penfold J, Steadman D, Martin G, Morris TP and Simmonds JR. PC CREAM-97 (PC CREAM-98 code update) NRPB Chilton NRPB-SR-296 (EUR 17791) (1997).

A5.5 IAEA, Principles for the exemption of radiation sources and practices from regulatory control. IAEA Safety Series No.89 (1988).

A5.6 IAEA, Clearance of materials resulting from the use of radionuclides in medicine, industry and research. IAEA TECDOC-1000 (1998).

Table A5.1 Collective Dose Data for Representative Atmospheric Discharges Truncated at 500 Years

Radio-nuclides	Collective Dose (ManSv)								
	UK			EU			World		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
H-3	2.00E-03	2.64E-03	3.20E-03	6.34E-03	6.94E-03	7.64E-03	6.91E-03	7.51E-03	8.21E-03
C-14	2.22E-01	2.56E-01	2.82E-01	1.79E+00	1.95E+00	2.19E+00	1.22E+01	1.24E+01	1.26E+01
Ar-41	0.00E+00	8.34E-06	3.20E-05	0.00E+00	9.32E-06	2.70E-05	*0.00E+00*	*9.32E-06*	*2.70E-05*
Co-58	8.30E-08	1.13E-07	1.50E-07	1.60E-07	1.84E-07	2.00E-07	*1.60E-07*	*1.84E-07*	*2.00E-07*
Co-60	1.30E-05	1.70E-05	2.20E-05	2.60E-05	2.94E-05	3.20E-05	*2.60E-05*	*2.94E-05*	*3.20E-05*
Kr-85	1.06E-04	1.26E-04	1.47E-04	4.66E-04	4.88E-04	5.16E-04	9.27E-07	2.07E-03	3.38E-03
Sr-90	8.60E-07	1.13E-06	1.30E-06	4.10E-06	5.24E-06	5.90E-06	4.10E-06	5.24E-06	5.90E-06
I-131	6.20E-05	1.38E-04	2.50E-04	6.90E-05	9.42E-05	1.30E-04	6.90E-05	9.42E-05	1.30E-04
I-133	1.60E-05	2.68E-05	4.30E-05	2.40E-05	3.10E-05	4.80E-05	2.40E-05	3.10E-05	4.80E-05
Xe-133	5.80E-05	7.38E-05	9.00E-05	1.20E-04	1.38E-04	1.50E-04	1.20E-04	1.38E-04	1.50E-04
Cs-137	4.60E-06	5.84E-06	7.10E-06	1.40E-05	1.52E-05	1.60E-05	1.40E-05	1.52E-05	1.60E-05
Total	**0.22**	**0.26**	**0.28**	**1.81**	**1.97**	**2.13**	**12.3**	**12.4**	**12.6**

Table A5.2 Collective Dose Data for Annual Limit Atmospheric Discharges Truncated at 500 Years

Radio-nuclides	Collective Dose (ManSv)								
	UK			EU			World		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
H-3	3.21E-03	4.27E-03	5.21E-03	1.01E-02	1.11E-02	1.21E-02	1.10E-02	1.20E-02	1.30E-02
C-14	3.47E-01	3.99E-01	4.37E-01	2.83E+00	3.07E+00	3.33E+00	1.92E+01	1.94E+01	1.97E+01
Ar-41	0.00E+00	1.25E-05	4.80E-05	0.00E+00	1.40E-05	4.00E-05	*0.00E+00*	*1.40E-05*	*4.00E-05*
Co-58	1.40E-07	1.84E-07	2.40E-07	2.60E-07	3.02E-07	3.30E-07	*2.60E-07*	*3.02E-07*	*3.30E-07*
Co-60	2.00E-05	2.68E-05	3.50E-05	4.10E-05	4.56E-05	4.90E-05	*4.10E-05*	*4.56E-05*	*4.90E-05*
Kr-85	1.78E-04	2.08E-04	2.38E-04	7.64E-04	8.00E-04	8.44E-04	5.47E-03	5.51E-03	5.55E-03
Sr-90	1.30E-06	1.76E-06	2.00E-06	6.40E-06	8.26E-06	9.40E-06	6.40E-06	8.26E-06	9.40E-06
I-131	9.00E-05	2.02E-04	3.60E-04	1.00E-04	1.36E-04	1.90E-04	1.00E-04	1.36E-04	1.90E-04
I-133	2.60E-05	4.52E-05	7.30E-05	4.10E-05	5.22E-05	8.00E-05	4.10E-05	5.22E-05	8.00E-05
Xe-133	8.70E-05	1.09E-04	1.30E-04	1.80E-04	2.06E-04	2.30E-04	1.80E-04	2.06E-04	2.30E-04
Cs-137	6.90E-06	8.74E-06	1.10E-05	2.10E-05	2.28E-05	2.40E-05	2.10E-05	2.28E-05	2.40E-05
Total	**0.35**	**0.40**	**0.44**	**2.84**	**3.08**	**3.34**	**19.2**	**19.5**	**19.7**

Note: The doses to World population from discharges of H-3, C-14 and Kr-82 were derived by adding the ‘first pass’ dispersion dose for Europe to the global dose component for World obtained from PC CREAM in accordance with the methodology adopted by WEC. The maximum collective dose to UK population is due to discharges from Sizewell, while the highest collective doses to Europe and the World are due to Dungeness and Sizewell. The lowest collective dose to UK population is due to discharges from the Dungeness site, while discharges from Heysham and Hartlepool are responsible the lowest doses to EU and World populations. All values from PC CREAM.

Table A5.3 Collective Dose Data for Representative Liquid Discharges Truncated at 500 Years

Nuclide	Collective Dose (ManSv)								
	UK			EU			World		
	min	mean	max	min	mean	max	min	mean	max
H-3	9.60E-06	1.37E-05	1.90E-05	5.80E-05	7.04E-05	7.80E-05	1.50E-03	1.50E-03	1.50E-03
C-14	4.80E-04	7.86E-04	1.10E-03	2.80E-03	3.72E-03	4.50E-03	5.00E-02	5.12E-02	5.20E-02
Fe-55	1.30E-06	4.14E-06	1.10E-05	4.90E-06	1.45E-05	3.10E-05	4.90E-06	1.47E-05	3.20E-05
Co-58	1.80E-07	5.84E-07	1.30E-06	6.00E-07	1.57E-06	2.60E-06	6.20E-07	1.57E-06	2.60E-06
Co-60	1.60E-06	5.18E-06	1.40E-05	6.80E-06	1.37E-05	2.10E-05	6.90E-06	1.43E-05	2.20E-05
Ni-63	1.40E-07	2.90E-07	5.50E-07	2.00E-07	1.37E-06	2.50E-06	2.00E-07	1.50E-06	2.70E-06
Sr-90	3.40E-11	1.43E-10	2.80E-10	1.70E-10	5.06E-10	7.30E-10	1.90E-10	5.94E-10	8.60E-10
Cs-137	6.90E-08	2.52E-07	4.80E-07	3.60E-07	9.36E-07	1.40E-06	4.00E-07	1.12E-06	1.70E-06
Ce-144	1.40E-06	7.20E-06	1.80E-05	4.50E-06	2.32E-05	4.70E-05	4.60E-06	2.34E-05	4.70E-05
Pu-241	1.80E-10	5.88E-10	1.70E-09	6.70E-10	2.14E-09	4.80E-09	6.70E-10	2.18E-09	4.90E-09
Total	**0.0005**	**0.0008**	**0.0012**	**0.0029**	**0.0039**	**0.0047**	**0.052**	**0.053**	**0.054**

Table A5.4 Collective Dose Data for Annual Limit Liquid Discharges Truncated at 500 Years

Nuclide	Collective Dose (ManSv) 500 years								
	UK			EU			World		
	min	min	min	min	min	min	min	min	min
H-3	1.60E-05	2.36E-05	3.30E-05	1.00E-04	1.18E-04	1.30E-04	2.60E-03	2.60E-03	2.60E-03
C-14	7.50E-04	1.27E-03	1.80E-03	4.50E-03	5.94E-03	7.20E-03	8.00E-02	8.14E-02	8.30E-02
Fe-55	2.00E-06	6.20E-06	1.60E-05	7.70E-06	2.27E-05	4.90E-05	7.70E-06	2.27E-05	4.90E-05
Co-58	3.00E-07	9.64E-07	2.10E-06	9.90E-07	2.58E-06	4.20E-06	1.00E-06	2.60E-06	4.30E-06
Co-60	2.60E-06	8.54E-06	2.30E-05	1.10E-05	2.28E-05	3.60E-05	1.10E-05	2.34E-05	3.60E-05
Ni-63	2.00E-07	4.20E-07	8.00E-07	2.80E-07	1.98E-06	3.60E-06	2.90E-07	2.18E-06	3.90E-06
Sr-90	5.20E-11	2.20E-10	4.30E-10	2.70E-10	7.70E-10	1.10E-09	2.90E-10	9.16E-10	1.30E-09
Cs-137	1.10E-07	4.18E-07	7.90E-07	6.00E-07	1.58E-06	2.40E-06	6.60E-07	1.85E-06	2.80E-06
Ce-144	3.10E-07	1.64E-06	4.10E-06	1.00E-06	5.36E-06	1.10E-05	1.10E-06	5.38E-06	1.10E-05
Pu-241	3.40E-10	1.10E-09	3.20E-09	1.20E-09	3.92E-09	8.80E-09	1.20E-09	4.02E-09	9.00E-09
Total	**0.0008**	**0.0013**	**0.0019**	**0.0046**	**0.0061**	**0.0074**	**0.082**	**0.084**	**0.086**

Note: The doses due to H-3 and C-14 are summations of doses from the first pass and global circulation components of the radionuclides. The maximum dose to UK population is due to discharges from the Heysham site, while Sizewell discharges are responsible for the maximum doses to EU and World populations. The lowest calculated collective doses to all population groups are due to discharges from the Hinkley Point site. All values obtained from PC CREAM.

Table A5.5 Population Data

Region	Population
UK	5.50E+07
Europe	7.00E+08
World	1.00E+10

Table A5.6 Average per Caput Doses at Predicted Discharge Levels Truncated to 500 years (Sv/y of discharge)

Region	Aerial Release	Marine Discharges
UK	4.69E-09	2.36E-11
Europe	2.78E-09	8.71E-12
World	1.24E-09	8.40E-12

Appendix 6 – Independent radiological assessment of doses from potential short term releases

Introduction

A6.1 The information provided by WEC includes an assessment of the potential short-term gaseous discharges that may arise, e.g. during routine maintenance operations of the plant. The objective was to determine the potential for higher doses if short duration peak activity concentrations in air and foodstuffs coincide with particular agricultural or other seasonal variations. The timescale of releases to the marine environment are relatively less important; due to the effect of the limitation in pumping capacity of radioactive liquid discharge tanks and the distance at which releases occur from the shore. The methodology used to assess doses from short-term planned discharges to atmosphere is described in this Appendix.

A6.2 The radiological assessments undertaken by WEC and in this independent assessment are based on the methods outlined in Reference A6.1 and use the ADMS 4.1 atmospheric dispersion model [Ref. A6.2].

A6.3 This assessment is based on the predicted maximal monthly discharge values, as presented by WEC. The validity of the discharge predictions themselves has not been assessed.

Short-term Discharges to Atmosphere

A6.4 The predicted short-term discharge rates and the total activities discharged over a 30 minute release period are presented in Table A6.1. In accordance with information provided by WEC, these releases are assumed to occur from a 55.7 m high stack (main plant vent) located on a building with dimensions 70 x 43 x 50 m. The building was assumed to be downwind of the stack in order to provide a conservative estimate of doses.

A6.5 The ADMS 4.1 dispersion model was used to estimate activity concentrations in the air and deposited on the ground at potential receptor locations of 100 m and 500 m. These distances were chosen to maintain consistency with those used in the assessment of continuous discharges, as outlined in Appendix 3. Dry and wet deposition was modelled simultaneously, using the default deposition velocities specified within the ADMS 4.1 model set out in Table A6.2. Meteorological data were defined on the basis of recommendations set out in Reference A6.1, and are summarised in Table A6.3.

Receptor Points and Habit Data

A6.6 The most exposed members of the public from short-term discharges were assumed to be located at a habitation at 100 m from the point of release, which is assumed to be the location of the candidate representative person from continuous atmospheric discharges, as outlined in Appendix 3.

A6.7 Activity concentrations were determined at ground level at 100 and 500 m downwind of the release point. The activity concentrations in air, related to the defined release rates, and the deposition rate and cumulative deposition were determined using ADMS 4.1, and are presented in Table A6.4.

A6.8 It is assumed that the most exposed members of the public remain at this location throughout the duration of passage of the short-term release plume (30 minutes) outdoors. No location factor has therefore been applied to doses from irradiation from the cloud. An indoor occupancy of 0.9 and a location factor of 0.1 have been applied to calculation of external dose over a year following deposition, in accordance with the approach adopted in NRPB-W54 [Ref. 6.1].

A6.9 Doses from food pathways are based on similar receptor points and habits as for the continuous discharge assessment.. Green and root vegetables and fruit have been assumed to be sourced at 100 m from the discharge; other agricultural products have been assumed to be from 500 m.

Exposure Pathways

A6.10 The exposure pathways considered were:

- Internal exposure from inhalation of radionuclides from the plume. The secondary inhalation of radionuclides which have been deposited on the ground and resuspended was not included, since the release did not include radionuclides for which this pathway is likely to provide a significant contribution to dose [Ref. A6.1].;
- External dose from exposure to radionuclides in the short-term release plume (‘cloudshine’) and beta and gamma radiation from radionuclides deposited on the ground (’groundshine’);
- Internal dose from radionuclides from ingestion of local fruit and vegetable produce, cow and sheep meat and cow milk.

Doses from Short-term Releases

A6.11 Inhalation rates for adults, children and infants were derived from those in Reference A6.3. Activity concentrations in air at 100 m were used and assumed to be equivalent indoors and outdoors. Dose coefficients for inhalation and ingestion were taken from the Euratom Basic Safety Standards [Ref. A6.4] and external dose factors for ‘cloudshine’ were taken from FGR-12 [Ref. A6.5]. These values are presented in Table A6.5 and A6.6 respectively.

A6.12 The doses arising from deposited activity were estimated on the basis of data presented in Reference 6.1. The external doses arising from deposition were based on the integrated effective doses after an integrated deposit of 1 Bq m^{-2} over 1 year and the total deposit at 100 m.

A6.13 Doses arising from terrestrial food pathways were estimated on the basis of food concentration factors derived from the equilibrium factors provided in the FARMLAND model incorporated within PC CREAM [Ref. A6.6]. These factors were divided by the number of seconds in one year, in a manner consistent with that applied by WEC. These factors are presented in Table A6.7.

A6.14 The estimated dose arising from a single short-term release, from the exposure pathways above, is of the order of 13 µSv to an adult and around 11 µSv to other age groups. Inhalation has been predicted to be the primary exposure pathway, and carbon-14 was found to be the main contributor to inhalation dose, as indicated in Table A6.8.

A6.15 Reference A6.1 recommends that a first order approximation of the impact of multiple releases may be made by multiplying the dose estimated for a single release by a factor of 10.

References

A6.1 Smith, J G, Bedwell, P, Walsh C and Haywood, S M, A Methodology for Assessing Doses from Short-term Planned Discharges to Atmosphere, NRPB-W54, NRPB, Chilton (Issue 5, 2006).

A6.2 ADMS 4, Industrial Air Pollution Model, http://www.cerc.co.uk/software/adms4.htm

A6.3 Smith, K R and Jones A L, Generalised Habit Data for Radiological Assessments, NRPB-W41, NRPB, Chilton (2003).

A6.4 Council Directive 96/29 Euratom of 13 May 1996, Laying Down Basic Safety Standards for the Protection of the Health of Workers and the General Public Against the Dangers Arising from Ionising Radiation. Official Journal of the European Communities, L159, Volume 39, 29 June 1996.

A6.5 EPA (1993). External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report No. 12, EPA-402-R-93-081 (Oak Ridge National Laboratory, Oak Ridge, TN; U.S. Environmental Protection Agency, Washington, DC).

A6.6 Mayall A, Cabianca T, Attwood C, Fayers CA, Smith JG, Penfold J, Steadman D, Martin G, Morris TP and Simmonds JR. PC CREAM-97 (PC CREAM-98 code update) NRPB Chilton NRPB-SR-296 (EUR 17791) (1997).

Table A6.1 Predicted Short-Term Discharges to Atmosphere

Radionuclide	Total release in 30 minutes (TBq)	Emission rate over 30 minutes (TBq/s)
H-3	2.42E-01	1.34E-04
C-14	8.30E-02	4.61E-05
Ar-41	1.71E-01	9.50E-05
Co-60	2.69E-07	1.49E-10
Kr-85	1.27E+00	7.05E-04
Sr-90	3.70E-08	2.06E-11
I-131	1.73E-05	9.61E-09
Xe-133	1.87E-01	1.04E-04
Cs-137	1.11E-07	6.17E-11
Other radio-iodines (I-133)	3.23E-05	1.79E-08
Other noble gases (Kr-85)	5.73E-01	3.18E-04
Other particulates (Co-58)	6.03E-07	3.35E-10

Table A6.2 Deposition and Washout Coefficients

Radionuclide	Deposition Velocity (m/s)	Washout Coefficient
H-3	0	0
C-14	0	0
Ar-41	0	0
Co-60	0.001	0.0001
Kr-85	0	0
Sr-90	0.001	0.0001
I-131	0.01	0.0001
Xe-133	0	0
Cs-137	0.001	0.0001
Other radiodiodides (I-133)	0.010	0.0001
Other noble gases (Kr-85)	0	0
Other particulates (Co-58)	0.001	0.0001

*washout coefficient determined using ADMS default values for constants A and B and based on 0.1mm/hr rainfall

Table A6.3 Meteorological Assumptions

Condition	Value
Rainfall	0.1mm/hour
Wind speed	3m/s
Boundary layer height	800m
reciprocal of the Monin-Obukhov length	0

Table A6.4 Activity Concentrations for Short-term Release Rates

Nuclide	100 m			500 m		
	Air Concentration (Bq/m^3)	Total deposition (Bq/m^2/s)	Total deposition for a 30 minute release (Bq/m^2)	Air Concentration (Bq/m^3)	Total deposition (Bq/m^2/s)	Total deposition for a 30 minute release (Bq/m^2)
H-3	5.80E+03	0.00E+00	0.00E+00	1.11E+03	0.00E+00	0.00E+00
C-14	1.99E+03	0.00E+00	0.00E+00	3.81E+02	0.00E+00	0.00E+00
Ar-41	4.10E+03	0.00E+00	0.00E+00	7.85E+02	0.00E+00	0.00E+00
Co-60	6.44E-03	2.53E-05	4.55E-02	1.22E-03	5.21E-06	9.39E-03
Kr-85	3.04E+04	0.00E+00	0.00E+00	5.83E+03	0.00E+00	0.00E+00
Sr-90	8.86E-04	3.46E-06	6.22E-03	1.68E-04	7.14E-07	1.29E-03
I-131	4.10E-01	5.30E-03	9.54E+00	7.25E-02	9.80E-04	1.76E+00
Xe-133	4.48E+03	0.00E+00	0.00E+00	8.59E+02	0.00E+00	0.00E+00
Cs-137	2.66E-03	1.04E-05	1.87E-02	5.05E-04	2.14E-06	3.86E-03
Other radiodiodides (I-133)	7.65E-01	9.90E-03	1.78E+01	1.35E-01	1.83E-03	3.30E+00
Other noble gases (Kr-85)	1.37E+04	0.00E+00	0.00E+00	2.63E+03	0.00E+00	0.00E+00
Other particulates (Co-58)	1.44E-02	5.66E-05	1.02E-01	2.74E-03	1.17E-05	2.10E-02

Table A6.5 Inhalation Dose Coefficients

Age group	Radionuclide	ICRP Lung class	Inhalation Sv/Bq	Ingestion Sv/Bq
Adult	H-3	V	1.8E-11	1.8E-11
	C-14	V	2E-09	5.8E-10
	Co-58	M	1.6E-09	7.4E-10
	Co-60	M	1E-08	3.4E-10
	Sr-90	M	3.6E-08	2.8E-08
	Cs-137	F	4.6E-09	1.3E-08
	I-131	F	7.4E-09	2.2E-08
	I-133	F	1.5E-09	4.3E-09
Child	H-3	V	2.3E-11	2.3E-11
	C-14	V	2.8E-09	8E-10
	Co-58	M	2.4E-09	1.7E-09
	Co-60	M	1.5E-08	1.1E-08
	Sr-90	M	5.1E-08	6.0E-08
	Cs-137	F	3.7E-09	1E-08
	I-131	F	1.9E-08	5.2E-08
	I-133	F	3.8E-09	1E-08
Infant	H-3	V	4.8E-11	4.8E-11
	C-14	V	6.6E-09	1.6E-09
	Co-58	M	6.5E-09	4.4E-09
	Co-60	M	3.4E-08	2.7E-08
	Sr-90	M	1.1E-07	7.3E-08
	Cs-137	F	5.4E-09	1.2E-08
	I-131	F	7.2E-08	1.8E-07
	I-133	F	1.8E-08	4.4E-08

Table A6.6 Factors for External Dose Rates used in the assessment.

Radionuclide	Cloud Shine (Sv/s per Bq/m^3)	Deposited Gamma (Sv/y per Bq/m2)*
H-3	0	0
C-14	2.61E-18	0
Ar-41	6.11E-14	0
Co-60	1.19E-13	4.38E-08
Kr-85	2.39E-16	0
Sr-90	9.72E-17	0
I-131	1.69E-14	2.48E-10
Xe-133	2.56E-14	0
Cs-137	2.75E-14	1.08E-08
Other radiodiodides (I-133)	2.39E-16	5.99E-10
Other noble gases (Kr-85)	4.44E-14	0
Other particulates (Co-58)	1.33E-15	0

*From NRPB-W54 [Ref. A6.1]

Table A6.7 Derived Transfer Factors for Terrestrial Foods

Radionuclide	Green Veg	Root Veg	Fruit	Milk	Cow Meat	Cow liver	Sheep Meat	Sheep Liver
	Bq/kg per Bq/m2	Bq/kg per Bq/m2	Bq/kg per Bq/m2	Bq/kg per Bq/m2	Bq/kg per Bq/m2	Bq/kg per Bq/m2	Bq/kg per Bq/m2	Bq/kg per Bq/m2
H-3	3.58E-06	3.17E-06	3.17E-06	3.58E-06	2.77E-06	2.77E-06	2.77E-06	2.77E-06
C-14	8.47E-06	1.69E-05	1.69E-05	8.47E-06	2.54E-05	2.54E-05	2.54E-05	2.54E-05
Co-60	3.49E-03	1.20E-05	5.77E-04	1.88E-03	6.09E-04	6.09E-02	9.67E-04	9.67E-02
Sr-90	3.71E-03	3.93E-05	5.80E-04	1.37E-03	2.92E-04	2.92E-04	3.61E-04	3.61E-04
I-131	1.31E-03	2.73E-04	9.80E-04	1.85E-03	6.60E-04	7.83E-04	1.01E-03	1.01E-03
Cs-137	4.19E-03	3.90E-03	2.32E-03	4.88E-03	2.48E-02	2.48E-02	4.60E-02	4.60E-02
Other radiodiodides (I-133)	1.96E-04	1.48E-06	1.69E-04	1.20E-04	7.10E-06	3.52E-05	2.15E-05	2.15E-05
Other particulates (Co-58)	2.90E-03	8.12E-06	5.04E-04	1.62E-03	2.16E-04	2.20E-02	3.68E-04	3.68E-02

*The parameters for tritium and carbon-14 are in the units of Bq/kg per Bq/m^3/s

Table A6.8 Estimated Doses from a Single Short-term Release (µSv)

	Inhalation	Cloud Gamma	Deposited Gamma	Ingestion	Total
Adult	6.13E+00	1.36E+00	2.93E-03	5.50E+00	**1.30E+01**
Child	2.49E+00	1.36E+00	2.93E-03	6.90E+00	**1.08E+01**
Infant	2.09E+00	1.36E+00	2.93E-03	8.67E+00	**1.21E+01**

Appendix 7 – The effect of alternative assumptions on the independent assessment

Introduction

A7.1 The total doses are predicted to be low from an AP1000 power plant based on predicted discharges and generic site conditions and within the range of 1 to 10 μSv/y. Given that doses are low, a limited uncertainty assessment has been made, taking into account three main areas:-

- ***Foetal and breastfed infant dose.*** The representative person for a prospective site is likely to include adult women of child bearing age who may be pregnant from time to time. Dose coefficients for foetuses have been published by the ICRP [Ref A7.1] and the HPA have provided factors linking the doses to adults to those to the foetus and breast fed infant [Ref A7.2]. These factors have been used to assess dose to the foetus and infant in the first months of life.

- ***Uncertainty in internal doses from radionuclides taken into the body exists.*** Recent reviews of doses and risks from radionuclides have suggested that uncertainty associated with internal doses from radionuclides may be greater than those for external exposure [e.g. Ref A7.3]. In response to this the Environment Agency has agreed to separate the estimates of effective doses from intakes of radionuclides, from estimates of effective doses from external exposure, so that uncertainty can be considered in more detail if required.

- ***Variation in wind direction around the generic site.*** The main assessment of dispersion of radionuclides discharged to air over the course of a year assumes a uniform wind rose. For a generic site no specific meteorological data exists, nonetheless the effect of a non-uniform wind rose, where the candidates for the representative person are assumed to be located in a predominant downwind location, on the predicted doses has been assessed.

- ***Location of candidates for the representative person affected by atmospheric discharges.*** The assessment of dispersion of radionuclides discharged to air assumes that the candidates for the representative person affected by atmospheric discharges live 100m from the release point and eat food produced at 500m from the release point. Other assessments that will be made assume that candidates for the representative person live and eat food produced at the location where air concentrations are highest. The affect of adopting these latter assumptions on predicted doses can be assessed.

Dose to Foetus and Breastfed Infant

A7.2 Doses to the foetus and breastfed infant may be assessed on the basis of the dose to an adult mother and foetal and breastfed infant dose coefficients [Ref. A7.1, A7.2]. HPA guidance [Ref. 7.3] indicates that explicit assessment of doses to the foetus is often not necessary. Four radionuclides (^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr) are identified for which such assessments are necessary. Sr-89 is the only one of these radionuclides included in the predicted releases from the AP1000. However, for the purposes of providing a scoping assessment of foetal doses from intakes by the foetus and breastfed infants, the doses to adults arising from inhalation and ingestion from atmospheric and marine discharges were multiplied by the time-weighted ratio of the dose coefficients for foetus (9 months) and breastfed infant during breastfeeding (3 months) to those of the adult. The relevant dose coefficients and multiplication factors are given in Table A7.1.

A7.3 The contribution to doses from key radionuclides to adults and foetus and breast fed infants from key who are either CRP1 (atmospheric discharges) or CRP2 (liquid discharges) are presented Table A7.2 and Table A7.3 respectively.

A7.4 The highest foetal/infant dose was 2.5 μSv/y to CRP1 who are most exposed to atmospheric discharges. This dose was 0.4 μSv/y higher than to the adult mother.

Internal/External Exposure

A7.5 The internal and external component of effective doses to members of the representative persons most exposed to aerial and liquid discharges from the AP1000 power plant are given in Tables A7.4 and A7.5.

The Effect of Local Meteorological Conditions

A7.6 The assessment made for atmospheric discharges groups the wind uniformly into 12 sectors. A uniform distribution means that the wind would blows into each sector 8.3% of the time. Doses from aerial discharges are proportional to air concentrations which, in turn are proportional to the frequency of wind blowing into the sector. A uniform windrose means that air concentration and doses are the same regardless of the sector.

A7.7 To assess the effect of a non uniform windrose on the doses it has been assumed that CRP1 are located in a predominant downwind direction such that the wind blows in that direction for 2 times more than that with a uniform windrose. This factor is based on an analysis of the difference in the amount of time the wind blows towards a given 30 degree wind angle for a coastal location in the North West of England, which is close to a number of proposed locations for new nuclear power stations. The resulting factor was between 1.63 and 1.85, which has been rounded to 2 for the purposes of this generic assessment.

A7.8 The range of doses from atmospheric discharges to a candidate for the reference person (CRP1) who is situated in a predominant downwind direction will be around twice that for a candidate for the reference person assuming a uniform windrose. Thus, such doses would be around 5.2 μSv/y to adult and 8.8 μSv/y to infant, compared with the uniform windrose dose of 2.6 μSv/y to adult and 4.4 μSv/y to infant.

The effect of adopting different locations for candidate reference person

A7.9 The dose assessment will also be influenced by the choice of the distance at which the candidate representative person (or receptor) is assumed to live and derive their foods, from the release point.

A7.10 In the independent assessment, standard assumptions regarding the habitation and domestic fruit and vegetable production (100 m) and agricultural produce (500 m) were made. In order to determine the likely magnitude of the difference such assumptions could make to the doses assessed, the ratios of the time integrated air concentrations at the assumed locations to the maximum values were determined, using the appropriate plots of air concentrations for a continuing release for 60% Category D conditions, from NRPB-R91 [Ref. A7. 5]. The integrated air concentration at 100 m was found to be around 70% of that at 200 m (the location of the maximum air concentration) and that at 500 m was found to be 50% of this value, as demonstrated in Table A7.5. By making alternative assumptions about the location of the terrestrial candidate representative person, it may therefore be possible to predict doses that are higher by up to a factor of 2 than the independent assessment.

References

A7.1 International Commission on Radiological Protection, Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother, ICRP Publication No. 88, Corrected Version 2001, Ann. ICRP 31 (1-3) (2001).

A7.2 International Commission on Radiological Protection, Doses to Infants from Ingestion of Radionuclides in Mother's Milk, ICRP Publication No. 95, Ann. ICRP 34 (3-4) (2004).

A7.3 Guidance on the Application of Dose Coefficients for the Embryo, Fetus and Breastfed Intant in Dose Assessments for Members of the Public, Health Protection Agency, RCE-5 (2008).

A7.4 Committee on Examining Radiation Risks of Internal Emitters, Report (2004).

Table A7.1 Adult, Foetal and Breast Feeding Infant Dose Coefficients and Derived Modification factors for Adult doses

Radionuclide	Inhalation			Ingestion			Inhalation factor	Ingestion factor
	Foetus	Infant	Adult	Foetus	Infant	Adult		
H-3	6.30E-11	3.00E-11	4.10E-11	3.10E-11	2.00E-11	1.80E-11	1.34E+00	1.57E+00
C-14	8.00E-10	2.60E-10	5.80E-10	8.00E-10	2.60E-10	5.80E-10	1.15E+00	1.15E+00
Sr-89	2.10E-09	4.30E-10	6.10E-09	1.20E-08	2.00E-09	2.60E-09	2.76E-01	3.65E+00
Sr-90	8.80E-09	3.90E-09	3.80E-08	4.30E-08	1.50E-08	3.10E-08	1.99E-01	1.16E+00
I-131	8.10E-09	1.90E-08	7.40E-09	2.30E-08	5.50E-08	2.20E-08	1.46E+00	1.41E+00

Table A7.2 Foetal Dose from discharges from the AP1000 Power plant (pregnant women CRP1 - most exposed to atmospheric discharges)

Radionuclide	Adult Dose (μSv/y)		Foetal/ infant doses (μSv/y)*	
	Inhalation	Ingestion	Inhalation	Ingestion
H-3	9.64E-03	5.20E-02	1.29E-02	8.16E-02
C-14	3.61E-01	2.10E+00	4.14E-01	2.41E+00
Sr-89	2.00E-06	1.15E-06	5.51E-07	4.19E-06
Sr-90	4.40E-06	3.97E-05	8.77E-07	4.60E-05
I-131	4.71E-04	2.69E-02	6.89E-04	3.79E-02
Total	**3.71E-01**	**2.18E+00**	**4.27E-01**	**2.53E+00**

*For the period of 12 months in which the foetal dose coefficient applies to 9 months and the dose coefficient for infants during lactation is applied for 3 months

Table A7.3 Foetal Dose from discharges from the AP1000 (pregnant women CRP2, - most exposed to liquid discharges)

Radionuclide	Adult Dose (μSv/y)		Foetal/ infant doses (μSv/y)*	
	Inhalation	Ingestion	Inhalation	Ingestion
H-3	0.00E+00	2.10E-03	0.00E+00	3.30E-03
C-14	0.00E+00	9.59E-01	0.00E+00	1.10E+00
Sr-89	0.00E+00	2.80E-07	0.00E+00	1.02E-06
Sr-90	0.00E+00	4.60E-07	0.00E+00	5.34E-07
I-131	0.00E+00	4.47E-05	0.00E+00	6.30E-05
Total	**0.00E+00**	**9.61E-01**	**0.00E+00**	**1.11E+00**

*For the period of 12 months in which the foetal dose coefficient applies to 9 months and the dose coefficient for infants during lactation is applied for 3 months

Table A7.4 Separation of internal and external doses to CRP1 (infant) who are most exposed to gaseous discharges from Stack 1 of the AP1000 Power plant

Radionuclide	Effective Dose to CRP1 AP1000 Power plant μSv/y		
	Total	External	Internal
Ar-41	3.43E-02	3.43E-02	0.00E+00
Ba-140	5.80E-07	5.56E-10	5.79E-07
C-14	3.98E+00	6.84E-07	3.98E+00
Co-58	3.26E-05	1.77E-07	3.24E-05
Co-60	1.07E-04	1.74E-07	1.07E-04
Cr-51	2.96E-08	1.14E-10	2.95E-08
Cs-134	3.60E-05	2.71E-08	3.60E-05
Cs-137	4.77E-05	4.35E-12	4.77E-05
H-3	1.20E-01	2.57E-07	1.20E-01
I-131	2.35E-01	1.68E-06	2.35E-01
I-133	6.76E-03	4.49E-06	6.76E-03
Kr-85	3.23E-04	3.23E-04	0.00E+00
Kr-85m	7.44E-05	7.44E-05	0.00E+00
Kr-87	3.42E-04	3.42E-04	0.00E+00
Kr-88	1.55E-03	1.55E-03	0.00E+00
Mn-54	7.91E-07	1.94E-09	7.89E-07
Nb-95	4.42E-07	1.44E-08	4.28E-07
Sr-89	7.77E-06	3.67E-11	7.77E-06
Sr-90	7.24E-05	1.33E-12	7.24E-05
Xe-131m	2.32E-04	2.32E-04	0.00E+00
Xe-133	7.20E-04	7.20E-04	0.00E+00
Xe-133m	1.47E-04	1.47E-04	0.00E+00
Xe-135	2.21E-03	2.21E-03	0.00E+00
Xe-135m	2.42E-03	2.42E-03	0.00E+00
Xe-138	6.23E-03	6.23E-03	0.00E+00
Zr-95	5.11E-07	5.33E-09	5.05E-07
Total	**4.39E+00**	**4.86E-02**	**4.34E+00**

Table A7.5 Separation of internal and external doses to CRP2 (adult) most exposed to liquid discharges from marine discharges from the AP1000 reactor design.

Radionuclide	Effective Dose to CRP 2 AP1000 Power plant µSv/y		
	Total	External	Internal
Ag-110m	5.05E-03	3.40E-06	5.05E-03
Ba-140	3.03E-06	8.35E-09	3.02E-06
C-14	9.59E-01	1.86E-08	9.59E-01
Ce-144	4.65E-05	3.34E-07	4.61E-05
Co-58	4.98E-04	2.78E-05	4.70E-04
Co-60	1.34E-03	1.17E-03	1.72E-04
Cr-51	1.28E-06	2.70E-08	1.26E-06
Cs-134	2.53E-04	3.66E-06	2.50E-04
Cs-136	2.49E-05	6.06E-08	2.48E-05
Cs-137	5.35E-04	6.34E-09	5.35E-04
Fe-55	3.62E-03	0.00E+00	3.62E-03
Fe-59	1.60E-04	2.34E-07	1.59E-04
H-3	2.10E-03	0.00E+00	2.10E-03
I-131	4.47E-05	6.22E-10	4.47E-05
I-133	2.78E-06	3.62E-11	2.78E-06
La-140	2.38E-07	1.92E-07	4.58E-08
Mn-54	2.94E-05	9.21E-06	2.02E-05
Na-24	5.64E-09	1.83E-09	3.81E-09
Nb-95	7.18E-07	4.79E-07	2.39E-07
Ni-63	1.54E-04	0.00E+00	1.54E-04
Pr-144	1.05E-10	4.48E-14	1.05E-10
Pu-241	3.20E-07	3.13E-13	3.20E-07
Ru-103	6.62E-04	1.13E-07	6.62E-04
Sr-89	2.80E-07	2.86E-11	2.80E-07
Sr-90	4.60E-07	2.69E-11	4.60E-07
Tc-99m	8.11E-08	2.45E-13	8.11E-08
Y-91	3.85E-09	2.75E-11	3.82E-09
Zn-65	3.15E-03	1.31E-06	3.15E-03
Zr-95	1.10E-06	3.21E-07	7.78E-07
Total	**9.77E-01**	**1.22E-03**	**9.76E-01**

Table A7.6 Time integrated air concentration for 20 m release height for 60% D stability category

Distance from release point	Air conc. (Bq s m-3)	Ratio of receptor distance to distance of max. Air conc.
100 m	2.00E-06	0.74
500 m	1.30E-06	0.48
Distance of max air conc.(200 m)	2.70E-06	-

Appendix 8 – Independent assessment of doses from direct radiation

Introduction

A8.1 Exposure of the public from direct radiation from nuclear sites in the UK is the responsibility of the HSE, who require site operators to measure direct radiation at the site perimeter and estimate exposure to a reference group on an annual basis.

A8.1 As no UK EPR nuclear power plants have yet been built and operated, it is necessary to estimate the direct radiation dose that may arise. For the purposes of this estimation, measured direct radiation data from Sizewell B have been used. This is currently the only operational PWR nuclear power station in the UK.

A8.2 Direct radiation exposure is included within this assessment for comparison against the relevant dose constraints, based on the most recent data available for Sizewell B.

A8.3 The assessment of doses from atmospheric and liquid discharges from the AP1000 is outlined in Appendices 3 and 4, respectively. These data are collated for application of dose constraints in Appendix 9.

Direct Exposure Estimates

A8.4 The dose to the representative person from direct radiation from Sizewell B in 2007 was assessed to be 4 μSv [Ref. A8.1], Table 8.1. The direct radiation measurements in previous years were higher, due to the contribution from the adjacent Magnox station (Sizewell A). The value in 2007 is considered to more appropriate for the purposes of this assessment than an average value due to the fact that Sizewell A ceased generation in 2006, and therefore the 2007 value is less likely to include a contribution from an adjacent source.

A8.5 This direct radiation estimate is assumed to apply to CRP1 only. It is assumed that local fisherman and their families who are CRP2 do not collect seafood from near to the site and do not live close enough to receive a dose from direct radiation. Application of direct radiation assumptions is summarised in Table 8.2.

References

A8.1 Food Standards Agency and Joint Environment Agencies. Radioactivity in Food and the Environment, 2007(RIFE-13) (2008).

Table A8.1 Sizewell B Dose Rate from Direct Radiation

Installation	Annual Dose to Reference Group for Direct Radiation (µSv/y)
Sizewell B	4

Table A8.2 Application of Direct Exposure to CRP 1 and CRP2

Installation	Candidate for representative person	Total Annual Dose to Reference Group for Direct Radiation (µSv/y)
AP1000 Power plant	CRP1 (gaseous discharges)	4
	CRP2 (liquid discharges)	0

Appendix 9 – Independent assessment of site dose and total dose

Introduction

A9.1 The Environment Agency has responsibility to assess the maximum doses to individuals which may result from a defined source for use at the planning stage in radiation protection [Ref A9.1]. The current applicable criteria are:

- 0.3 millisieverts per year (mSv/y) (300 µSv/y) from any source (source dose constraint);
- 0.5 millisieverts per year (mSv/y) (500 µSv/y) from the discharges from any single site (site dose constraint).

A9.2 The Environment Agency has also been directed to ensure that the sum of doses resulting from exposure to ionising radiation (total dose) does not exceed 1 mSv/y (1,000 µSv/y) [Ref A9.1].

A9.3 In its Consultation Guidance on the application of the 2007 ICRP Recommendations to the UK [Ref. A9.2], the HPA has recommended that a maximum source constraint for members of the public of 150 µSv/y for new nuclear power stations should be used.

Source Dose

A9.4 The dose for comparison with the source dose constraint includes the contribution from direct radiation. The assessment of doses from predicted future discharges from the AP1000 power plant is outlined in Appendices 3 and 4 for discharges to atmospheric and liquid discharges, respectively. The dose from direct radiation was estimated, as outlined in Appendix 8. The highest effective doses from this source were found to be 8.4 µSv/y, including a contribution of 4 µSv/y from direct radiation. These dose estimates are summarised in Tables A9.1 are well below the existing source constraint.

A9.5 It is proposed that the annual effective dose to the representative person summed over all relevant exposure pathways should be for comparison with the proposed dose constraint from new nuclear power stations [Ref.9.2]. It is therefore assumed that this would include the potential contribution from direct radiation from the power plant. The summed doses assessed from atmospheric and liquid discharges and from direct radiation are therefore also compared with the proposed maximum dose constraint for new nuclear power stations [Ref.9.2]. The doses, presented in Table A9.1, are also well below this level.

Site Dose

A9.1 To assess the dose from an AP1000 nuclear power plant located at a given site, for comparison with the 500 µSv/y site dose constraint, it would be necessary to include doses from future discharges from any other sources on the site and other sites with contingent boundaries. For the purposes of this assessment, it is assumed that the AP1000 is the only source located at the generic site. In this case, the source dose and site dose are equivalent. The representative person dose of 8.4 µSv/y is also significantly lower than the site constraint of 500 µSv/y.

A9.2 If the AP1000 were to be co-located with another current or past source of radioactive discharges, the site dose would need to be reassessed accordingly.

Total dose

A9.6 An assessment of total dose for comparison with the dose limit would take account of:

- Historical discharges from any other power plants or practices with which the AP1000 power plant is co-located;
- Historical discharges from other sites that lead to elevated levels of radioactivity in the area;
- Future discharges from the AP1000 and co-located power plants or other practices;
- Direct radiation from the AP1000 and co-located reactors or other practices; and,
- Future discharges from other sites that lead to elevated levels of radioactivity in the area.

A9.7 For a generic assessment it is not possible to make a realistic or meaningful estimate of the total dose, given that information on the location of the AP1000 nuclear power plant, co-located reactors or other sources cannot been defined. In the absence of such information, it may be assumed that the AP1000 is located at an isolated location at some distance from any existing or previous sources of radioactive discharges. In this case, the total dose would be equivalent to the source and site dose. The total representative person dose of 8.4 µSv/y is also significantly less than the dose limit of 1000 µSv/y.

A9.8 If the UK EPR were to be located in the vicinity of another source of radioactive discharges, the total dose would need to be reassessed accordingly taking into account discharges and direct radiation from any other sites.

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References

A9.1 Joint Agencies, Principles for the Assessment of Prospective Public Doses (Interim Guidance) December 2002.

A9.2 Health Protection Agency, HPA Advice on the Application of the ICRP's 2007 Recommendations to the UK, Consultation Document, HPA, Chilton, (2008).

Table A9.1 Summary of Doses from the AP1000 Power plant for Predicted Discharges (μSv/y) for Comparison against the Source Constraint and Proposed Maximum Dose Constraint for New Nuclear Power Stations

Candidate Representative person[a]	Age group	AP1000 Power plant Dose (μSv/y)			
		Atmospheric Discharges	Marine Discharges	Direct Radiation	Total Source Dose
Family at nearest dwelling (CCG1)	Adult	2.64	0.07	4	6.71
	Child	2.87	0.04	4	6.91
	Infant	4.39	0.04	4	8.43
Fisherman and family (CCG2)	Adult	1.61	0.98	0	2.59
	Child	1.87	0.29	0	2.17
	Infant	2.13	0.10	0	2.23

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