ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR-1') AND ASSOCIATED INFRASTRUCTURE

ASSESSMENT OF THE POTENTIAL RADIOLOGICAL IMPACT ON THE PUBLIC AND THE ENVIRONMENT

August 2015




Prepared by: J Slabbert

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PSI RISK CONSULTANTS CC

Prepared for: GIBB Pty Ltd

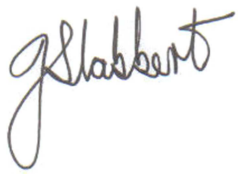
GIBB
ENGINEERING & ARCHITECTURE

On behalf of: Eskom Holdings Ltd

Eskom

DECLARATION OF INDEPENDENCE

I, Johan Slabbert, an independent consultant, hereby confirm my independence as a specialist and declare that I do not have any interest, be it business, financial, personal or other, in any proposed activity, application or appeal in respect of which GIBB (Pty) Ltd was appointed as environmental assessment practitioner in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), other than fair remuneration for worked performed, specifically in connection with the Environmental Impact Assessment for the proposed conventional nuclear power station ('Nuclear-1'). I further declare that I am confident in the results of the studies undertaken with information made available by Eskom and conclusions drawn as a result of it – as is described in my attached report.



Full Name: Johan Slabbert

Title / Position: Radiation Protection Specialist
Qualification(s): BSc Hons; M.Phil, Environmental Management
Experience (years/ months): 34 years
Registration(s): Pr Sci Nat

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EXECUTIVE SUMMARY

South Africa considers the construction of a nuclear power plant (NPP) consisting of a combination of reactor units with a total electrical power capacity of up to 4 000 MWe and its associated infrastructure. The Environmental Impact Assessment (EIA) makes provision for the potential future expansion of a NPP to allow for a total capacity of approximately 10 000 MWe on a site. It is envisaged that light water reactors (LWR) and specifically GEN III pressurised water reactors (PWR) will be the selected technology.

The structure of this report is based on a prospective radiological impact assessment as required at an early stage of a nuclear authorisation process in terms of the National Nuclear Regulator Act (NNR Act). This report, therefore, does not follow the typical structure of an EIA specialist report as it applies to non-radiological impacts assessments. These EIA reports include qualitative significance ratings for environmental impacts that are categorised as High, Medium or Low, The significance category of an impact depends on the nature, intensity, extent, duration, consequence and probability of the impact. The fact that the radiological impacts and an assessment of their cumulative effects have to meet NNR regulatory criteria that are based on internationally recognised and accepted systems of radiological protection, result in a low significance of a NPP's radiological impact for normal operations. The result of the cumulative radiological impacts where more than one nuclear facility could impact the same receiving environment, must also meet specific dose and risk criteria equivalent to a low impact.

The potential radiological impacts on the public and the environment at the three proposed sites, Thyspunt, Bantamsklip, and Duynefontein, were investigated as part of an assessment of the feasibility of each of the sites. The investigation included the following aspects:

1) Nuclear power plant radiological discharges to the environment during normal operation and public dose.
2) Nuclear power plant accidents and radiological risk to the public.
3) Radiological risk to non-human biota.
4) Background radiation at the three sites.

The results of the investigations into these four aspects provide responses to four possible questions that interested and affected parties may have regarding nuclear safety.

1) *What is the radiological health risk by living next to one of the sites?*

   South African radiological safety regulations specify an annual effective dose limit of 1 milli-Sievert (mSv) to a member of the public from all authorised actions involving nuclear and radioactive material. To ensure that the limit is not exceeded and protective measures are applied to achieve a dose as low as reasonable achievable (ALARA), a dose constraint is also specified for individual sources such as a NPP. In South Africa, the dose constraint is 0.25 mSv per year. The dose constraint value is representative of an extremely low health risk when compared to normal operational discharges of noxious materials from many other industrial activities. The dose constraint is also a small fraction of the natural background radiological dose of 2.4 mSv per year, the global average.

   An assessment of operational radioactive discharges from representative GEN III nuclear power plants was carried out by considering specific characteristics of each site

and using conservative assumptions. The regulatory dose constraint of 0.250 mSv per year to a member of the public can be met at each of the three sites**.**

2) *What is the risk of a nuclear accident?*

The majority of NPPs operating today were built in the nineteen seventies and eighties. NPP accidents at Three Mile Island, Chernobyl, and Fukushima resulted in serious questions about nuclear safety and the future of nuclear power plants. An overview is provided of the nuclear safety criteria applicable to accidents and some of the safety assessment methodologies. The safety features of GEN III reactors and the fundamental objective to practically eliminate large releases of radioactivity in the event of a severe accident that involves reactor fuel damage are discussed. It is concluded that GEN III NPP designs should meet the regulatory risk criteria. An assessment of a specific NPP design selected for a site will have to provide the final nuclear safety case before NPP operation will be allowed by the National Nuclear Regulator.

3) *What are the radiological risks to non-human biota?*

The radiological protection of non-human species has evolved considerably over recent years. Where radiological protection used to focus on human protection based on the assumption that, if humans are protected, non-humans living in the same environment would be sufficiently protected, the explicit consideration of Radiological Protection of the Environment is now recommended by the International Commission on Radiological Protection (ICRP). A screening assessment was performed of the radiation dose rates to a set of reference animals and plants from radioactive discharges during normal operation of a NPP. The dose rates are less than the reference value of 10 microgray per hour (µGy/h), a value well below any dose rate where measureable effects in organisms would be detected.

Much research is carried out to determine the effects nuclear accidents on non-human biota. The United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) produced an authoritative Fukushima report in which radiological exposures of selected non-human biota were estimated. UNSCEAR concluded that the possibility of effects on non-human biota in both the terrestrial and aquatic (freshwater and marine) environments was geographically constrained and that, in areas outside the constrained area, the potential for effects on biota may be considered insignificant.

4) What are the current ionising radiation and radioactivity levels at the sites' environments?

Background radiation surveys were carried over a period of approximately one year at each of the sites. The results indicate that the radiation dose to people living at the coastal areas near the three sites is lower than global average dose of approximately 2.4 mSv per year. One of the objectives of the surveys was to identify any radioactivity anomalies that may exist in the regions where the sites are located.

High terrestrial radioactivity of natural origin was detected at a location west of the Thyspunt site. The radioactivity results of marine biota confirmed international findings on the naturally occurring radionuclide polonium-210 and its potential high dose contribution to humans when compared to other radionuclides. Artificial radionuclides, for example Cs-137, were detected at all three sites. Globally, the presence of Cs-137 is attributed to historic events such as atmospheric atomic weapons tests.

The results of the prospective radiological assessments for the three sites presented in this report confirm environmental impacts of low significance and low cumulative effects.

GLOSSARY

Activity	The expectation value of the number of nuclear transformations occurring in a given quantity of material per unit time. The SI unit of activity is per second (s^{-1}) and its special name is becquerel (Bq)
Alpha radiation	Emission of energy from the atomic nucleus as alpha particles. Alpha particles are comparatively large, positively charged nuclei of helium, and have a low penetrating power, e.g. being stopped by a few centimetres of air or a sheet of paper.
Artificial radioactivity	Radioactivity not of a natural origin (see definition of NORM) and is produced as a result of human technological processes, for example, inside a nuclear power reactor.
Background radiation	The radiation in the natural environment, including cosmic and cosmogenic radiation and radiation from naturally occurring radioactive elements. It may also be referred to as natural background radiation.
Beta radiation	This is emission of energy from the atomic nucleus as beta particles. Beta particles are equivalent to electrons and are able to penetrate approximately a metre of air or a centimetre of water.
Bio-accumulation	The process by which contaminants in the environment are accumulated in increasing concentrations up the food chain (e.g. from benthic organisms consumed by fish and by humans).
Contamination	Radioactive substances on surfaces or within solids, liquids, or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places.
Cosmic radiation	Radiation of great penetrating power reaching the earth from all directions of outer space.
Cosmogenic radiation	Radiation that results from the interaction of cosmic radiation with the Earth's atmosphere, for example radioactive carbon, C-14, which is created in the earth's atmosphere.
Critical Group (also see Representative Person)	A group of members of the public (in the general population) which is reasonably homogeneous with respect to its exposure for a given radiation source and given exposure pathway and is typical of individuals receiving the highest dose by the given exposure pathway from the given source.
Derived Consideration Reference Level	A band of non-human biota dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of reference animal or plant, when considered together with other relevant information, can be used as a point of reference. The point of reference serves to optimise the level of effort expended on environmental protection and is dependent upon the overall management objectives and the relevant exposure situation.

GLOSSARY

Detects	Radionuclides reported at environmental media concentrations above the minimum detectable activity (MDA) in a laboratory radioanalysis report.
Discharge	Planned and controlled release of radioactive material to the environment (usually gaseous or liquid).
Dose	Absorbed dose: t is the fundamental dose quantity given by: $$D = \frac{d\bar{\varepsilon}}{dm}$$ Where $d\bar{\varepsilon}$ is the mean energy imparted to matter of mass dm by ionising radiation. The SI unit for absorbed dose is joule per kilogram (Jkg^{-1}) and its special name is gray (Gy). Committed Effective Dose: A weighted measure of the radiation energy received or absorbed by the whole body and measured in units of sievert (Sv); more specifically, the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body. The commitment period is taken to be 50 years for adults, and to age 70 years for children. Annual Effective Dose: The total effective dose, E_T to a person is calculated according to the following formula: $$E_T = H_p(d) + \sum_j e(g)_{j,ing} I_{j,ing} + \sum_j e(g)_{j,inh} I_{j,inh}$$ where $H_p(d)$ is the personal dose equivalent from exposure to penetrating gamma radiation during the year; $e(g)_{j,ing}$ and $e(g)_{j,inh}$ are the committed effective dose per unit intake by ingestion and inhalation for radionuclide j by the group of age g; and $I_{j,ing}$ and $I_{j,inh}$ are the intakes via ingestion or inhalation of radionuclide j during the same period.
Dose rate	The amount of ionising radiation received over a given period.
Dose constraint	A prospective and source-related restriction on the individual dose from a source (e.g. Nuclear Power Plant), which provides a basic level of protection for the most highly exposed individuals from a source, and serves as an upper bound on the dose in optimisation of protection for that source. For public exposure, the dose constraint is interpreted as the annual effective dose equal to 250 μSv/y, an upper bound on the annual doses that members of the public should receive from a nuclear site (Thyspunt, Bantamsklip, and Duynefontein).

GLOSSARY

Exposure	The act or condition of being subject to ionising radiation Public exposure is exposure incurred by members of the public from radiation sources, excluding any occupational or medical exposure and the normal local natural background radiation. Potential exposure is exposure that is not expected to be delivered with certainty but that may result from an accident at a source or an event or sequence of events of a probabilistic nature, including equipment failures and operating errors.
Exposure pathway	A route by which radiation or radionuclides can reach humans and cause exposure. An exposure pathway may be very simple, e.g. external exposure from airborne radionuclides, or a more complex chain, e.g. internal exposure from drinking milk from cows that ate grass contaminated with deposited radionuclides.
Gamma radiation	High energy, short wave length electromagnetic radiation of nuclear origin. Gamma rays are the most penetrating when compared to alpha and beta radiation.
Groundwater	Water beneath the Earth's surface, accumulating as a result of infiltration and seepage, and serving as the source of springs, wells, etc.
Gray (Gy)	The special name for the SI unit of absorbed dose: 1 Gy = J kg^{-1}.
Intake	The process of taking nuclides into the body either by inhalation (typically as dust with air) or by ingestion (drinking water and/or eating food).
KPA	Abbreviation for Kinetic Phosphorescence Analysis, a technique to determine elemental uranium concentration in an environmental sample.
MDA	Abbreviation for Minimum Detectable Activity, the activity which, if present in a sample, produces a counting rate that will be detected (i.e. considered to be greater than analysis system background) with a certain level of confidence.
Non-human biota (also refer to Reference Animal and Plant)	Species of fauna and flora. The term *Wildlife* is also used in the literature.
NORM	Abbreviation for Naturally Occurring Radioactive Material. The main contributions of human exposure to ionising radiation arise from natural sources, e.g. cosmic rays, the nuclides in the earth's crust, and the natural radioactivity of the human body. Of the natural nuclides in the earth's crust (NORM), those that are found to be the main sources of human radiation exposure are potassium-40 (K-40), thorium-232 (Th-232), uranium-235 (U-235) and uranium-238 (U-238), and decay products from the latter three nuclides.

	Potassium is a common element, and the radioactive isotope K-40 constitutes 0.012% of all potassium in its natural form. The three heavy nuclides (Th-232, U-235, and U-238) decay to produce other elements, which in turn decay further through a chain which includes several elements, eventually to end in stable isotopes of lead. An example of a significant daughter nuclide in these decay chains is radon (Rn-222). It is a gaseous decay product and the main contributor to background dose.
Nuclide (radionuclide)	An element or isotope that is radioactive as a result of the instability of the nucleus of its atom (e.g. radium or uranium).
Radiation (ionising)	The emission and propagation of energy through space or matter in the form of electromagnetic waves (gamma rays) or fast-moving particles such as alpha and beta particles.
Radioactive	The condition of a material exhibiting the spontaneous decay of an unstable atomic nucleus into one or more different elements (e.g. uranium decays into various isotopes of radium, thorium, and lead).
Radioactive material	Material designated by the National nuclear Regulator as being subject to regulatory control because of its radioactivity, often taking account of both activity and activity concentration.
Radiation Effect	Stochastic effects of radiation: Malignant disease and heritable effects for which the probability of an effect occurring, but not its severity, is regarded as a function of dose without threshold. Deterministic effect: Injury in populations of cells, characterised by a threshold dose and an increase in the severity of the reaction as the dose is increased further. Also termed tissue reaction. In some cases, deterministic effects are modifiable by post-irradiation procedures including biological response modifiers.
Radon gas	A naturally occurring radioactive gas within the decay chain of U-238.
Reference Animal or Plant	A hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.
Representative Animal or Plant	A particular species or group of organisms selected during a site-specific assessment, taking account of their assumed location with respect to the source. In many cases, the actual representative organisms chosen for this purpose may be the same as, or very similar to, the Reference Animals and Plants; however, in some cases, they may be very different.
Reference Person	A hypothetical aggregation of human (male and female) physical and physiological characteristics arrived at by international consensus for

	the purpose of standardizing radiation dose calculations
Representative Person	An individual receiving a dose that is representative of the more highly exposed individuals in the population. This term is equivalent of, and replaces, “the average member of the Critical Group”.
Risk	A multi-attribute quantity expressing hazard, danger, or probability of harmful or injurious consequences associated with actual or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.
Sievert (Sv)	The SI unit of equivalent dose and effective dose, equal to 1 J/kg. In this report it refers to effective dose, the summation of tissue equivalent doses, each multiplied by the appropriate tissue weighting factor.
Sites	The Eskom sites at Thyspunt, Bantamsklip, and Duynefontein being assessed for Nuclear Power Plants.
Source	Any physical entity, e.g. the nuclear power plant, or procedure that results in a potentially quantifiable radiation dose to people and non-human biota.
Source Term	The amount and radionuclide composition of material released (or postulated to be released) from a facility such as a nuclear power plant and used in modelling releases of radionuclides to the environment.

SYMBOLS AND ABBREVIATIONS

µSv	microsievert, 10^{-6} sievert (one millionth of a sievert)
Bq	becquerel
Bq/ℓ	becquerel per litre
Bq/m^3	becquerel per cubic metre
f.w.	fresh weight (of environmental biota sample)
Gy	Gray
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ID	Identification (of samples)
mBq	millibequerel, 10^{-3} Bq (one thousandth of a becquerel)
mSv	millisievert, 10^{-3} sievert (one thousandth of a sievert)
NNR	National Nuclear Regulator
NPP	Nuclear Power Plant
RAP	Reference Animal or Plant
REPAP	Representative Animal or Plant
SABS	South African Bureau of Standards
SANAS	South African National Accreditation System
T.U.	Tritium Units (0.118 Bq/T.U.)
TLD	Thermoluminescent Dosimeter
Unc	Uncertainty (statistical)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organization
$\mu g/m^3$	microgram per cubic metre

Various notations used for expressing quantities, results, and parameter values are the following:

10 can be expressed as 1E01 or 1×10^1;
100 can be expressed as follows in scientific notation: 1E02 or 1×10^2;
0.1 is 1E-01 or 1×10^{-1} (one tenth);
0.01 is 1E-02 or 1×10^{-2}; etc.

Radionuclides are specified in two equivalent ways, for example an isotope of radium, either ^{226}Ra or Ra-226.

INTRODUCTION AND STRUCTURE OF THE REPORT

South Africa considers the construction of a nuclear power plant (NPP) consisting of a combination of reactor units with a total electrical power capacity of up to 4 000 MWe and its associated infrastructure. The three sites included in the environmental impact assessment (EIA) are Thyspunt, Bantamsklip, and Duynefontein. The EIA makes provision for the potential future expansion of a NPP to allow for a total capacity of approximately 10 000 MWe on a site. It is envisaged that light water reactors (LWR) and specifically GEN III pressurised water reactors (PWR) will be the selected technology.

The Thyspunt site is situated in the Eastern Cape on the coast between the towns of Oyster Bay in the west and St. Francis Bay in the east (Figure 1 below).The site for the proposed Nuclear-1 power station is currently vacant. There are a number of houses on the adjacent properties, but these are far outside the proposed Proactive Action Zone (PAZ) of 800 m from the proposed nuclear power station. To the north of the sand dunes, which span the northern portion of the site, the dominant land use is dairy farming.

Bantamsklip is situated along the Southern Cape coast and is located approximately mid-way between Danger Point and Quoin Point (Figure 1 below). The site for the proposed Nuclear-1 forms a part of the total Bantamsklip property. The proposed site is vacant and utilised for activities such as flower harvesting, as well as fishing and illegal harvesting of abalone. Only the Farm Groot Hagelkraal 318 is declared as a private nature reserve (Groot Hagelkraal Private Nature Reserve status), in terms of Section 12(4) of the Western Cape Nature and Conservation Ordinance, 1974 (Ordinance 19 of 1974), and not the entire site.

The Duynefontein site is located adjacent, and to the north, of the existing Koeberg Nuclear Power Station, which is situated on the Cape West Coast, approximately 27 km north of Cape Town (Figure 1 below). The proposed site falls within the existing Eskom-owned property (which includes the site of the existing Koeberg Nuclear Power Station) as well as the Koeberg Nature Reserve.

Terms of reference and methodology

The structure of this report is based on a prospective radiological impact assessment as required at an early stage of a nuclear authorisation process in terms of the National Nuclear Regulator Act (NNR Act). This report, therefore, does not follow the typical structure of an EIA specialist report as it applies to non-radiological impacts assessments. These EIA reports include qualitative significance ratings for environmental impacts that are categorised as High, Medium or Low, The significance category of an impact depends on the nature, intensity, extent, duration, consequence and probability of the impact. The fact that the radiological impacts and an assessment of their cumulative effects have to meet NNR regulatory criteria that are based on internationally recognised and accepted systems of radiological protection, result in a low significance of a NPP's radiological impact for normal operations. The result of the cumulative radiological impacts where more than one nuclear facility could impact the same receiving environment, must also meet specific dose and risk criteria equivalent to a low impact.

The potential radiological impact on the public and the environment was therefore assessed at each site. The report also provides information on the existing background radiation at the three sites.

The report consists of four parts:

- Part 1: Nuclear power plant radiological discharges to the environment during normal operation and public dose
- Part 2: Nuclear power plant accidents and radiological risk to the public
- Part 3: Radiological risk to non-human biota
- Part 4: Background radiation at the three sites

The four parts can be read independently. A reader who requires a more general introduction to ionising radiation, for example, can start with Part 4 (Background Radiation).

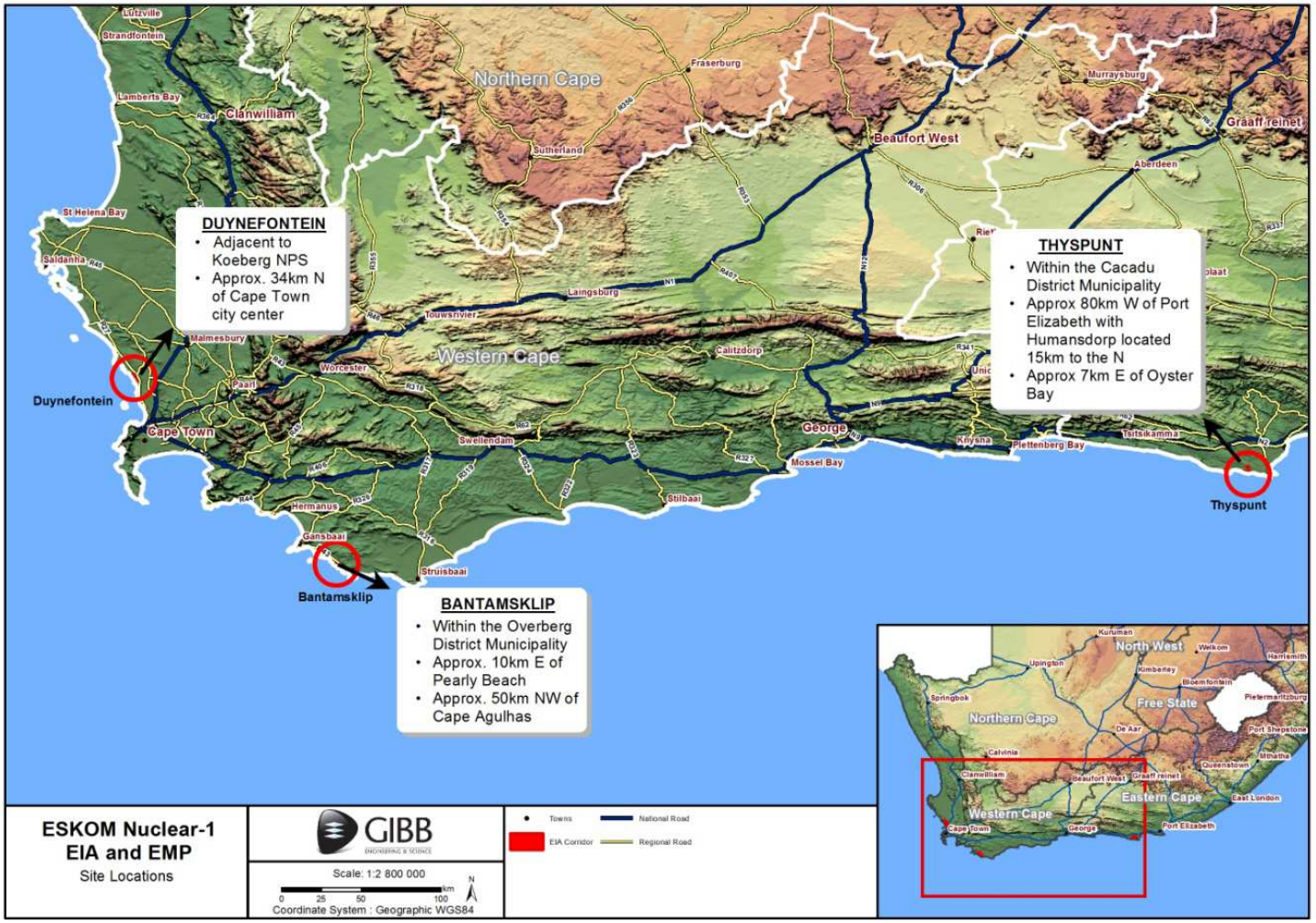


Figure 1 Alternative site locations (Duynefontein, Thyspunt and Bantamsklip) deemed suitable for further consideration in the EIA

1 NUCLEAR POWER PLANT RADIOLOGICAL DISCHARGES TO THE ENVIRONMENT DURING NORMAL OPERATION AND PUBLIC DOSE

1.1 Purpose and scope of the dose assessment

This chapter presents an assessment of operational radioactive discharges from a NPP and the resulting potential radiological impact on the public. The purpose is to demonstrate that the NNR's regulatory dose limit of 1 mSv/y as well as the more restrictive constraint of 0.25 mSv/y effective dose to a member of the public can be met at each of the three sites. The dose limit and constraint applies to the dose in additional to the natural background dose of the average global value is approximately 2.4 mSv/y (refer to Part 4) for a discussion of background radiation at the sites).

The annual effective dose to members of the public is the sum of the dose obtained within one year from external exposure and the dose from intake (ingestion and inhalation) of radionuclides in this year as a result of normal and authorised discharges from a NPP.

The radiological safety assessment is carried out for two categories of radioactive effluent discharges from a NPP:

- normal and continuous operational discharges – it is assumed that these discharges continue for 60 years, the planned operational life of a NPP; and
- short-term contingency discharges that result from minor operational occurrences that can be kept under control and defined as part of normal operation.

1.2 Regulatory framework

1.2.1 Legislation and the radiological protection framework

The EIA is carried out in terms of the National Environmental Management Act, Act No. 107 of 1998 (NEMA) and its EIA regulations published in April 2006. This report provides supporting information to the EIA on radiological impacts pertaining to the feasibility of the three sites to accommodate new NPPs. The radiological protection framework for a NPP is based on the following legislation:

- National Nuclear Regulator Act, 1999 (Act No. 47 of 1999) [1.14.1];
- Regulation No. R. 388 in Terms of Section 36, read with Section 47 of National Nuclear Regulator Act, 1999 (Act No. 47 of 1999) on Safety Standards and Regulatory Practices [1.14.2];
- Regulations on Licensing of Sites for New Nuclear Installations, 2010 [1.14.3]. The specific regulation on public impact is quoted below:

"Requirements for a Site Safety Report

5. A Site Safety Report referred to in Regulation 3 (2)(a) must contain the following…

(6) An analysis of the impact on the public due to normal operations of the new nuclear installation, including minor occurrences that can be kept under control, to demonstrate compliance with the dose limits. This analysis must include the impact of all nuclear installations and actions on the site, existing and proposed, for which authorizations have been granted by the Regulator."

The National Nuclear Regulator Act (NNR Act) requires radiological safety assessments during specific stages in the life of a NPP, i.e. siting, design, construction, operation, decontamination, decommissioning and closure of a NPP. The Safety Assessment Report (SAR) of a NPP is accompanied by technical documents known as General Operating Rules (GORs). The SAR and the suite of GORs constitute a Safety Case that has to be approved by the NNR. The safety assessment methodologies and safety principles in the GORs are based on international best practice such as those documented in the publications of the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP). The GORs deal with NPP aspects that correspond with the requirements of National Environmental Management Act, Act No. 107 of 1998 (NEMA) for non-radiological impacts. Examples of GORs are as follows:

- Radiation Protection Programme for Worker and the Public
- Environmental Surveillance Programme and Radiation Protection of the Environment
- Radioactive Waste Management Programme
- Operating Technical Specifications to ensure safe operation of a NPP
- Maintenance Programme.
- Surveillance Programmes covering aspects such as periodic and re-qualification testing, in-service inspection, plant condition monitoring, fuel integrity monitoring, etc.)
- Emergency Plan
- Quality Management Programme
- Security Plan

The fact that the NNR Act is the primary legal framework to deal with all matters of nuclear safety can be deduced from other EIA relevant legislation that refers specifically to the NNR Act. The National Environmental Management: Waste Act (2008), for example, makes reference to the NNR Act by way of the following description of its application:

"Application of Act

4. (1) This Act does not apply to— 40 (a) radioactive waste that is regulated by the hazardous Substances Act. 1973 (Act No. 15 of 1973). the National Nuclear Regulator Act, 1999 (Act No. 47 of 1999), and the Nuclear Energy Act, 1999 (Act No. 46 of 1999);"

The Major Hard Installation Regulations (No.R.692) issued in terms of the Occupational Health and Safety Act, 1993, also requires a pubic risk assessment but states the following:

"These regulations shall not apply to nuclear installations registered in terms of the Nuclear Energy Act, 1993 (Act No. 131 of 1993)."

The elements of the Nuclear Regulatory Framework consists of legally binding requirements by International Safety Conventions, laws passed by Parliament that govern the regulation of South Africa's nuclear industry, regulations, authorizations, conditions of authorizations, requirements and guidance documents that the National Nuclear Regulator uses to regulate the industry.

The NNR's policy for regulating radiation safety is in line with international consensus and requires that the risks to both the workforce involved in licensed activities and the public should not exceed prescribed limits for both normal operation and for potential accidents, and that both individual and population risks be maintained as low as reasonably achievable, social and environmental factors being taken into consideration. These fundamental principles lead to a system of radiation dose limitation for persons occupationally exposed to radiation and for members of the public.

1.2.2 Regulatory dose limits and dose constraints

NNR regulations in [1.14.2] specify acceptable radiation dose limits for exposure of people and the environment arising under normal operations and as a consequence of nuclear incidents. An annual effective dose limit of 1 milli-Sievert (1 mSv/y) from all actions involving radiation and radioactive material authorised by the NNR is applicable to members of the public. To ensure that the dose limit is not exceeded during normal operation of a NPP, a dose constraint is specified equal to 0.25 mSv/y, also expressed in micro-Sievert as 250 µSv/y. For the purposes of the radiological impact assessment, each site must comply with 250 µSv/y.

1.2.3 Risk Criteria

Risk criteria in the regulations address the mortality risk from nuclear energy and radiation to the present and future generations. In order to control the risk to members of the public due to accident conditions a limit of 10-7 (1 in 10 million) fatalities per person per annum is established for all nuclear installations in South Africa. This figure is based on comparison with other risks imposed on society by industry and various natural disasters. (For example flying on one of the world's major airlines on any single flight, an individual has a 1 in 4.7 million chance of being killed, according to PlaneCrashInfo.com, which tracked accident data from 1993 to 2012). Based on a projection of ten nuclear sites in South Africa during the operational lifetime of the existing nuclear installations, a factor of 0.1 is applied to this figure to obtain the risk limit of 10-8 fatalities per person per annum for each site (1 in 100 million). The risk to the public is calculated using projections on the relevant site-specific data (e.g. demographic, agricultural, farming practices, food consumption data). A peak-to-average ratio of 50 is used to obtain an acceptable variation in risk in the country. This gives an upper risk limit for an individual of 5 × 10-6 (1 in 5 million) fatalities per annum applicable cumulatively to all nuclear installations in the country.

1.2.4 Radiological assessments during siting

The nuclear authorisation process of a new NPP normally consists of a number of stages. The early stage is that of siting and a safety assessment focuses on the characteristics of a site, especially those characteristics that have to be considered in the safety of a future NPP.

A generic set of NPP parameters can be specified in the case where a vendor has not yet been selected and a detail design is not available. The set of parameters constitutes a plant parameter envelope within which a future NNP must fit. It includes safety criteria such as seismic, meteorological, sea level, and other conformance requirements, as well as the regulatory dose limit and constraint.

The sites were assessed in terms of radiological dose to the public based on the condition that a Generation 3 (GEN III) NPP is built on the site. Radioactivity discharge information is available for some of the GEN III NPPs. The Westinghouse AP1000 and AREVA EPR NPPs, because of their public available radioactivity discharge information, were selected for this safety assessment and are considered representative of GEN III reactors in terms of radiological discharges to the environment. Though detailed analysis will be performed once the vendor technology has been chosen, the intention here is to evaluate the feasibility of siting a NNP at any of the three sites hence the use of AP1000 and EPR. In any case, it is expected that any chosen technology regardless of the generation type will have to demonstrate compliance to limits as set by the NNR before a Nuclear Installation Authorisation can be granted by the regulator.

1.3 Approach to public dose assessment

1.3.1 Overview

The dose assessment was carried out for a conservative and enveloping total thermal energy generation capacity of 33 000 MW_{th} the equivalent of electricity generation of approximately 10 000 MWe on a site. The impact is assessed at the end of 60 years of NPP operation, an approach that accounts for any build-up of radioactivity in the environment.

In order to assess the public dose from normal operational radioactive discharges, one has to model the dispersion of radioactive discharges in the environment. This is followed by radio-ecological modelling, which includes a complex web of environmental transfer mechanisms illustrated in Figure 1-1. This information then has to be combined with human habit data so that the various exposure pathways can be identified and public dose can be calculated.

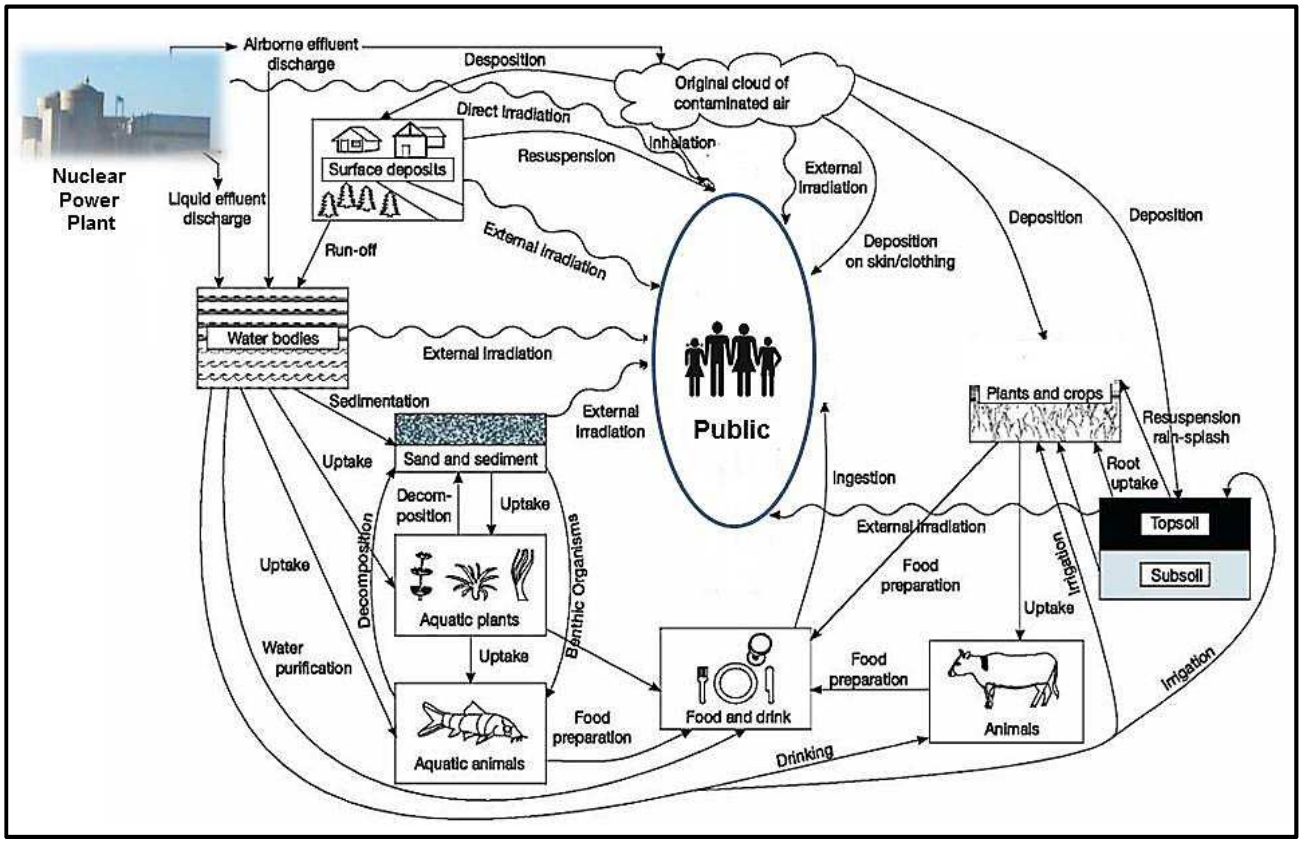


Figure 1-1 Dispersion and environmental transfer of radioactive discharges

The dose assessment for a new NPP is a prospective assessment. A number of different methods are available for the process of estimating annual dose. These methods range from deterministic calculations to more complex probabilistic techniques. A deterministic approach based on conservative assumptions was followed. It provides a bounding assessment of dose that demonstrates compliance with the regulatory dose constraint of 250 µSv/y.

A dose assessment based on more realistic assumptions to demonstrate optimisation of radiological protection as part of the ALARA (as low as reasonably achievable) principle [1.14.4], requires detail design information of the NPP to be built. It forms part of the Safety

Analysis Report (SAR) typically prepared for the licensing stage required for construction and it is expected that more realistic assumptions should result in a significantly lower dose to the public when compared to the results reported in this site assessment. In the current site assessment, for example, the atmospheric discharges are assumed to be at ground level. In a real situation, the discharge will be at a typical height of 40 m or more, equal to the design height of the NPP stack. This will result in improved dispersion when compared to dispersion from ground level discharges, lower atmospheric concentrations in the public domain and therefore a lower radiological impact.

1.3.2 Dose assessment methodologies

1.3.2.1 Main components of the annual dose to a member of the public from normal operation

The annual dose, whether as a result of intake of radionuclides via ingestion and inhalation, or external radiation, comprises three basic components:

- dose from continuous airborne and liquid discharges;
- dose from short-term airborne discharges resulting from minor operational occurrences; and
- dose from continuous external radiation from the NPP containment structures.

1.3.2.2 Continuous discharges to the environment

Dose assessment for normal operation of the NPP is done with the software program *PC-CREAM 08* [1.14.5]. There are various similar programs available internationally to perform a dose assessment. *PC-CREAM 08* was chosen because of its extensive international user base and it implements the updated European Commission methodology for assessing the radiological impact of routine releases of radionuclides to the environment. It was also used in the generic design assessments of the EPR and AP1000 in the United Kingdom [1.14.6].

PC-CREAM 08 is a complex model that has two main divisions called '*Models*' and '*ASSESSOR*'. The Models division includes a series of mathematical models that predict the transfer of radionuclides through the environment and provide estimates of activity concentrations in various environmental media. The output of these models is then used as input to the dose assessment part of the program ASSESSOR. The exposure pathways that were assessed are illustrated in Figure 1-2 and Figure 1-3.

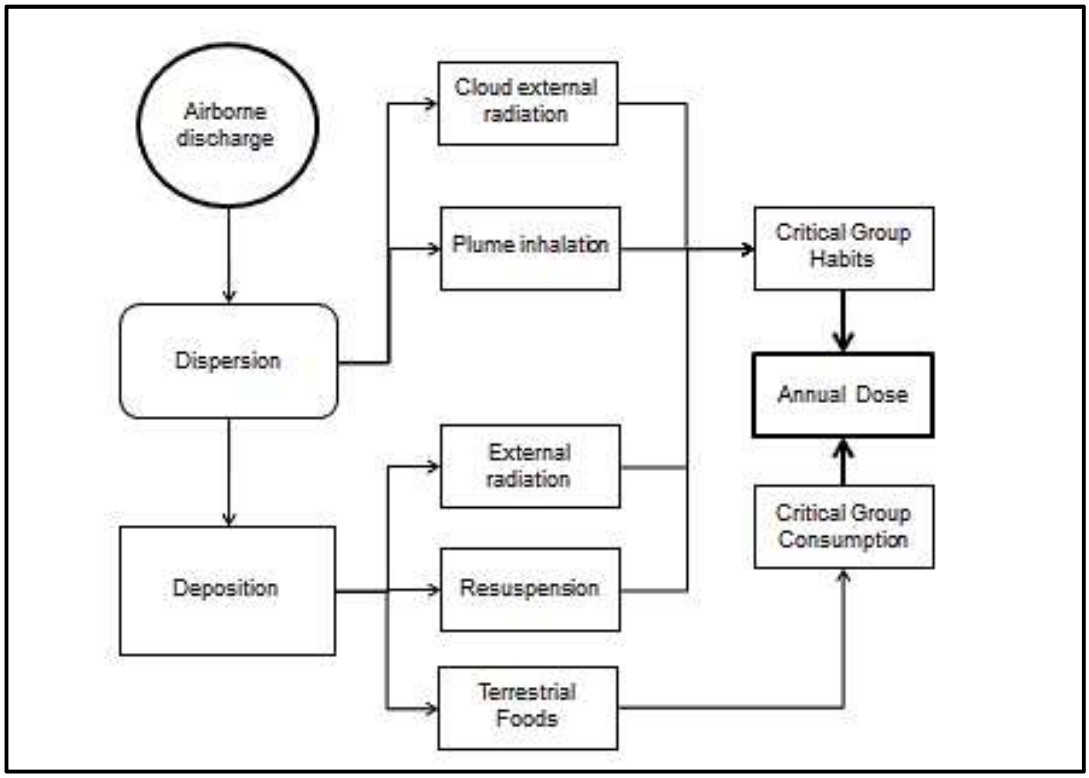


Figure 1-2: Dose assessment framework for airborne discharges

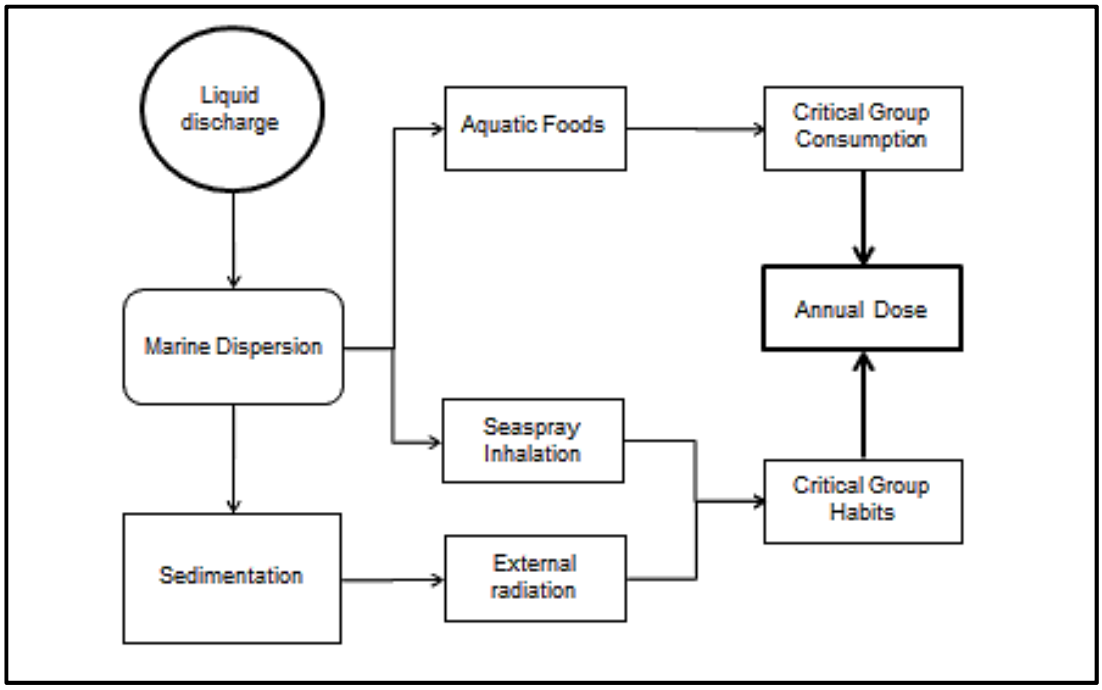


Figure 1-3: Dose assessment framework for liquid discharges

A more detailed discussion of *PC-CREAM* is provided in Appendix 1.

1.3.2.3 Short-term discharges resulting from minor occurrences during normal operation

When the radiological impact of discharges from a NPP is assessed, it is normally assumed that discharges occur continuously and uniformly over a year. However, during normal operations when radionuclides are discharged to the atmosphere, it is possible that short-term contingency discharges due to routine maintenance operations, particular features of operation, or minor occurrences may occur. Such short-term discharges may lead to doses that are higher, or lower, than would be expected if it were assumed that the discharges are continuous over a year. A dose assessment of contingency discharges as a result of minor occurrences is required [1.14.3].

The radiological impact of the contingency discharges to the atmosphere for radioactivity consisting of noble gases, particulates, and halogens, is assessed using the code *PC COSYMA* [1.14.7]. PC COSYMA is widely used for public dose following accidents that involve a large spectrum of radionuclides except H-3 and C-14. A special and conservative implementation of *PC-CREAM is used* for the radionuclides H-3 and C-14. The dose from the contingency discharges is added to the annual dose calculated for normal and continuous discharges.

1.3.2.4 Continuous external radiation from the NPP during normal operation

The third and final component of the total annual dose to a member of the public is that from external radiation. The main sources of radiation are the reactor buildings and the fuel buildings. The external dose outside the NPP owner controlled boundary is estimated by decreasing the design dose on the NPP containment buildings inversely with distance.

1.4 Continuous discharges and its environmental dispersion

1.4.1 Introduction

Radioactivity that is discharged from the confines of NPP containment structures is characterised in terms of source terms. The source term describes the quantity of the individual radionuclides and their physiochemical characteristics, e.g. radioactive decay, whether particulate or gaseous, and its chemical form.

Liquid and airborne source terms used in the radiological assessment represent a power envelope of 33 000 MWth. This approach introduces adequate conservatism in the dose assessment to address the uncertainties as a result of not having a specific NPP design and its source terms at this stage.

The source terms in this report are derived from the data available on two reference reactor types representative of GEN III PWR designs, AP1000 and EPR. Both these reactor types have passed international regulatory safety assessments. Enveloping airborne and liquid source terms were constructed by selecting the maximum of each individual radionuclide source term when comparing the two reactor types. The individual radionuclide source term was then scaled up from a single reactor unit to represent the thermal power of multiple reactor units producing 33 000 MWth. The source term and its derivation are included in Appendix 3.

1.4.2 Airborne discharges

Long-term average values of atmospheric concentrations and ground deposition from continuous discharges are calculated using a sector-averaged version of the Gaussian plume model [1.14.8], a model that is part of the *PC-CREAM 08* software code system. The NNP environment was divided into a total of 18 circular sectors of equal size. The sector-specific weather data collected by the on-site weather station over a one-year period was used and it is expected that average wind speeds and their annual average directions will not change significantly over the lifetime of the NPP. Weather data representative of longer periods, e.g. 5 years, will be used in the design-specific safety assessment during future nuclear licensing stages.

The proposed NPP will consist of more than one reactor unit and in all likelihood more than one ventilation stack for airborne discharges. For the purposes of the site safety assessments, discharges are combined into one virtual discharge point at ground level providing a conservative estimate of public dose and environmental impact from the discharge at each site. The differences in atmospheric concentrations calculated for different release heights are illustrated in Figure 1-4 and it clearly shows the higher concentrations from a ground level discharge compared to discharges at elevated levels. The discharges for an actual NPP will be at an effective height well above ground level, resulting in higher dispersion and therefore a lower dose. The AP1000, for example, discharges most of the airborne effluent from a main plant vent that has an effective stack height of approximately 60 m. About 12 per cent of the total release takes place from the turbine building vent which has an effective stack height of approximately 40 m [1.14.9].

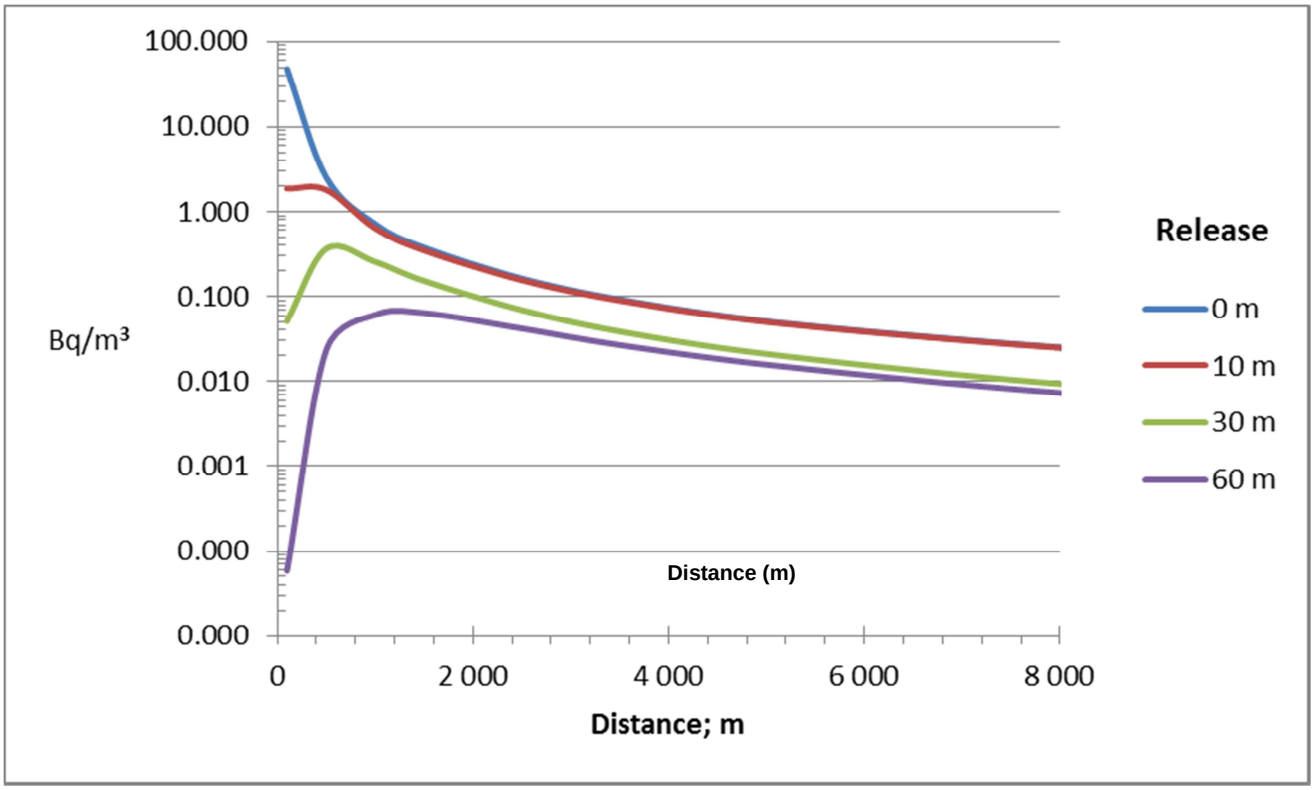


Figure 1-4: A sensitivity study of atmospheric concentrations as a function of discharge height

The important parameters and their values used in the modelling of radioactivity concentrations in air and deposited on the ground are listed in Table 1-1.

Table 1-1: Atmospheric dispersion parameters

Parameters	Values
Weather data	Site specific hourly weather data for a full year
Level of release	Ground level release (0 m)
Deposition velocity (ms^{-1})	a) 1×10^{-2} (Iodine isotopes) b) 0 (noble gases, H-3 and C-14; specific environmental transfer models are used for H-3 and C-14 that negates the requirement for deposition assessment) c) 1×10^{-3} (other radionuclides)
Rain washout coefficient (s^{-1})	a) 0 (noble gases) b) 1×10^{-4} (other radionuclides)
Surface roughness factor (m)	0.3 (typical of agricultural areas)

Figure 1-5, Figure 1-6, and Figure 1-7 illustrate the typical wind directions and velocities at the three sites. Note that the wind flow vectors are depicted, i.e. the direction in which the wind is blowing as opposed to the traditional wind rose that shows the direction from which the wind is blowing. The figures, therefore, show those directions in which discharged radioactivity will be transported at higher frequencies.

At Thyspunt, for example, the main radiological impact is expected to be in the areas located east-northeast, east, east-southeast, and southeast of the NPP. An example of air concentrations and ground depositions as a function of wind direction is that of Cs-137, normally considered an important radionuclide in terms of its environmental impact and human exposure. The concentrations as a function of 18 sectors of wind directions at Thyspunt are listed in Table 1-2. Sector 1 is north and subsequent sectors are numbered in a clockwise direction, i.e. sector 9 is south etc. This type of calculation was carried out for each radionuclide in the source term for airborne discharges at each of the sites.

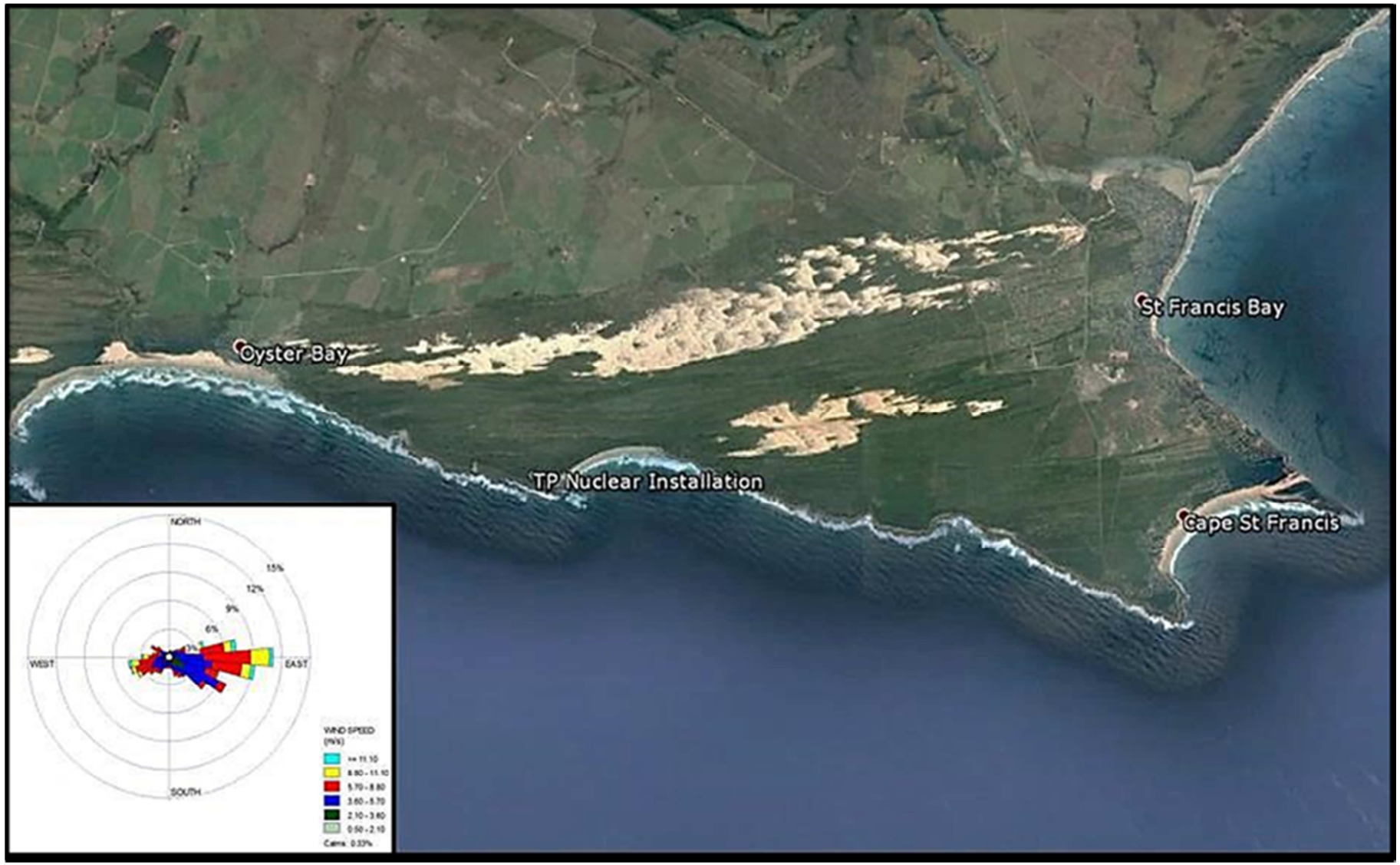


Figure 1-5: The Thyspunt site region and wind flow directions

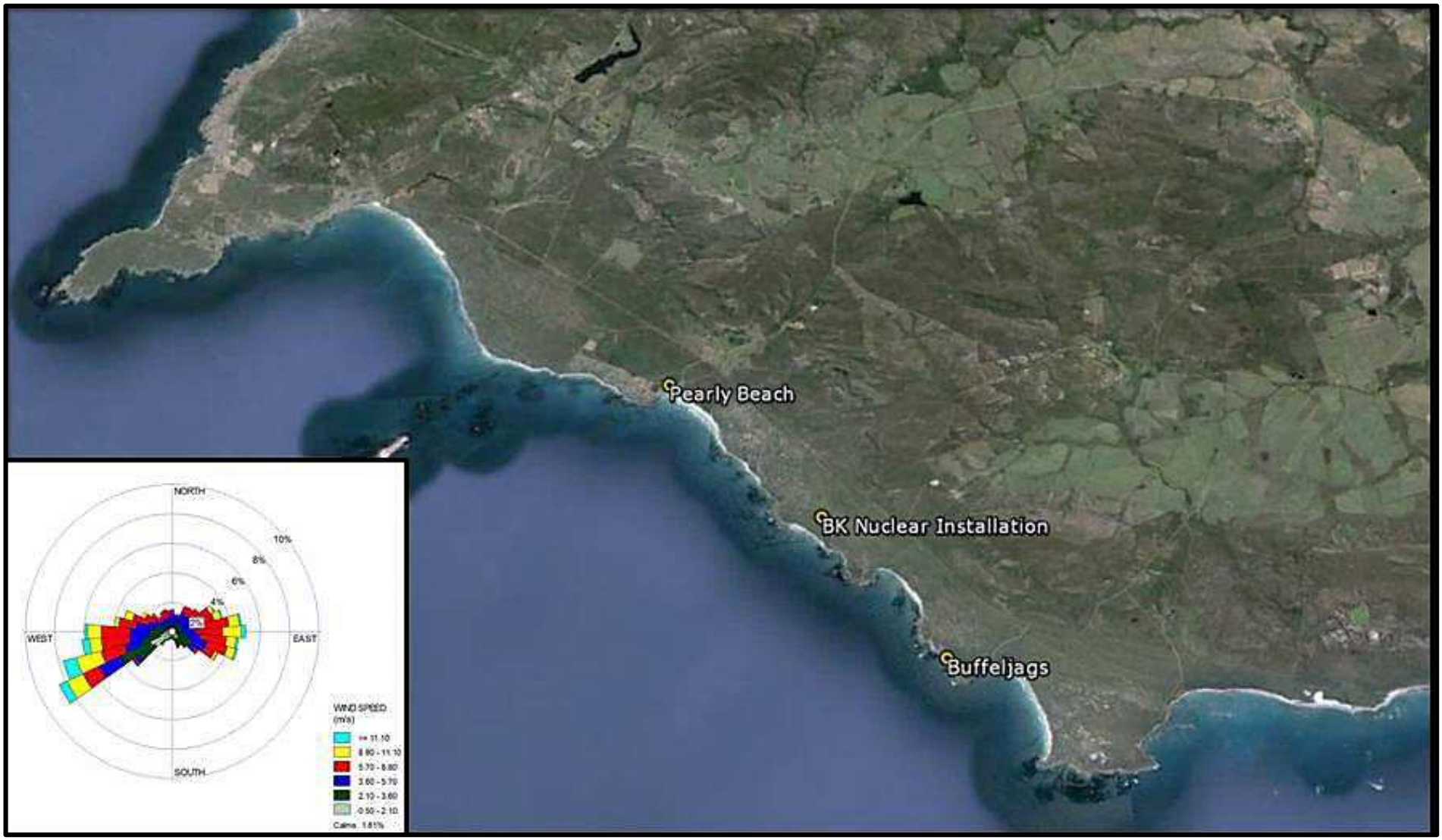


Figure 1-6: The Bantamsklip site region and wind flow directions

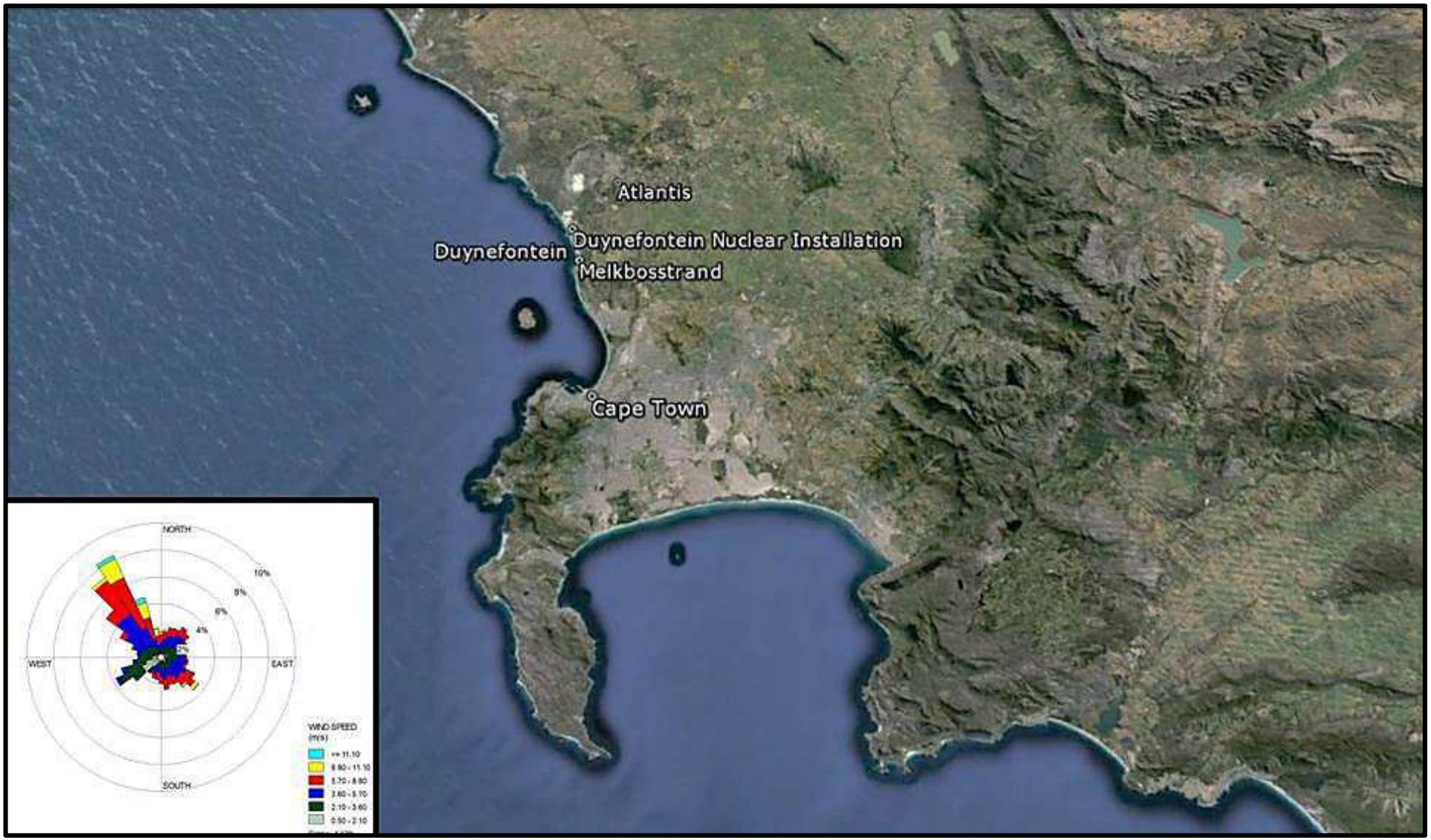
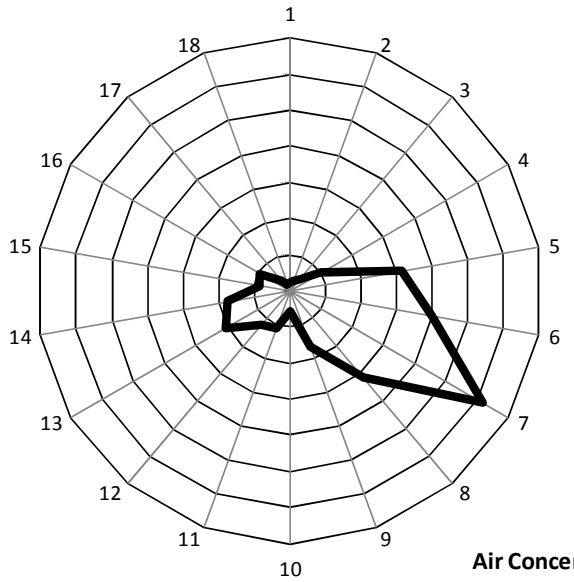


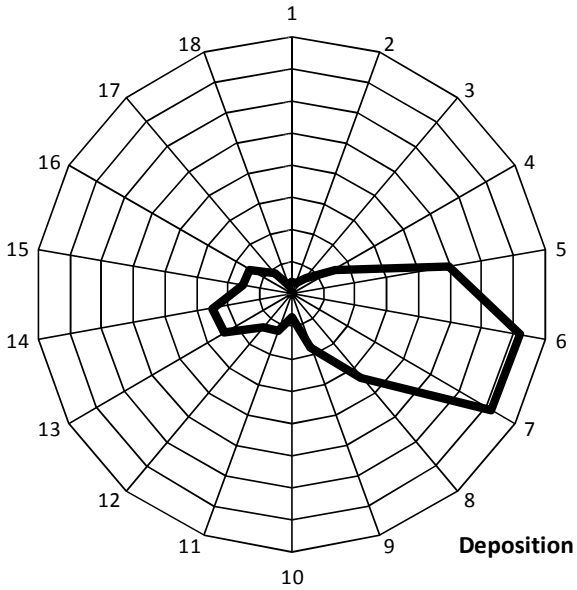
Figure 1-7: The Duynefontein site region and wind flow direction

Table 1-2: Thyspunt annual average air concentration and surface deposition rates of Cs-137 (annual source term is 5.24E+8 Bq/y) at a distance of 2.5 km

Distance (km)	Wind Sector Air Concentration (Bq/m^3)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2.5	4.98E-07	5.97E-07	8.52E-07	1.99E-06	6.27E-06	7.96E-06	1.23E-05	6.26E-06	3.34E-06	1.17E-06	2.20E-06	2.41E-06	4.10E-06	3.50E-06	1.64E-06	1.89E-06	7.30E-07	3.71E-07
	Wind Sector Surface Deposition (Bq/m^2/s)																	
2 500	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	7.54E-10	7.68E-10	1.28E-09	3.13E-09	9.90E-09	1.44E-08	1.44E-08	6.78E-09	3.54E-09	1.42E-09	2.45E-09	2.69E-09	4.82E-09	5.01E-09	3.13E-09	2.98E-09	1.67E-09	6.27E-10



Air Concentration



Deposition on ground

1.4.3 Liquid discharges

A common and conservative dispersion modelling approach was followed for all three sites. A single discharge point is considered for radioactive liquid discharges. The discharges are assumed to take place into a local marine compartment with volume 2.0E08 m^3 (10 km along the shore, 2 km seaward and an average depth of 10 m), and this compartment is linked to a regional oceanic compartment [1.14.8] to allow for long-term mixing.

It is proposed that the outfall pipelines/tunnels to dispose of seawater used for cooling, shall have multiple discharge points in order to facilitate dispersion of the warmed water and mixing with the relatively cooler seawater. The objective of the outfall works will be to transfer the heated water at least beyond the surf zone (estimated to be in the order of 3.5 km to a depth of 30 m below mean sea level as per the Marine Impact Assessment). The design velocity of the water in the pipes will be such to ensure adequate dispersion into the sea.

The controlling parameters and their values used for the sites are listed in Table 1-3. The chemical element dependent parameter values included in Table 1-3 show different values for four specific elements. The radionuclides of these elements are important contributors to the dose from liquid releases. Two values for each element, one which is a default value in *PC-CREAM 08* and the other from the *ERICA* software program used for non-human biota (see Part 3), were used to perform an initial sensitivity analysis (not distinguishing between CR and CR_{WO}). The *ERICA* data resulted in approximately 40 per cent lower dose.

The dimensions of the local marine compartment are based on a conservative selection from typical dimensions of a large set of other local marine compartments described in *PC-CREAM*. Site-specific values for the controlling parameters in respect of marine dilution will be obtained from detailed oceanographic studies when optimisation studies are performed for a specific NPP design in subsequent nuclear licensing stages.

The annual average radioactivity concentrations calculated for the local marine compartment are used to estimate the annual dose for the public dose as well as non-human biota in Part 3.

Only liquid releases to the sea are considered in the prospective dose calculations. Groundwater impacts are negligible when compared to discharges to the sea. A justification for not including groundwater impacts at this stage is provided in Appendix 2.

Table 1-3: Marine compartment parameters

Marine Component	Volume (m^3)	Depth (m)	Coastline Length (m)	Volumetric Exchange Rate (m^3/y)	Suspended Sediment Load (t/m^3)	Sedimentation Rate ($t/m^2/y$)	Sediment Density (t/m^3)	Diffusion Rate (m^2/y)
Local marine compartment	2.00E+08	1.00E+01	1.00E+04	4.00E+09	2.00E-04	1.00E-04	2.60E+00	3.15E-02
Regional ocean	8.98E+17	3.80E+03	–	–	1.00E-08	3.00E-06	2.60E+00	3.15E-03

Element Dependent Parameters of Radionuclides Important in Dose Calculations		Sediment Distribution Coefficient, KD – Deep Water (Bq/t per Bq/m^3)	Sediment Distribution Coefficient, KD – Coastal Water (Bq/t per Bq/m^3)	Fish Concentration Factor (Bq/t per Bq/m^3)	Crustaceans Concentration Factor (Bq/t per Bq/m^3)	Molluscs Concentration Factor (Bq/t per Bq/m^3)	Seaweed Concentration Factor (Bq/t per Bq/m^3)
Caesium	Default PC Cream Coefficients	2.00E+03	3.00E+03	1.00E+02	3.00E+01	3.00E+01	5.00E+01
	ERICA Coefficients	4.00E+03	4.00E+03	8.60E+01	4.10E+01	6.60E+01	5.00E+01
Carbon	Default PC Cream Coefficients	2.00E+03	2.00E+03	2.00E+04	2.00E+04	2.00E+04	1.00E+04
	ERICA	1.00E+03	1.00E+03	1.20E+04	1.00E+04	1.00E+04	1.00E+04

	Coefficients						
Cobalt	Default PC Cream Coefficients	1.00E+07	2.00E+05	1.00E+03	1.00E+04	5.00E+03	1.00E+04
	ERICA Coefficients	3.00E+05	3.00E+05	5.60E+03	1.80E+03	5.10E+03	1.00E+04
Silver	Default PC Cream Coefficients	1.00E+04	1.00E+03	5.00E+02	5.00E+03	1.00E+04	2.00E+03
	ERICA Coefficients	1.00E+04	1.00E+04	2.90E+03	1.60E+04	3.20E+04	2.00E+03

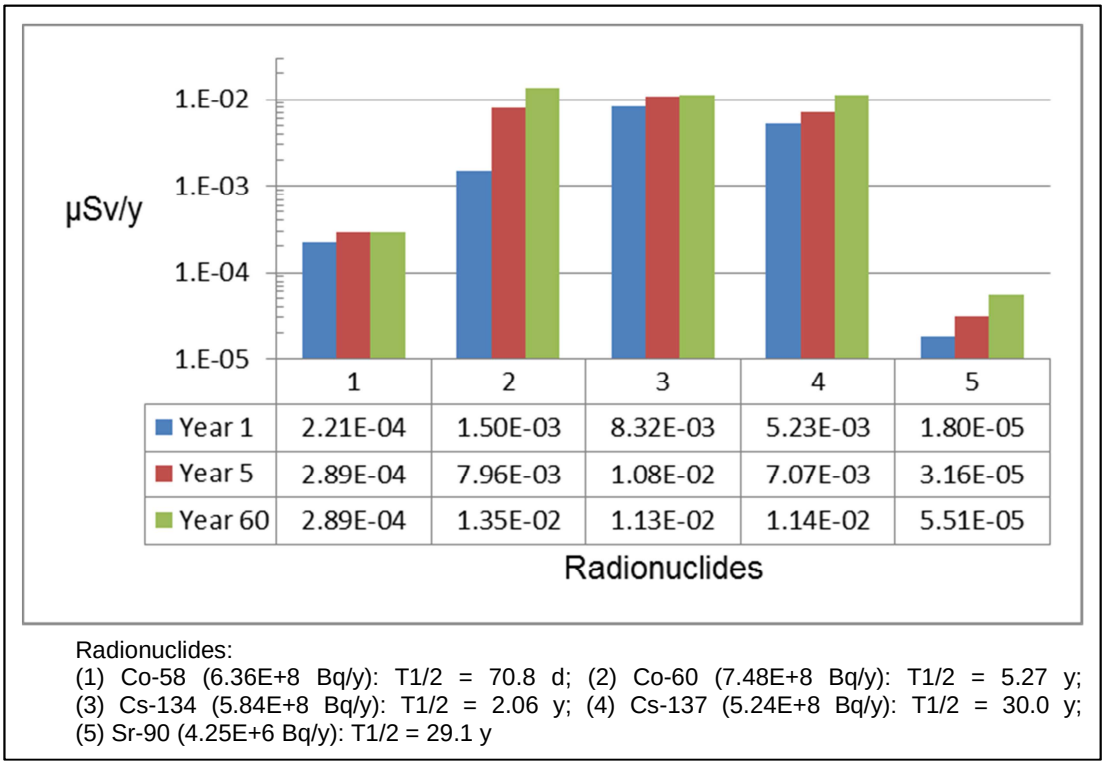
1.5 Build-up of radionuclides in the environment

An important aspect of the liquid discharge is the potential build-up of radionuclides in the environment during the life of a NPP, e.g. in beach sediments. The decay half-live of a radionuclide is an important factor determining the potential build-up, apart from the sediment distribution factors for the different chemical species of radionuclides. Table 1-4 provides information on two radionuclides to illustrate the build-up behaviour of different radionuclides. I-131 has a short half-life and will not increase in the sediment with time. Cs-137, however, has a relatively long half-life and its concentration will gradually increase during the operating life of the NPP.

Table 1-4: Radionuclide build-up in marine sediments as a function of nuclide decay half-life

Years of NPP Operation and Liquid Effluent Discharge	Marine Sediment Concentration (Bq/kg)		
	1 y	5 y	60 y
Cs-137: 6.93E+9 Bq/y $T_{1/2}$ = 30 y	1.66E-01	7.21E-01	2.21E+00
I-131: 3.67E+8 Bq/y $T_{1/2}$ = 8.04 d	1.74E-05	1.74E-05	1.74E-05

The build-up of radionuclides concentrations in soils and marine sediments during the lifetime of the NPP is taken in account in the dose assessment. Figure 1-8 illustrates this effect for some example radionuclides (assuming that all other environmental factors remain constant). Radioactivity build-up was included in the dose assessment by calculating the radionuclide concentrations in the environmental media after 60 years of continuous discharges [1.14.8]. The overall build-up effect in the terrestrial environment for example, even though pronounced for some individual nuclides such as Co-60, does not result in a significant dose increase over the lifetime of the NPP.



Radionuclides:
(1) Co-58 (6.36E+8 Bq/y): T1/2 = 70.8 d; (2) Co-60 (7.48E+8 Bq/y): T1/2 = 5.27 y; (3) Cs-134 (5.84E+8 Bq/y): T1/2 = 2.06 y; (4) Cs-137 (5.24E+8 Bq/y): T1/2 = 30.0 y; (5) Sr-90 (4.25E+6 Bq/y): T1/2 = 29.1 y

Figure 1-8: Terrestrial environmental build-up of radionuclides – radionuclide soil concentration (Bq/g) after 1, 5, and 60 years of NPP operation

1.6 Human activities at the sites

1.6.1 Thyspunt

Although a relatively small percentage of the area is under urban development, there are several coastal resort towns in the vicinity of the site. Oyster Bay is located less than 5 km to the west of the site, and Cape St. Francis and St. Francis Bay are situated approximately 12.5 km to the east. These coastal towns are important and well-established tourist destinations.

Oyster Bay and the settlement of Umzamowethu are the closest residential areas to the site. Oyster Bay is predominantly a holiday town with a small permanent population. Many of the houses are occupied only during peak holiday periods whereas Umzamowethu has mostly permanent residents. Other urban settlements within the 20 km radius of the site include Humansdorp and the southern portion of Jeffreys Bay (Paradise Beach).

Agricultural activities consist mostly of dairy farming and associated agricultural production involving wheat and corn. No agricultural production occurs within 2.5 km of the site. Milk production is concentrated in the areas beyond the 5 km radius throughout the west-northwest to northeast sectors. Two areas, 5 km northwest and 7.5 km east-northeast, reflect higher than average milk production figures. The main cattle farming areas correspond closely with the areas in which milk production dominates.

Future land use is not expected to be significantly different from the current use.

Marine species such as squid, south coast rock lobster, and fish are commercially harvested in the area. Recreational fishing is also popular and is practised from the accessible coastal sites

and ski boats. The beach areas at Oyster Bay, St. Francis, and Cape St. Francis are popular tourist destinations. The area stretching from Jeffreys Bay to Cape St. Francis represents one of the prime surfing destinations in the world.

1.6.2 Bantamsklip

A survey of land use in the region of the site shows that within 5 km very little cultivation of land takes place. No major farming activities are present within 5 km of the site centroid. Agricultural activities occur beyond 5 km and are predominantly associated with sheep and cattle farming for the purpose of producing meat for markets. In addition, milk is produced for major dairy product manufacturers.

Pearly Beach, a holiday resort village is the only notable urban settlement within the site vicinity. It is situated roughly 5 km northwest of the proposed site. Buffeljags, a small rural fishing community, lies along the coastal edge roughly 5 km east of the site. The inhabitants practise subsistence fishing. An abalone farm is located east of Buffeljags.

1.6.3 Duynefontein

The residential area of Duynefontein is the nearest settlement to the site (approximately 3 km south of the proposed footprint of a new NPP). Other urban settlements within the site vicinity are Atlantis (north-northeast), Melkbosstrand (south-southeast), Bloubergstrand (south-southeast), and Philadelphia (east).

Some smallholdings are located in an easterly direction, beyond the R27 road. The R27 forms the Owner Controlled Boundary (OCB) in this direction and at a distance of approximately 2.5 km from the NPP. The Koeberg nature reserve is situated between the R27 and the proposed NPP footprint. Small informal settlements also occur in the vicinity of the site and in the direction of Melkbosstrand, east of the R27 road.

No commercial agricultural production occurs inside the 5 km zone around the site. This area includes the Koeberg Nature Reserve. Other parts of this area are covered by natural vegetation (low shrubland) and fallow agricultural land. The area to the north of the site, stretching from Atlantis to the West Coast, contains limited farming activity, due to the fact that much of the land is owned by Eskom and the State and characterised by sparse vegetation and sandy soil. The bulk of the northern area contains natural vegetation and forms part of the Koeberg Nature Reserve.

The east-southeast sectors are characterised by dryland cultivation, with the well-established large wheat farms of Philadelphia and associated production of fodder crops. Dairy production takes place on some of the nearby farms. Closely associated with the dairy industry is land used for grazing of cattle and fodder production. Wheat and fodder production occurs beyond 5.0 km of the site. Meat cattle are concentrated between 5 km and 16 km east-southeast and south-southeast of the site. No significant vegetable production occurs in the area. The Morningstar smallholding area, to the southeast of the site, is predominantly characterised by residential uses and small stud farms.

Fishing activities include commercial fishing, subsistence fishing, and recreational fishing. Edible molluscs (e.g. white and black mussel, abalone), West Coast rock lobster, and seaweed are collected. The distribution of fish processing facilities in the region are associated with the commercial marine fishing industry and are predominantly located at Cape Town and other coastal towns. Reliable data on subsistence fishing for the site region is not available.

Subsistence fishing is practised at Yzerfontein where snoek and hake are caught and sold by vendors within the surrounding towns. The coastline within the region is popular with recreational line fishermen.

With regard to recreational activities, the coastal region surrounding the site is a popular tourist destination and includes Cape Town and several resort towns. Recreational and tourism activities that occur along the coast include swimming, surfing, kite-surfing, boating, and recreational fishing. Beach areas most likely to be impacted by the NPP are Duynefontein and Melkbosstrand immediately south of KNPS and to a lesser degree Silwerstroomstrand, approximately 10 km north of KNPS.

Spatial Development Frameworks determined that rural and high-potential agricultural land should be retained for agricultural purposes as far as possible. Urban development of settlements within the site region will be contained within the proposed urban edges that are intended to control growth and limit lateral expansion of towns. Industrial development is planned within the existing industrial areas of Cape Town and the smaller towns within the site region. It is expected that heavy industrial uses will be developed in Atlantis, where it is permitted. It is therefore unlikely that land use in the vicinity of the site will change significantly in the foreseeable future.

1.7 Critical groups and representative persons

1.7.1 The approach to defining critical groups

A dose assessment requires information on human settlement areas at a site. The annual radiation doses received by members of the public as a result of radionuclide discharges will vary depending on factors such as proximity to the point of radioactive discharge, dietary and behavioural habits, age, and variations in the environmental dispersion of NPP discharges. The information is used to define a critical group (CG). The critical group should be representative of those individuals in the population expected to receive the highest levels of dose from a NPP. The critical group should be small enough to be relatively homogenous with respect to those factors (e.g. age, diet, and behaviour) that affect the doses received. It is also necessary to choose the time when these doses are at a maximum value. In this site assessment, the annual effective dose assessment is calculated at year 60, the expected life of the NPP, and when build-up of radionuclides in the environment is at a maximum.

In recent years, the International Commission on Radiological Protection (ICRP) [1.14.10] has defined a concept related to the critical group, i.e. the representative person (RP). The representative person is equivalent to, and replaces, the ‘average member of the critical group’. The NNR Act and the associated regulations for safety standards still contain the term *critical group*. Therefore, to avoid conflict with the terminology that appears in the legislation and regulations, this report will continue to use the term *critical group*.

An approach was followed to provide a bounding and conservative estimate of the annual dose to the critical group. The approach defined here allows the determination of the maximum potential annual dose during a siting safety assessment when large uncertainties exist in respect of future changes in human settlement and habits.

A bounding dose to members of the public can be determined by considering multiple, and to a large extent hypothetical, critical groups as follows:

- Coastal sites would typically require the assessment of radiological impacts on two types of critical groups:
    - a farming family; and
    - a fishing family.
- A critical group is constructed by combining the habit data of the two family types. This represents a hypothetical construct, which is conservative in respect of all the exposure pathways considered in the dose assessment. A fishing family, for example, does not necessarily consume the same amount of local farm products as the farming family. It is reasonable to assume that permanent residents in the nearby towns and on farms in the vicinity of the sites will be enveloped by this approach. Their actual exposure pathways will form a subset of exposure pathways of these two types of critical groups. If the maximum dose calculated in this manner meets the regulatory dose constraint, further analysis at this early licensing stage should not be necessary. This approach can be seen as determining annual dose for hypothetical exposure conditions.

The ICRP [1.14.11] has developed radionuclide specific dose coefficients for six age groups (3 months; 1, 5, 10, and 15 years; and adult). However, the ICRP considers that three age groups are generally sufficient to encompass age-related exposure and dose variations. The ICRP states that the level of detail afforded by its provision of dose coefficients for six age groups is not necessary in making prospective assessments of dose given the inherent uncertainties usually associated with estimating dose to the public and with identification of the critical group. It recommends the use of three age groups for estimating annual dose to the representative person for prospective assessments. These groups are:

- infant: 0–5 years;
- child: 6–15 years; and
- adult: 16–70 years.

For practical implementation of this recommendation, dose coefficients and habit data for a 1-year-old infant, a 10-year-old child, and an adult should be used to represent the three age categories. This is the approach for age groups used in *PC-CREAM 08*. In all cases, committed dose from radionuclides taken into the body are integrated to age 70. This is done with the use of dose coefficients for ingestion and inhalation from [1.14.8]. The dose assessment for the Thyspunt site was done for 5 age groups: 1, 5, 10, and 15 years, and an adult. It was shown that the total annual doses from all exposure pathways for the two age groups, 5 and 15 years old, are less than the doses determined for either a 1-year-old or an adult when considering typical habit and ingestion data.

Table 1-5: Exposure pathways used for dose assessment

Atmospheric Exposure Pathways	Marine Exposure Pathways
Inhalation of airborne radionuclides	Inhalation of radionuclides in sea spray from the local marine compartment
External gamma dose from airborne radionuclides	External gamma dose from radionuclides in sediment (beach sand at edge of the local marine compartment)
External beta dose from airborne radionuclides	External beta dose from radionuclides in sediment
External gamma dose from deposited radionuclides	External gamma dose from radionuclides on fishing gear
Inhalation from resuspended radionuclides	Consumption of radionuclides in fish, molluscs, and crustaceans
Consumption of radionuclides in beef, cattle liver, cow milk, mutton, sheep liver, green vegetables, root vegetables, fruit, and grain	–

Other potential exposure pathways, e.g. external radiation when swimming in the sea, make an insignificant contribution to the annual dose. The radioactivity concentrations of discharged Co-60 in seawater and beach sediment, for example, can be compared. The concentration in seawater in the local marine compartment calculated with *PC-CREAM 08*, is approximately 0.005 Bq/ℓ. This activity can be compared to the approximately 7 Bq/kg in beach sand. The different radioactivity concentrations for the two different environmental media indicate that the external radiation dose as a result of longer time spent on a beach by most people, is potentially much greater than time spent swimming in the sea (although in absolute terms still a small dose). Accidental ingestion of seawater is also negligible considering the low radionuclide concentrations and low volumes of accidental ingestion.

The annual dose for each critical group was determined by using the enveloping habit and consumption data listed in Appendix 4.

In order to account for the uncertainties as a result of developments in respect of human settlements and habits between the time of this report and the actual NPP commissioning, a range of hypothetical critical groups are considered in each of the wind sectors, at locations as near as is possible to the NPP's proposed footprint, taking into consideration Eskom's owner controlled boundaries of the sites and natural land features, e.g. the large dunes at Thyspunt. Some of these locations coincide with actual human settlements.

All exposure pathways resulting from airborne discharges are based on the predicted atmospheric and deposited radioactivity concentrations at each critical group location. Seafood is supplied from the local marine compartment. The objective is to effectively create a range of separate hypothetical critical groups with the same composite habit data but at different locations thereby providing a bounding range of potential annual doses.

1.7.2 Thyspunt critical groups

The doses were calculated for ten critical groups, designated CG01 to CG10, The critical groups CG01 and CG02 are located at Oyster Bay and the settlement of Umzamowethu, the closest residential areas to the site. Subcritical groups CG03 to CG07 are located in areas

representative of the nearest possible farming areas. CG08, CG09, and CG10 represent locations towards St. Francis and Cape St. Francis, further away from the site than CG01 and CG02, but with higher frequency wind directions.

The locations of the subcritical groups are shown in Figure 1-9 and the selected locations are described in more detail in Table 1-6.

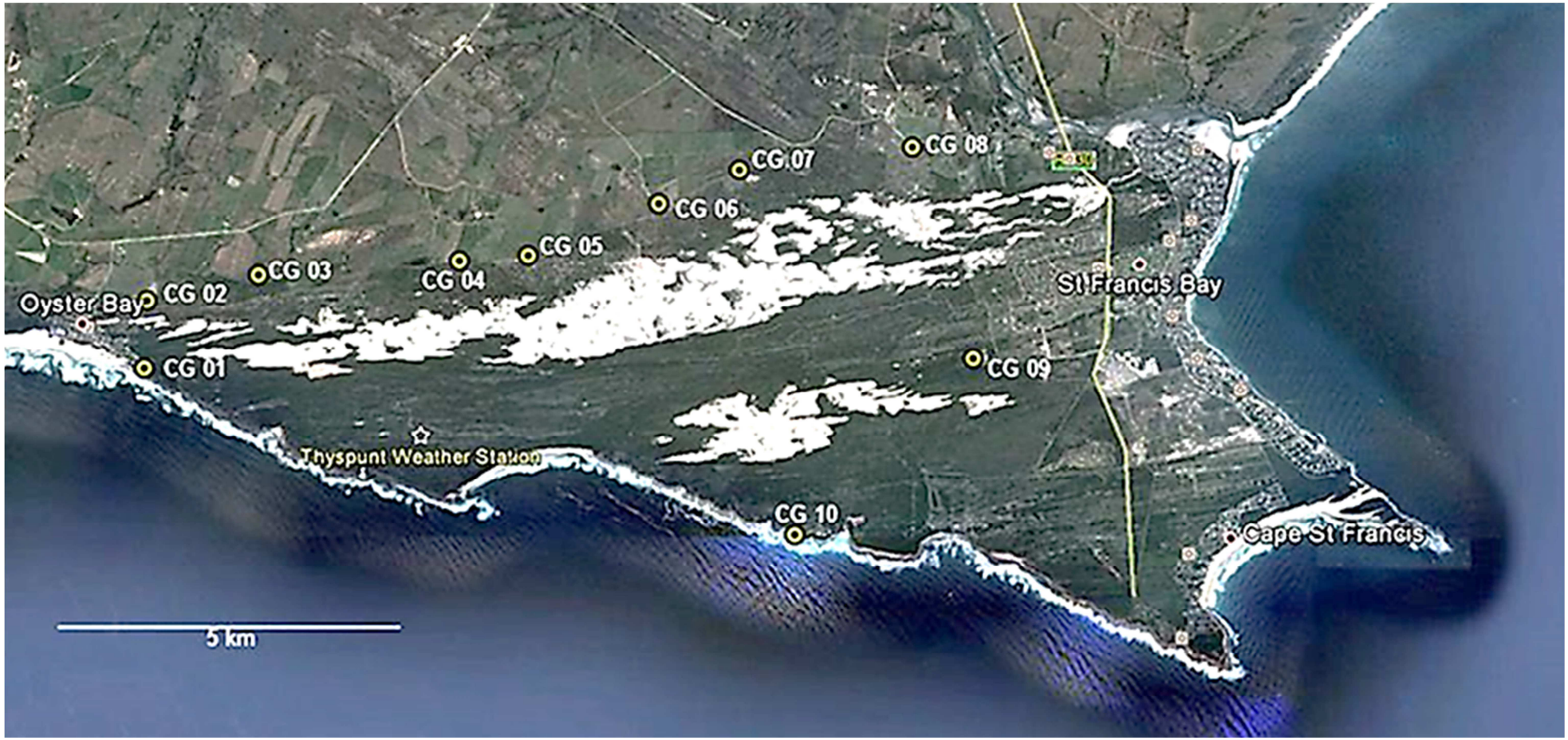
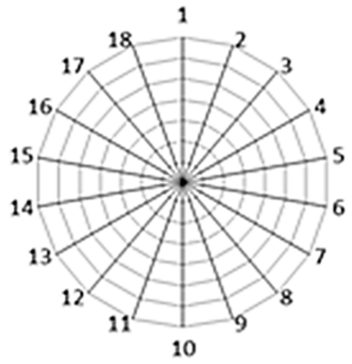


Figure 1-9: Thyspunt critical groups

Table 1-6: Thyspunt critical groups in relation to the different wind sectors

Wind Sectors (18) for Assessing Atmospheric Dispersion of Gaseous Discharges from the Nuclear Installation(s)	

Wind Sector No.		**Wind Direction Interval, Degrees**		**Avg. Sector Degrees**	**Critical Group (CG)**	**CG Distance from Nuclear Installation(s) (km)**
Sectors over Land Surface	1	10	30	20		
	2	30	50	40	4	2.66
	3	50	70	60	5	3.14
	4	70	90	80	6	4.94
					7	6.19
					8	8.46
	5	90	110	100	9	8.25
	6	110	130	120	10	5.67
Sectors over Sea Surface	7	130	150	140		
	8	150	170	160		
	9	170	190	180		
	10	190	210	200		
	11	210	230	220		
	12	230	250	240		
	13	250	270	260		
	14	270	290	280		
Sectors over Land Surface	15	290	310	300	1	4.32
	16	310	330	320	2	4.62
	17	330	350	340	3	3.47
	18	350	10	0		

1.7.3 Bantamsklip critical groups

The doses were calculated for eleven critical groups, designated CG01 to CG11, located in wind sectors listed in Table 1-7 and illustrated in Figure 1-10. The hypothetical radiological impacts were determined at distances of 2.5 km in the various wind sectors. Dose assessments were also carried out for the Pearly Beach and Buffeljags locations, located approximately 5 km away from the NPP and representative of more doses from airborne discharges.

The small permanent community at Buffeljags, which is dependent on the sea for their livelihood, is depicted in Figure 1-11 . An abalone aquaculture industry is located next to the settlement.

Table 1-7: Bantamsklip critical groups in relation to the different wind sectors

CG Identification	Distance from NPP (m)	Sector as shown in Figure 1-10
1	2500	7
2	2500	6
3	2500	5
4	2500	4
5	2500	3
6	2500	2
7	2500	1
8	2500	18
9	2500	17
10	2500	16
11	2500	15
Pearly Beach	5000	16
Buffeljags	5000	7

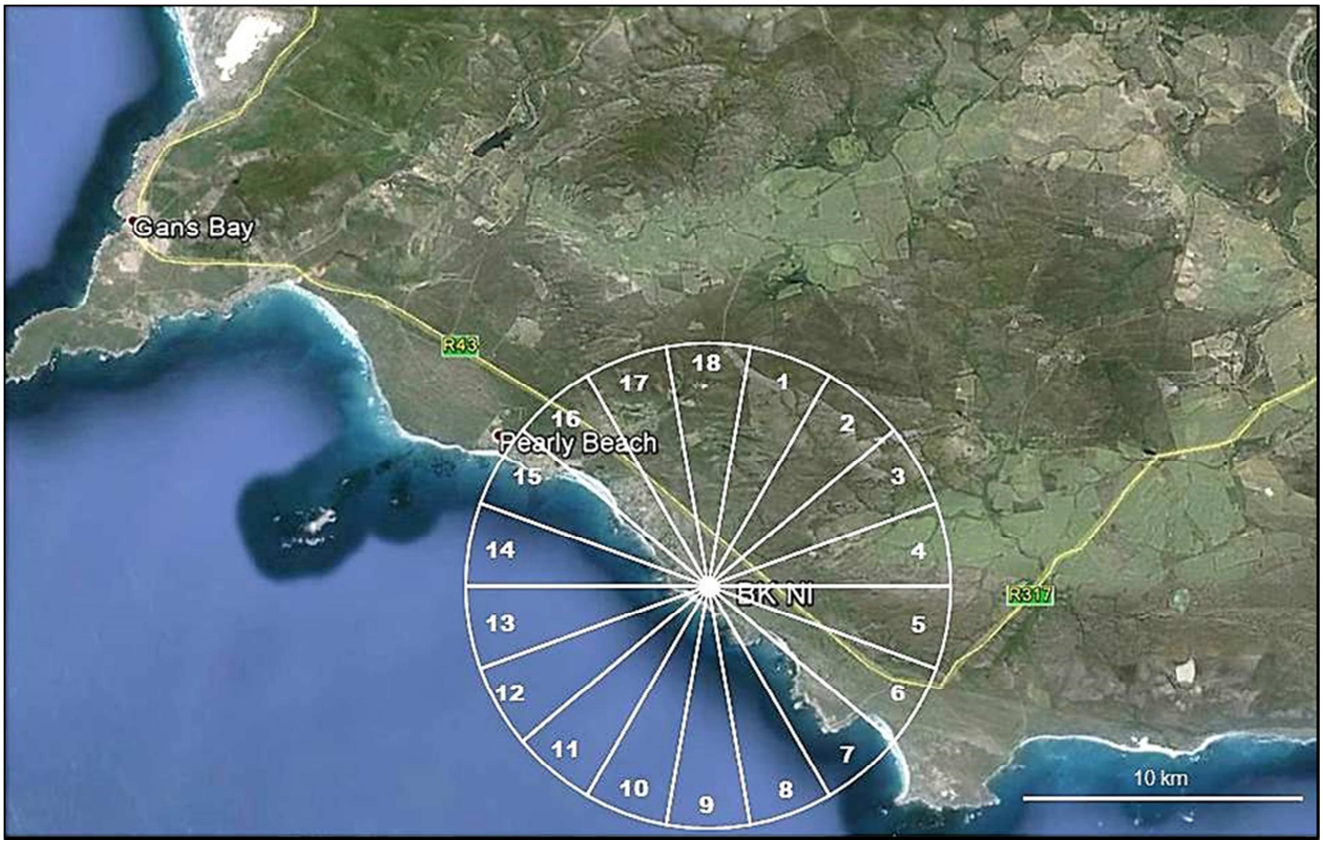


Figure 1-10: Bantamsklip wind sectors

Figure 1-11: Location of Buffeljags relative to the NPP (indicated as BK NI)

1.7.4 Duynefontein critical groups

The doses were calculated for eleven critical groups, designated CG01 to CG11, corresponding to wind sectors 8 to 1 and 18 to 16 respectively; illustrated in Figure 1-12.

Table 1-8: Duynefontein critical groups in relation to the different wind sectors

CG Identification	Sector	Distance (km)
CG01	8	2.5
CG02	7	2.5
CG03	6	2.5
CG04	5	2.5
CG05	4	2.5
CG06	3	2.5
CG07	2	5.0
CG08	1	5.0
CG09	18	5.0
CG10	17	5.0
CG11	16	5.0

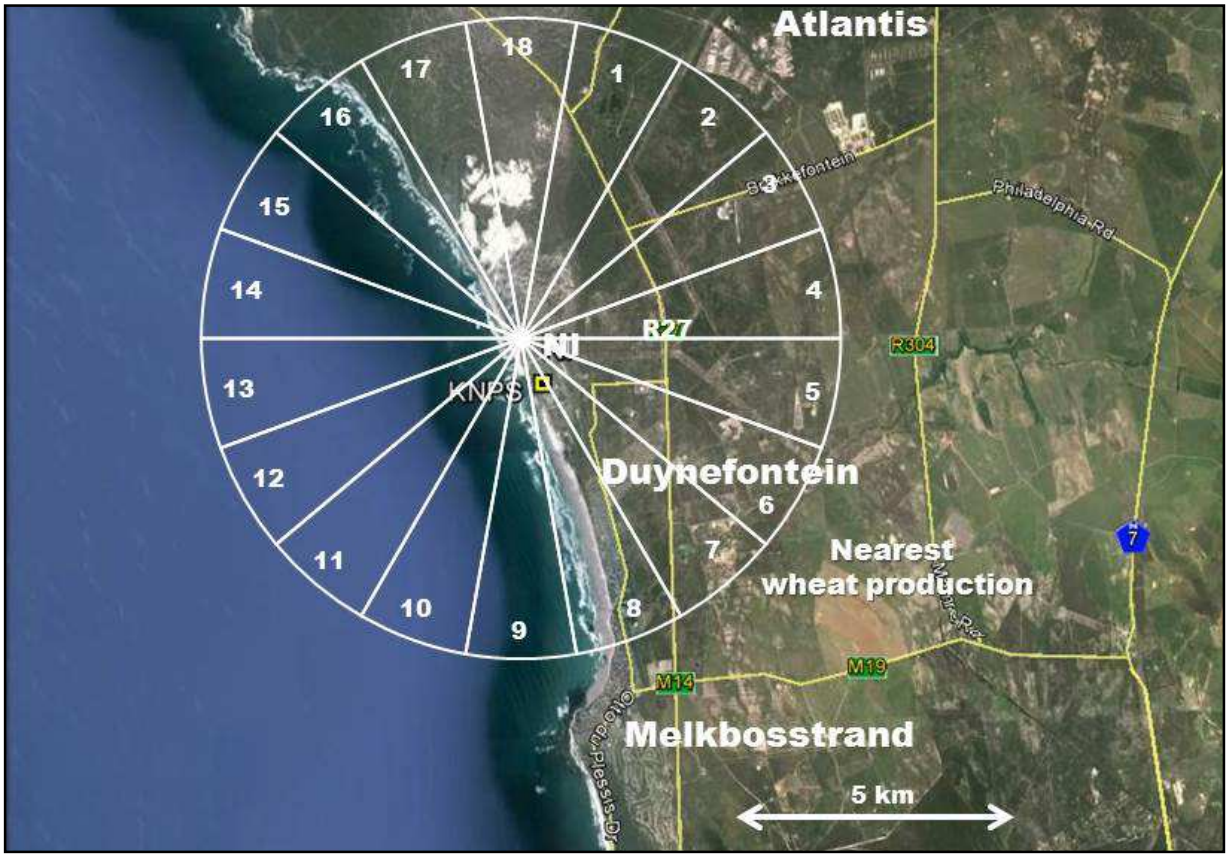


Figure 1-12: Duynefontein wind sectors and critical groups

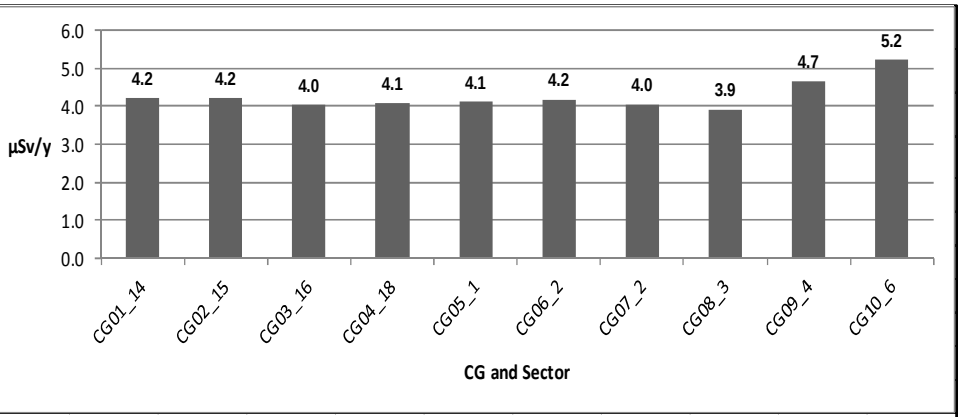
1.8 Public dose from routine atmospheric discharges

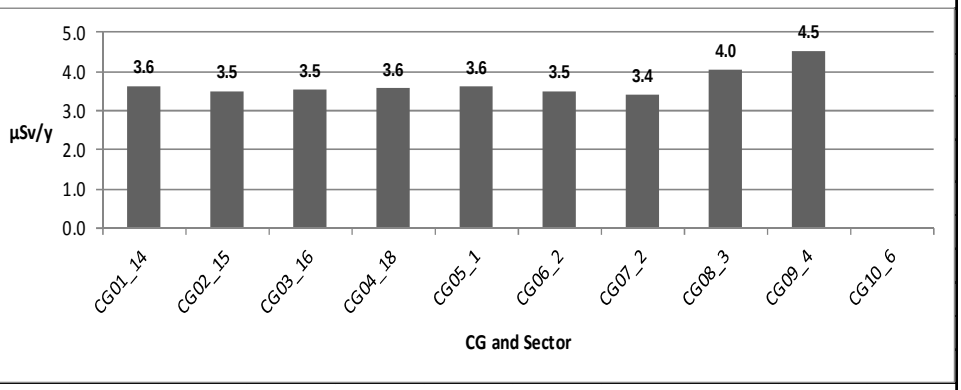
1.8.1 Thyspunt

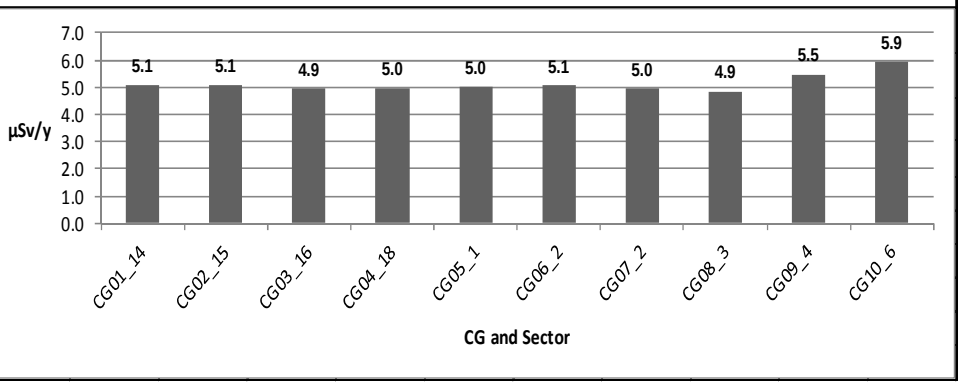
The total dose from airborne discharges for each subcritical group is listed in Table 1-9. The maximum dose from atmospheric discharges is for the infant age group at CG10. The various dose components are listed in Figure 1-13.

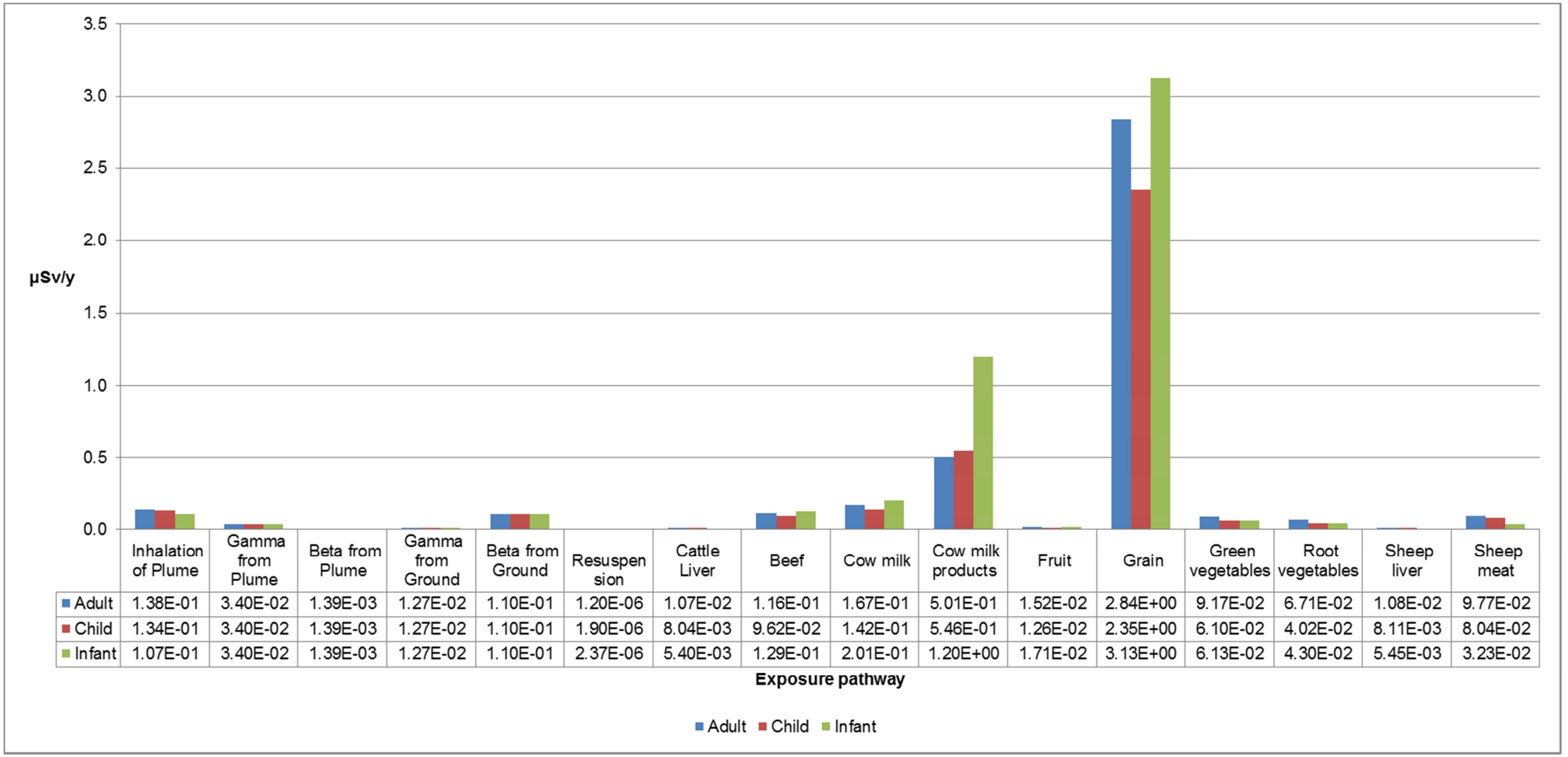
Table 1-9: Thyspunt annual dose to critical groups from NPP normal airborne discharges

	CG	µSv/y
Adult	CG01	4.2
	CG02	4.2
	CG03	4.0
	CG04	4.1
	CG05	4.1
	CG06	4.2
	CG07	4.0
	CG08	3.9
	CG09	4.7
	CG10	5.2
Child	CG01	3.6
	CG02	3.6
	CG03	3.5
	CG04	3.5
	CG05	3.6
	CG06	3.6
	CG07	3.5
	CG08	3.4
	CG09	4.0
	CG10	4.5
Infant	CG01	5.1
	CG02	5.1
	CG03	4.9
	CG04	5.0
	CG05	5.0
	CG06	5.1
	CG07	5.0
	CG08	4.9
	CG09	5.5
	CG10	5.9









	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resuspension	Cattle Liver	Beef	Cow milk	Cow milk products	Fruit	Grain	Green vegetables	Root vegetables	Sheep liver	Sheep meat
Adult	1.38E-01	3.40E-02	1.39E-03	1.27E-02	1.10E-01	1.20E-06	1.07E-02	1.16E-01	1.67E-01	5.01E-01	1.52E-02	2.84E+00	9.17E-02	6.71E-02	1.08E-02	9.77E-02
Child	1.34E-01	3.40E-02	1.39E-03	1.27E-02	1.10E-01	1.90E-06	8.04E-03	9.62E-02	1.42E-01	5.46E-01	1.26E-02	2.35E+00	6.10E-02	4.02E-02	8.11E-03	8.04E-02
Infant	1.07E-01	3.40E-02	1.39E-03	1.27E-02	1.10E-01	2.37E-06	5.40E-03	1.29E-01	2.01E-01	1.20E+00	1.71E-02	3.13E+00	6.13E-02	4.30E-02	5.45E-03	3.23E-02

Figure 1-13: Thyspunt – Dose components from normal airborne discharges at CG02

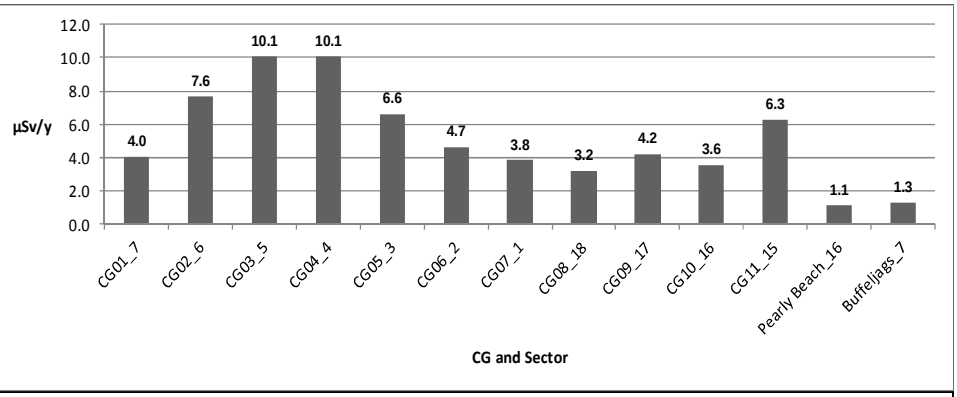
1.8.2 Bantamsklip

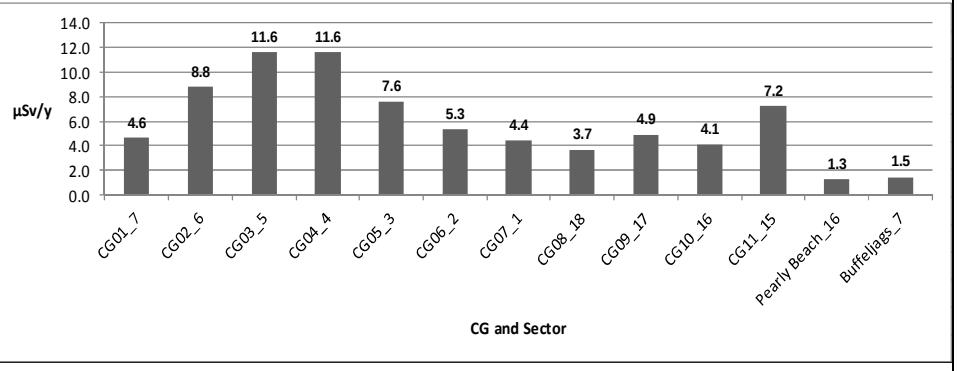
The dose results for the various CGs are listed in Table 1-10. The dose estimates for CG01 to CG11 are purely hypothetical doses. The eastern wind sectors (sectors 4 and 5) have the highest doses for the infant age group.

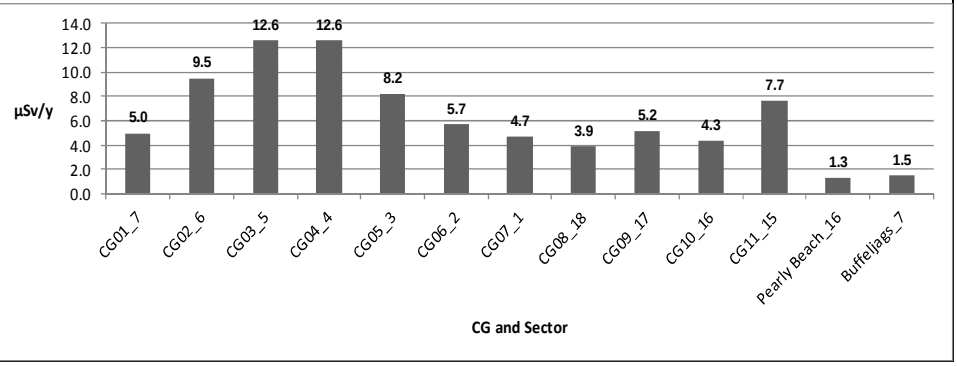
The various dose components for the three age groups are illustrated in Figure 1-14.

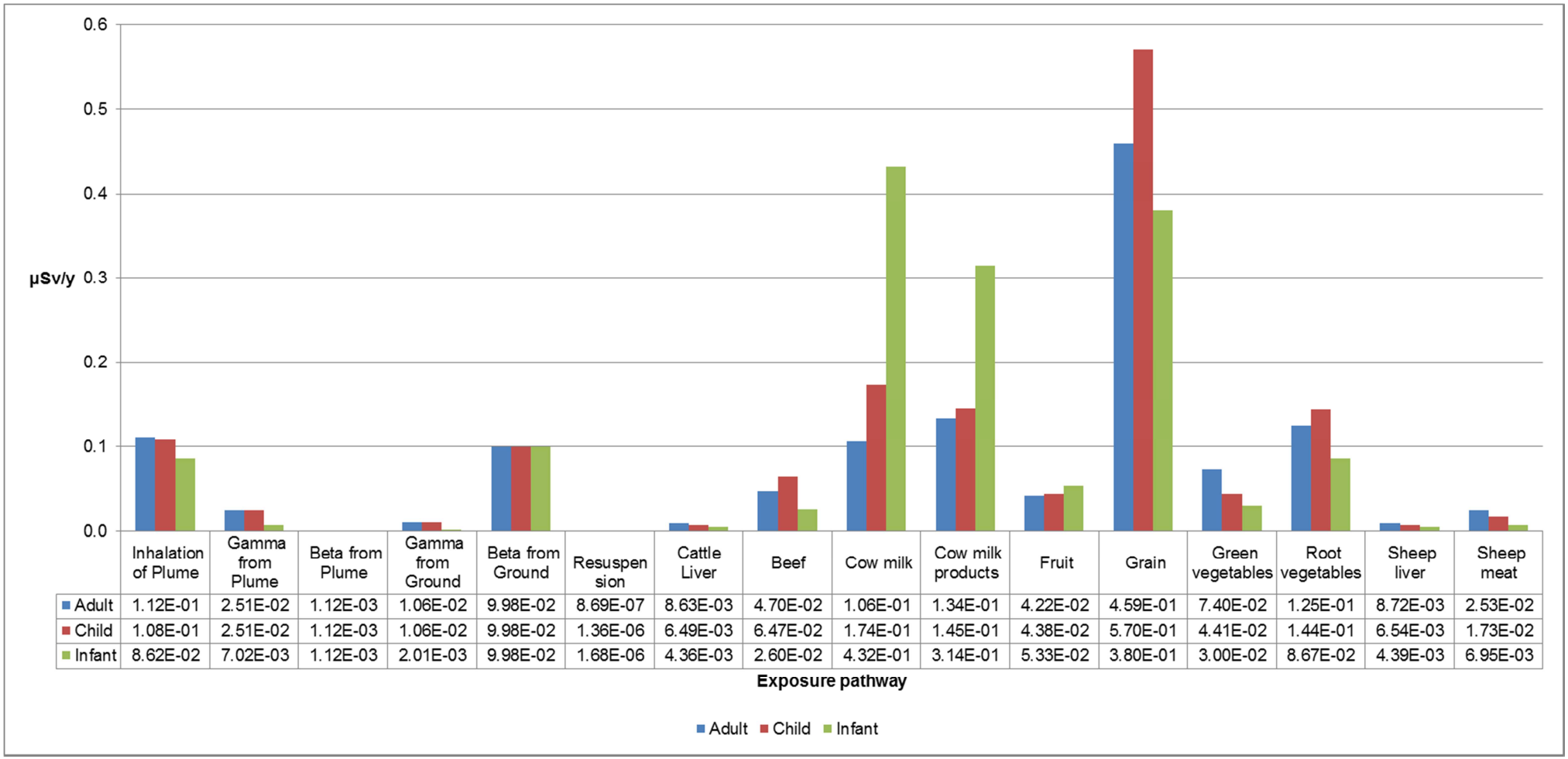
Table 1-10: Bantamsklip – Dose from normal airborne discharges

	CG	µSv/y
Adult	CG01	4.0
	CG02	7.6
	CG03	10.1
	CG04	10.1
	CG05	6.6
	CG06	4.7
	CG07	3.8
	CG08	3.2
	CG09	4.2
	CG10	3.6
	CG11	6.3
	Pearly Beach	1.1
	Buffeljags	1.3
Child	CG01	4.6
	CG02	8.8
	CG03	11.6
	CG04	11.6
	CG05	7.6
	CG06	5.3
	CG07	4.4
	CG08	3.7
	CG09	4.9
	CG10	4.1
	CG11	7.2
	Pearly Beach	1.3
	Buffeljags	1.5
Infant	CG01	5.0
	CG02	9.5
	CG03	12.6
	CG04	12.6
	CG05	8.2
	CG06	5.7
	CG07	4.7
	CG08	3.9
	CG09	5.2
	CG10	4.3
	CG11	7.7
	Pearly Beach	1.3
	Buffeljags	1.5









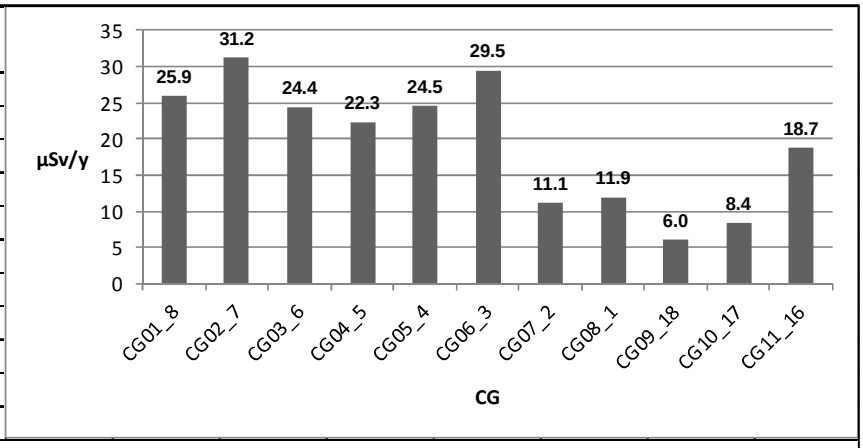
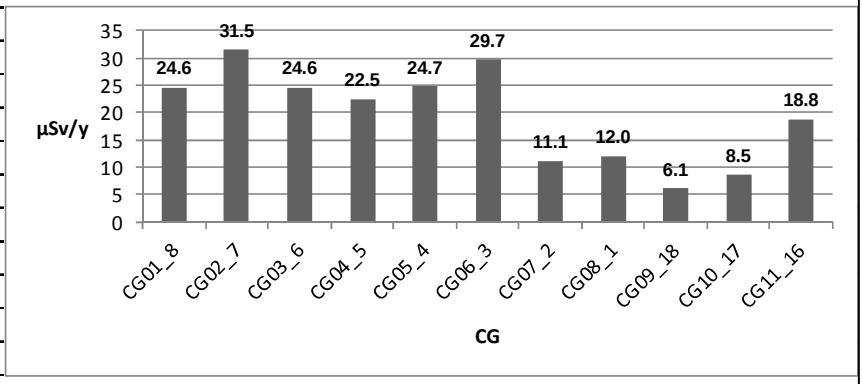
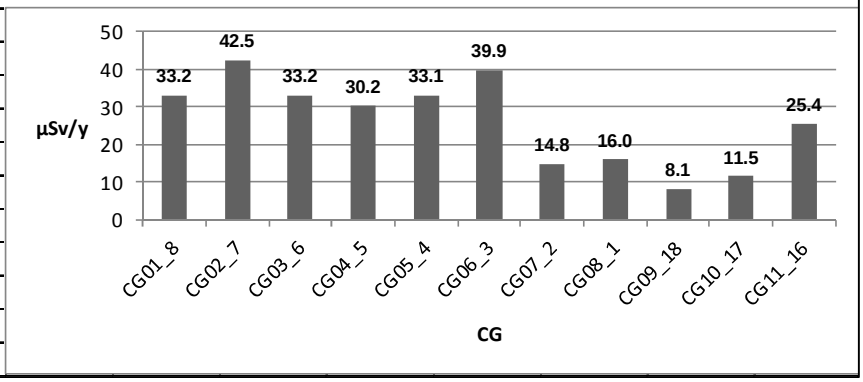
	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resuspension	Cattle Liver	Beef	Cow milk	Cow milk products	Fruit	Grain	Green vegetables	Root vegetables	Sheep liver	Sheep meat
Adult	1.12E-01	2.51E-02	1.12E-03	1.06E-02	9.98E-02	8.69E-07	8.63E-03	4.70E-02	1.06E-01	1.34E-01	4.22E-02	4.59E-01	7.40E-02	1.25E-01	8.72E-03	2.53E-02
Child	1.08E-01	2.51E-02	1.12E-03	1.06E-02	9.98E-02	1.36E-06	6.49E-03	6.47E-02	1.74E-01	1.45E-01	4.38E-02	5.70E-01	4.41E-02	1.44E-01	6.54E-03	1.73E-02
Infant	8.62E-02	7.02E-03	1.12E-03	2.01E-03	9.98E-02	1.68E-06	4.36E-03	2.60E-02	4.32E-01	3.14E-01	5.33E-02	3.80E-01	3.00E-02	8.67E-02	4.39E-03	6.95E-03

Figure 1-14: Bantamsklip – Dose components from normal airborne discharges at Buffeljags

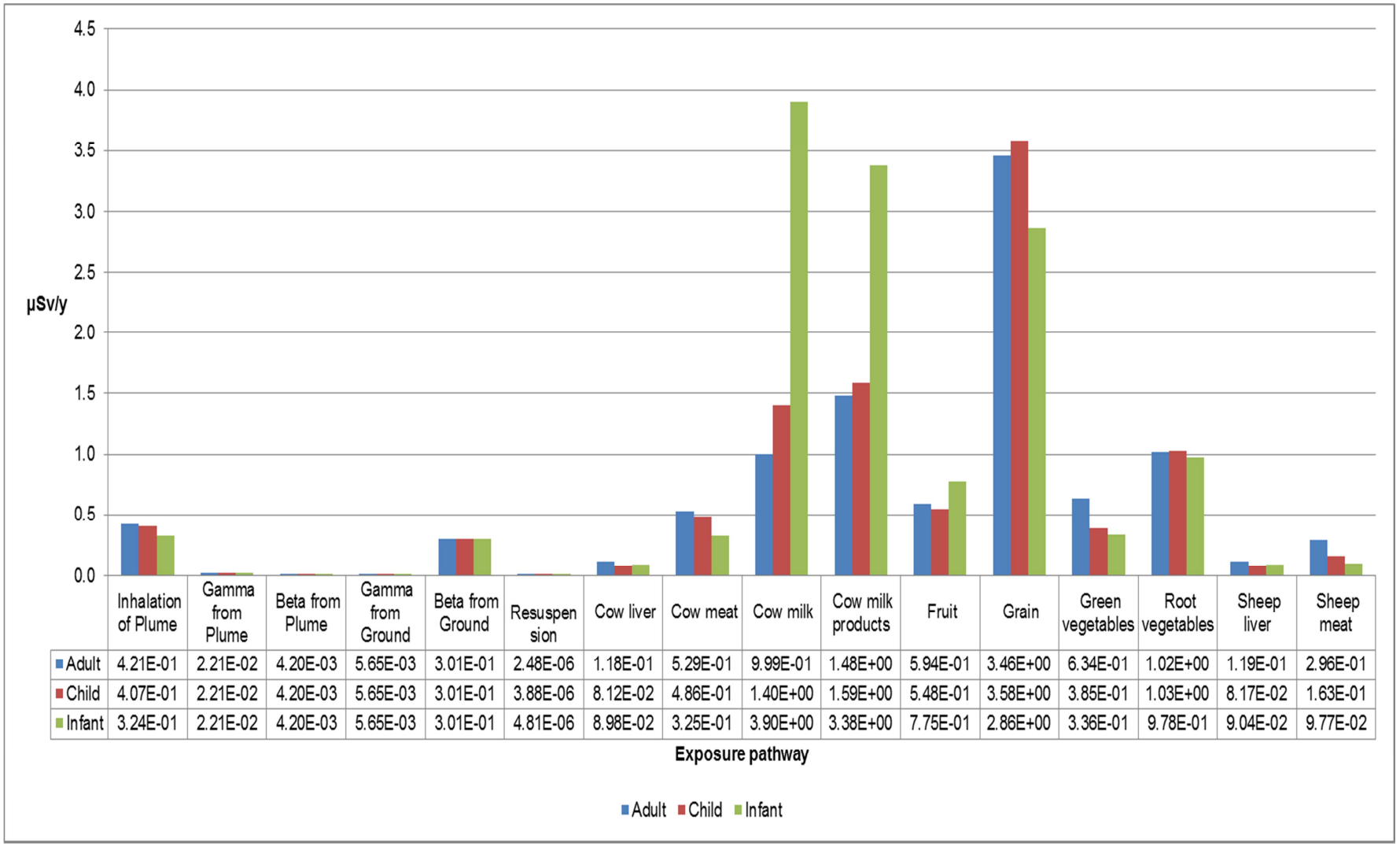
1.8.3 Duynefontein

The dose results for the various CGs are listed in Table 1-11. Wind sector 7 in Figure 1-7 will deliver the highest doses.

Table 1-11: Duynefontein – Dose from normal airborne discharges

	CG	µSv/y	
Adult	CG01_8	26	
	CG02_7	31	
	CG03_6	24	
	CG04_5	22	
	CG05_4	25	
	CG06_3	30	
	CG07_2	11	
	CG08_1	12	
	CG09_18	6	
	CG10_17	8	
	CG11_16	19	
Child	CG01_8	25	
	CG02_7	32	
	CG03_6	25	
	CG04_5	23	
	CG05_4	25	
	CG06_3	30	
	CG07_2	11	
	CG08_1	12	
	CG09_18	6	
	CG10_17	9	
	CG11_16	19	
Infant	CG01_8	33	
	CG02_7	43	
	CG03_6	33	
	CG04_5	30	
	CG05_4	33	
	CG06_3	40	
	CG07_2	15	
	CG08_1	16	
	CG09_18	8	
	CG10_17	12	
	CG11_16	25	

A potential dose is for a critical group located in the nearest existing grain production area, CG02 in wind sector no.7. The relative contributions from potential exposure pathway components are illustrated in Figure 1-15. It shows the large potential dose for infants from milk and milk products and from grain consumption for all age groups.



	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Resuspension	Cow liver	Cow meat	Cow milk	Cow milk products	Fruit	Grain	Green vegetables	Root vegetables	Sheep liver	Sheep meat
Adult	4.21E-01	2.21E-02	4.20E-03	5.65E-03	3.01E-01	2.48E-06	1.18E-01	5.29E-01	9.99E-01	1.48E+00	5.94E-01	3.46E+00	6.34E-01	1.02E+00	1.19E-01	2.96E-01
Child	4.07E-01	2.21E-02	4.20E-03	5.65E-03	3.01E-01	3.88E-06	8.12E-02	4.86E-01	1.40E+00	1.59E+00	5.48E-01	3.58E+00	3.85E-01	1.03E+00	8.17E-02	1.63E-01
Infant	3.24E-01	2.21E-02	4.20E-03	5.65E-03	3.01E-01	4.81E-06	8.98E-02	3.25E-01	3.90E+00	3.38E+00	7.75E-01	2.86E+00	3.36E-01	9.78E-01	9.04E-02	9.77E-02

Figure 1-15: Duynefontein – Annual dose components from airborne discharges at nearest grain production area

1.9 Public dose from routine liquid discharges to the sea

1.9.1.1 Thyspunt

The annual dose from liquid discharges was tested for its sensitivity in respect of the following important parameters:

- Conservative and more realistic consumption data;
- KD, the dimensionless sediment distribution coefficient – the ratio of the radioactivity concentration per unit mass of particulate (Bq/kg dry weight) to the radioactivity concentration per unit mass of seawater (Bq/kg); and
- CR, the concentration ratios in marine species – the ratio of the radioactivity concentration per unit mass of organism (Bq/kg wet weight) to the radioactivity concentration per unit volume of seawater (Bq/ℓ).

Doses were also calculated for two different sets of KD and CR. The default values of *PC-CREAM 08* and *ERICA,* a rrorradioecology risk software [1.14.12], were used together with the different consumption values. The values of these coefficients should be validated by site-specific studies (for all three sites) when the detail baseline environmental monitoring is carried out before commencing operation. It is important to note that CR values used in ERICA are for whole organisms (CR_{wo}) and in some cases are greater than CR values that are used for human dose assessment.

The two sets of results representing the range of doses are reported in Table 1-12.

Table 1-12: Thyspunt – Annual dose from normal and routine liquid discharges

Age/Pathway	Crustaceans (µSv/y)	Fish (µSv/y)	Molluscs (µSv/y)	External Beta from Beaches (µSv/y)	External Beta from Fishing Equipment (µSv/y)	External Gamma from Beaches (µSv/y)	External Gamma from Fishing Equipment (µSv/y)	Sea Spray Inhalation (µSv/y)	Total (µSv/y)
Upper Bound									
Adult	1.65E+00	8.98E+00	3.15E+01	1.06E-02	2.22E-02	3.58E+00	3.58E-02	2.63E-05	**45.7**
Child	1.70E+00	7.43E+00	3.27E+01	2.65E-03	5.54E-03	8.94E-01	8.94E-03	5.87E-06	**42.8**
Infant	9.39E-01	9.92E+00	1.78E+01	5.30E-04	0.00E+00	1.79E-01	0.00E+00	8.43E-07	**28.8**
Lower Bound									
Adult	1.51E+00	1.53E+00	1.54E+00	1.08E-02	1.40E-02	3.72E+00	3.72E-02	2.63E-05	**8.4**
Child	1.49E+00	8.48E-01	1.54E+00	2.71E-03	3.49E-03	9.29E-01	9.29E-03	5.87E-06	**4.8**
Infant	0.00E+00	9.92E-01	0.00E+00	5.42E-04	0.00E+00	1.86E-01	0.00E+00	8.43E-07	**1.2**

1.9.1.2 Bantamsklip

The annual dose result from liquid discharges was tested for its sensitivity in respect of the following important parameters:

- KD, the dimensionless sediment distribution coefficient;
- CR, the concentration ratios in marine species; and
- fraction of fish caught in the local marine compartment –The value of this fraction is normally assumed to be 0.1 (10 per cent) because of the migratory patterns of fish and the large fraction of fish consumption contributed by pelagic fish outside the local marine compartment. However, because of the location of the subsistence fishing community at Buffeljags, a fraction as high as 0.5 was also investigated to account for a potential higher consumption of 'local' fish species.

A local marine compartment has higher predicted radionuclide concentrations than its adjacent and larger regional compartment. A more accurate value for the fraction of fish caught in the local compartment can be obtained by a future investigation of the different species of fish that are found in the local compartment and their migratory patterns, together with the quantities of each fish species caught and consumed at Buffeljags. The use of a fraction equal to 0.5 is regarded as conservative. The values of KD and CR should also be investigated further by carrying out site-specific studies before commencing operation.

The liquid pathways dose results are reported in Table 1-13 for four scenarios:

- Scenario 1: Conservative CF and KD (*PC CREAM* default values) and a local compartment fraction for fish equal to 0.5;
- Scenario 2: Conservative CF and KD values (*PC CREAM* default values) and a local compartment fraction for fish equal to 0.1;
- Scenario 3: Smaller CF and KD (*ERICA* default values) and a local compartment fraction for fish equal to 0.5; and
- Scenario 4: Smaller CF and KD (*ERICA* default values) and a local compartment fraction for fish equal to 0.1.

The critical group located at Buffeljags has the highest maximum potential dose when compared to the dose estimate for Pearly Beach.

Table 1-13: Bantamsklip – Annual dose from normal and routine liquid discharges

Age Group	Scenario	Crustaceans (µSv/y)	Fish (µSv/y)	Molluscs (µSv/y)	Seaweed (µSv/y)	External Beta from Beaches (µSv/y)	External Beta from Fishing Equipment (µSv/y)	External Gamma from Beaches (µSv/y)	External Gamma from Fishing Equipment (µSv/y)	Sea Spray Inhalation (µSv/y)	Total (µSv/y)
Adult	1	7.30E+00	7.24E+01	3.24E+01	0.00E+00	1.06E-02	2.22E-02	3.58E+00	3.58E-02	1.15E-04	**116**
	2	7.30E+00	1.45E+01	3.24E+01	0.00E+00	1.06E-02	2.22E-02	3.58E+00	3.58E-02	1.15E-04	**58**
	3	4.30E+00	5.11E+01	1.93E+01	0.00E+00	1.08E-02	1.40E-02	3.72E+00	3.72E-02	1.15E-04	**79**
	4	4.30E+00	1.02E+01	1.93E+01	0.00E+00	1.08E-02	1.40E-02	3.72E+00	3.72E-02	1.15E-04	**38**
Child	1	2.23E+01	5.99E+01	1.02E+01	0.00E+00	2.65E-03	5.54E-03	8.94E-01	8.94E-03	1.02E-04	**93**
	2	2.23E+01	1.20E+01	1.02E+01	0.00E+00	2.65E-03	5.54E-03	8.94E-01	8.94E-03	1.02E-04	**45**
	3	1.32E+01	4.24E+01	6.14E+00	0.00E+00	2.71E-03	3.49E-03	9.29E-01	9.29E-03	1.02E-04	**63**
	4	1.32E+01	8.48E+00	6.14E+00	0.00E+00	2.71E-03	3.49E-03	9.29E-01	9.29E-03	1.02E-04	**29**
Infant	1	0.00E+00	4.00E+01	0.00E+00	0.00E+00	5.30E-04	0.00E+00	1.79E-01	0.00E+00	7.35E-05	**40**
	2	0.00E+00	8.00E+00	0.00E+00	0.00E+00	5.30E-04	0.00E+00	1.79E-01	0.00E+00	7.35E-05	**82**
	3	0.00E+00	2.83E+01	0.00E+00	0.00E+00	5.42E-04	0.00E+00	1.86E-01	0.00E+00	7.35E-05	**29**
	4	0.00E+00	5.67E+00	0.00E+00	0.00E+00	5.42E-04	0.00E+00	1.86E-01	0.00E+00	7.35E-05	**59**

1.9.1.3 Duynefontein

The calculated annual dose from liquid discharges was tested for its sensitivity in respect of the following two important parameters:

- sediment distribution coefficient (KD); and
- concentration ratios in marine species (CR).

A range of doses was calculated using two different sets of KD and CR values, the default values of *PC-CREAM 08* and *ERICA*. The liquid pathways dose results are reported in Table 1-14.

Table 1-14: Duynefontein – Annual dose from normal liquid discharges

Marine Parameter Data Set	**Age Group**	**Crustaceans (µSv/y)**	**Fish (µSv/y)**	**Molluscs (µSv/y)**	**External Beta from Beaches (µSv/y)**	**External Beta from Fishing Equipment (µSv/y)**	**External Gamma from Beaches (µSv/y)**	**External Gamma from Fishing Equipment (µSv/y)**	**Sea Spray Inhalation (µSv/y)**	***Total* (µSv/y)**
Marine dispersion parameter values from the *ERICA* code	Adult	1.81E+01	1.02E+01	1.76E+01	1.08E-02	1.40E-02	3.72E+00	3.72E-02	2.63E-05	*49.6*
	Child	1.74E+01	4.45E+00	4.42E+00	2.71E-03	3.49E-03	9.29E-01	9.29E-03	5.87E-06	*27.3*
	Infant	3.14E+00	4.31E+00	0.00E+00	5.42E-04	0.00E+00	1.86E-01	0.00E+00	8.43E-07	*7.6*
Marine dispersion parameter values from the *PC CREAM 08* code	Adult	3.07E+01	1.45E+01	2.94E+01	1.06E-02	2.22E-02	3.58E+00	3.58E-02	2.63E-05	*78.2*
	Child	2.96E+01	6.29E+00	7.37E+00	2.65E-03	5.54E-03	8.94E-01	8.94E-03	5.87E-06	*44.2*
	Infant	5.31E+00	6.08E+00	0.00E+00	5.30E-04	0.00E+00	1.79E-01	0.00E+00	8.43E-07	*11.6*

1.10 Public dose from external radiation from the NPP buildings

Direct radiation from a NPP can potentially contribute to the public dose. The main source terms in this case are the buildings housing the reactor core and the stored irradiated fuel (fuel buildings). It is expected to make a small contribution to annual dose (normally not detectable with radiation monitoring equipment at distances beyond a site's owner controlled boundaries). The dose contribution from direct radiation can be estimated as follows.

Design specifications and radiation protection programmes at NPPs require that areas be designated as *Controlled*, *Supervised*, and *Non-controlled* areas [1.14.13]. The outside of buildings are classified *Non-controlled* areas and ambient dose levels have to be less than 1 mSv/y. The dose at the boundary of the site and where the nearest members of the public could reside is estimated using 1 mSv/y at 1 m from a building surface, as a radiation source. The radiation dose can be estimated as follows (to be followed up with shielding calculation for the specific NPP design at a later licensing stage):

$$\text{Annual dose} = \text{Dose rate at the NPP} \times 1/R$$

Any shielding from residential building structures is ignored and full-time occupancy is assumed at the distance where the dose is calculated. R is the distance from the NPP. This relationship between source and distance is more restrictive than what typically applies to a point source which could apply at large distances, i.e. $1/R^2$. The result for a distance larger than 2 km, for example, is:

- Dose rate (owner controlled boundaries > 2 km) ≤ 0.5 µSv/y;

The decrease in dose from a NNP with distance is illustrated in Figure 1-16.

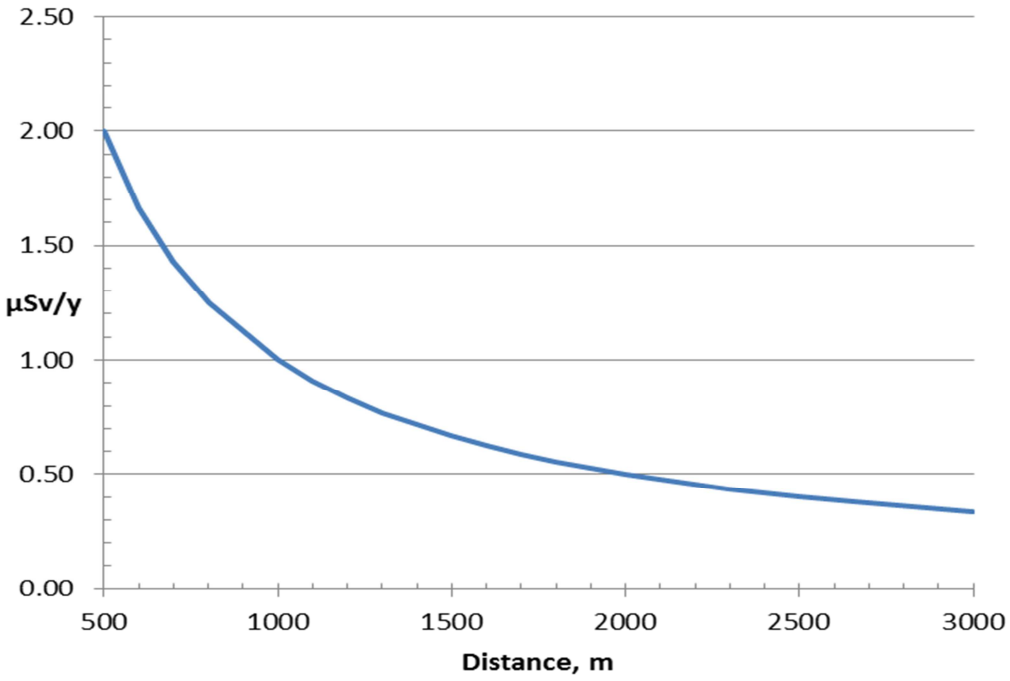


Figure 1-16: Annual external radiation dose as a function of distance from the NPP

TLD	Sector	km	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
9	NNW	1.5	Koeberg Owner Controlled Boundary	24	20	22	21	21	21	21	18	23	20	21	24	21
10	N	2.0		26	23	23	22	23	26	24	19	26	25	23	28	24
11	NNE	2.9		23	22	22	20	20	23	21	19	22	22	20	24	21
12	NE	2.6		26	25	23	23	21	25	26	24	24	26	26	27	25
46	ENE	2.5		21	20	21	20	23	22	23	21	23	22	23	25	22
13	E	2.3		35	30	32	29	27	29	32	26	31	30	30	32	30
14	ESE	2.2		28	24	26	27	26	24	24	21	25	23	24	27	25
15	SE	1.5		27	30	28	28	29	31	29	25	30	29	30	32	29
16	SSE	1.5		33	33	32	30	29	31	33	30	33	35	32	35	32
17	NNW	3.3	Eskom Pole (op4)	19	19	19	14	18	16	21	12	20	16	20	19	18
18	N	4.0	Eskom Pole (op5)	34	34	35	35	34	36	36	34	38	37	38	43	36
19	NNE	8.5	Witzand Pump Station	32	28	29	25	28	29	29	28	27	29	30	30	29
20	NE	6.0	Donkergat	32	29	31	27	27	27	28	25	28	32	31	34	29
47	ENE	9.5	Langerug	49	46	41	44	44	44	44	40	46	51	47	48	45
21	E	6.5	Vaatjie	28	26	26	24	25	25	23	23	25	27	25	30	26
48	ESE	9.0	Witdam	30	26	27	26	26	25	26	25	28	29	31	31	27
22	SE	8.0	Blaauwberg plaas	60	62	60	57	61	.	61	60	65	61	65	67	62
23	S	6.0	Telkom Cable Melkbosstrand	45	41	42	41	41	42	42	43	51	49	48	51	45

The expected low radiation levels in the public domain are confirmed by results of the environmental monitoring programme at Koeberg NPP. Examples of typical radiation levels measured in the environment are illustrated in

Table 1-15. These are values reported in an annual Koeberg environmental surveillance report and as per normal practice submitted to the NNR[1.14.14]. The direct radiation from the Koeberg NPP in the public domain is not distinguishable from the natural background radiation measured on a monthly basis in the vicinity of Koeberg NPP. Some areas at a greater distance than the site boundary show higher values as a result of variations in terrestrial radiation associated with naturally occurring radioactivity in the underlying geological strata. The natural background radiation monthly dose rates at distances more than 3 km away, for example, vary between 18 and 62 µSv/month.

TLD	Sector	km	Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
9	NNW	1.5	Koeberg Owner Controlled Boundary	24	20	22	21	21	21	21	18	23	20	21	24	21
10	N	2.0		26	23	23	22	23	26	24	19	26	25	23	28	24
11	NNE	2.9		23	22	22	20	20	23	21	19	22	22	20	24	21
12	NE	2.6		26	25	23	23	21	25	26	24	24	26	26	27	25
46	ENE	2.5		21	20	21	20	23	22	23	21	23	22	23	25	22
13	E	2.3		35	30	32	29	27	29	32	26	31	30	30	32	30
14	ESE	2.2		28	24	26	27	26	24	24	21	25	23	24	27	25
15	SE	1.5		27	30	28	28	29	31	29	25	30	29	30	32	29
16	SSE	1.5		33	33	32	30	29	31	33	30	33	35	32	35	32
17	NNW	3.3	Eskom Pole (op4)	19	19	19	14	18	16	21	12	20	16	20	19	18
18	N	4.0	Eskom Pole (op5)	34	34	35	35	34	36	36	34	38	37	38	43	36
19	NNE	8.5	Witzand Pump Station	32	28	29	25	28	29	29	28	27	29	30	30	29
20	NE	6.0	Donkergat	32	29	31	27	27	27	28	25	28	32	31	34	29
47	ENE	9.5	Langerug	49	46	41	44	44	44	44	40	46	51	47	48	45
21	E	6.5	Vaatjie	28	26	26	24	25	25	23	23	25	27	25	30	26
48	ESE	9.0	Witdam	30	26	27	26	26	25	26	25	28	29	31	31	27
22	SE	8.0	Blaauwberg plaas	60	62	60	57	61	.	61	60	65	61	65	67	62
23	S	6.0	Telkom Cable Melkbosstrand	45	41	42	41	41	42	42	43	51	49	48	51	45

Table 1-15: Direct radiation from Koeberg NPP – Typical monthly radiation measurement results (µSv)

1.11 Public dose from short-term discharges following minor occurrences

1.11.1 Contingencies and the concept of annual allowable discharges

The NNR requires that a NPP establish annual allowable discharge quantities (AADQs) that will ensure compliance with the annual dose constraint of 250 μSv/y. Routine operational discharges are normally assessed by assuming that these discharges occur continuously and uniformly over a year. However, during normal operations, short-term contingency discharges associated with minor occurrences, are possible. The combined routine and contingencies discharges represent the maximum discharge for a NNP operating state that is defined as “normal”. A radiological safety assessment must therefore include discharges as a result of contingencies. [1.14.3]. The annual dose from contingency discharges plus the dose from normal continuous discharges must still respect the regulatory dose constraint.

A contingency discharge can temporarily result in elevated environmental radioactivity concentrations when compared to those from routine continuous discharges. It can lead to a peaking of activity concentrations in air and foodstuffs, which, combined with seasonal agricultural practices and variations in habit data, can lead to slightly higher doses than normal than if it were assumed that the same discharged radioactivity takes place uniformly over a year. Conditions during which there is a higher than normal likelihood for elevated short-term contingency discharges are for example [1.14.15]:

- during maintenance operations;
- refuelling outages and reactor start-up;
- purging a reactor cooling system; and
- a postulated event such as a nuclear fuel leak to the primary coolant requiring reactor shutdown accompanied by a release to the atmosphere from the gaseous waste product system before adequate radioactive decay time has been allowed for short-lived radionuclides.

The potential short-term doses are only assessed for airborne discharges. In the case of liquid discharges to the marine environment, effects from short-term contingency discharges are deemed to have a much lower radiological impact compared to airborne contingency discharges. The discharge rate to the sea when pumping from a liquid waste storage tank is limited. It is unlikely that significant volumes can be released into the marine environment over a short period of a few hours, as is possible with contingency discharges to the atmosphere. Also, for marine discharges via a pipeline into the sea and some distance away from the near shore (the proposed design for new NPPs), the timescale of the release is radiologically less important than is the case for atmospheric releases over agricultural land areas.

1.11.2 Methodology for assessing the short-term discharges

The methodology for assessing the dose contribution from short-term contingency discharges is different to the methods used for continuous and uniform discharges. The transient nature of the radioactive contamination in the environment requires the use of dynamic food chain models.

The methodology that is used here to estimate a bounding dose to a critical group as a result of contingency discharges is as follows:

a) Source term: The source term for contingencies is defined in Table 1-16. It is based on the EPR reactor because of its larger source term per MW_{th} for the environmentally important radionuclides C-14, Cs-134, and Co-60, when compared to the AP1000. The contingency source term is chosen to represent an airborne discharge that is assumed to be six times greater than the average monthly continuous discharge per reactor unit occurring over a 24-hour period.

Table 1-16: Source term for a contingency discharge

Radionuclide	Activity Discharged per Reactor Unit per Contingency (Bq)
H-3	1.5E+12
C-14	4.5E+11
Kr-85	6.95E+11
Xe-133	3.16E+12
Xe-135	9.90E+11
Ar-41	1.45E+11
Xe-131m	1.50E+10
I-131	1.82E+08
I-133	2.18E+08
Co-58	4.34E+07
Co-60	5.12E+07
Cs-134	3.98E+07
Cs-137	3.57E+07

The EIA considers a NPP will consist at most of large reactor units generating approximately 9 000 MW_{th}, e.g. EPR type reactors. However, this report for public dose assessment purposes, considers a conservative scenario where a maximum total power of 33 000 MW_{th} is generated at a site. This is equivalent to approximately seven EPR reactor units (4500 MWth/Reactor Unit). Additional conservatism is introduced by assuming that there is one short-term contingency discharge per reactor unit during a year, therefore seven of these discharges per year at a site. The source term assumed for a discharge is large enough to envelop the possibility of several independent contingency discharges per reactor unit.

b) The pathways of exposure are the following:

- ingestion of foodstuffs;
- inhalation and external irradiation from the plume; and
- external irradiation from deposited radionuclides.

The safety analysis computer code system *PC-COSYMA* [1.14.7] was used to calculate the atmospheric concentrations and deposition of radionuclides and to estimate the short-term and long-term doses from a contingency discharge. It is a code system that has a wide international user base. It is routinely used for KNPS accident

analysis by Eskom as well as the NNR. A description of the code is provided in the EIA Emergency Planning Report. The dynamic food chain models in *PC-COSYMA* are used to determine the long-term dose from the ingestion of foodstuffs in the year following the short-term radioactivity release. The radioactivity concentrations are calculated in a conservative manner. It is assumed that during the discharge, the wind is blowing towards the nearest critical group.

c) The two radionuclides H-3 and C-14 cannot be modelled with *PC-COSYMA* since these two radionuclides are not important members of typical NPP severe accident source terms. A specific activity approach is adopted for calculating their concentrations in foodstuff. It is assumed that all foodstuffs come into rapid equilibrium with the air following a contingency discharge of H-3 and C-14. The specific activity of each radionuclide in the food is equal to the atmospheric concentration over a 24-hour period, the assumed duration of a contingency discharge.

The dose from noble gases, particulates, and iodine radionuclides is divided into two dose components. The first component is the early dose. The early dose is imparted during passage of the plume. The second component is a long-term dose component and is determined by the ingestion pathway. More than 90 per cent of the ingestion dose is imparted during the first year following the discharge.

It is important to note that the dose calculated for contingency discharges for noble gases, iodine, and particulate, is for adults. This is the only age group allowed for in the accident code *PC-COSYMA*. However, the dose for the 1-year old, the most sensitive age group in respect of continuous airborne discharges, could be 20 per cent greater than for an adult considering the results for normal discharges in section 1.9. For this reason, a factor equal to 1.2 is applied to the adult dose to represent the estimated dose to a 1-year old.

1.11.3 Dose estimates for the three sites

The estimated short-term contingency dose contribution to the critical groups defined for each of the three sites are listed in Table 1-17, Table 1-18, and Table 1-19.

Table 1-17: Thyspunt – Estimated dose in the 1-year period following a short-term discharge

Critical Group	Age Group	Dose from C-14 and H-3 µSv/y	Noble Gases, Iodine, and Particulates – Short Term Dose µSv/y	Dose from Ingestion – Long Term µSv/y	Total Dose µSv/y
CG02	Adult	1.9	5.3	6.3	13.5
	Infant	2.2	6.4	7.6	16.1

Table 1-18: Bantamsklip – Estimated dose in the 1-year period following a short-term discharge

Critical Group	Age Group	Dose from C-14 and H-3 µSv/y	Noble Gases, Iodine, and Particulates – Short Term Dose µSv/y	Dose from Ingestion – Long Term µSv/y	Total Dose µSv/y
CG03	Adult	4.3	1.6	0.6	6.5
	Infant	5.0	1.9	0.7	7.6
Buffeljags	Adult	0.5	1.0	0.3	1.8
	Infant	0.6	1.2	0.4	2.2

Table 1-19: Duynefontein - Estimated dose in the 1-year period following a short-term discharge

Critical Group	Age Group	Dose from C-14 and H-3 µSv/y	Noble Gases, Iodine, and Particulates – Short-Term Dose µSv/y	Dose from Ingestion – Long Term µSv/y	Total Dose µSv/y
CG02 at 2.5 km	Adult	14.1	1.6	1.1	16.9
	Infant	18.2	2.0	1.4	21.5
Farm area at 5 km	Adult	4.5	1.0	0.6	6.1
	Infant	5.8	1.2	0.8	7.8

1.12 Total annual public dose from normal operations

The main objective of the radiological assessments for the three sites is to demonstrate that the regulatory dose constraint of 250 µSv/y for a member of the public can be met.

At the Duynefontein site, the dose from the existing Koeberg NPP must be added to prospective dose estimate of the planned NPP. A simplified approach was followed to arrive at a total dose for the site. The annual doses to the public reported by KNPS for the years 2003 to 2011 are shown in Table 1-20. The maximum public dose reported was for the year 2003 and shown a downward trend. This dose value was added to the total estimated critical group dose for the new NPP.

Table 1-20: Annual public dose reported by KNPS

Year	Maximum Annual Dose for a Member of the Public μSv/y
2003	12.2
2004	8.7
2005	6.0
2006	4.0
2007	4.0
2008	4.3
2009	5.0
2010	3.5
2011	3.0
Average	*5.6*

The maximum total effective doses from all exposure pathways for each site's critical groups are listed in Table 1-21. The results for 4 000 $MW_{e,}$ the electrical power specified in the EIA, have been derived by scaling the bounding results for 10 000 MW_e (33 000 MW_{th}). It shows that the dose constraint value can be met with adequate margin.

Table 1-21: Total annual dose to critical groups at Thyspunt, Bantamsklip, and Duynefontein

Site	Critical Group	Age Group	Airborne Exposure Pathways (µSv/y)	Liquid Exposure Pathways (µSv/y)	Short-term Discharges following Minor Occurrences (µSv/y)	External Radiation (µSv/y)	Maximum Public Dose reported by KNPS (µSv/y)	*Total Dose 10 000 MW_e (33 000 MW_{th}* (µSv/y)	*Total Dose 4 000 MW_e*	
									µSv/y	*% of Dose Constraint*
Thyspunt	CG02	Adult	4.2	45.7	13.5	0.5	–	*63.9*	*25.6*	*10.2*
		Child	3.6	42.8	16.1	0.5		*63.0*	*25.2*	*10.1*
		Infant	5.1	28.8	16.1	0.5		*50.5*	*20.2*	*8.1*
	CG10	Adult	5.2	45.7	13.5	0.5		*64.9*	*26.0*	*10.4*
		Child	4.5	42.8	16.1	0.5		*63.9*	*25.6*	*10.2*
		Infant	5.9	28.8	16.1	0.5		*51.3*	*20.5*	*8.2*
Bantamsklip	CG03	Adult	10.1	57.8	6.5	0.5	–	*74.9*	*30.0*	*12.0*
		Child	11.6	93.4	7.6	0.5		*113.1*	*45.2*	*18.1*
		Infant	12.6	8.2	7.6	0.5		*28.9*	*11.6*	*4.6*
	Buffeljags	Adult	1.3	116.0	1.8	0.5		*119.6*	*47.8*	*19.1*
		Child	1.5	93.4	2.2	0.5		*97.6*	*39.0*	*15.6*
		Infant	1.5	40.2	2.2	0.5		*44.4*	*17.8*	*7.1*
Duynefontein	CG02 at 2.5 km	Adult	31.2	78.2	16.9	0.5	12.2	*139.0*	*55.6*	*22.2*
		Child	31.5	44.2	21.5	0.5	12.2	*109.9*	*44.0*	*17.6*
		Infant	42.5	11.6	21.5	0.5	12.2	*88.3*	*35.3*	*14.1*
	CG (Farmi	Adult	10.0	78.2	6.1	0.5	12.2	*107.0*	*42.8*	*17.1*

	ng Activities) at 5 km	Child	10.1	44.2	7.8	0.5	12.2	*74.8*	*29.9*	*12.0*
		Infant	13.5	11.6	7.8	0.5	12.2	*45.6*	*18.2*	*7.3*

1.13 Limitations and assumptions

Any potential radiological impact assessment has associated with it many factors that introduce uncertainties, due to the models and the values adopted for a large number of parameters describing systems for which models are created. The models are simplified representations of complex environmental and human systems. Various environmental media form the components of the radionuclide transfer paths leading to exposure of human beings.

In particular, model applications such as for detail design assessments and optimisation studies, it may be necessary to quantify these uncertainties in much more detail than was done in this site radiological assessment. The dose assessment presented adopted a cautious approach using conservative assumptions since the main objective is to demonstrate site suitability and not design optimisation. Site suitability is achieved when the regulatory dose constraint is met.

A brief overview is provided of some of the main assumptions and uncertainties in the dose assessment performed for the site.

1.13.1 Source terms

A bounding source term was used that is representative of the maximum power generating capacity of 33 000 MW_{th} during a 60-year operating period of NPP consisting of a number of nuclear reactors. The average annual power level will be lower than this maximum value because of the sequential construction of reactor units and lower than 100 per cent capacity factors as a result of refuelling outages, for example.

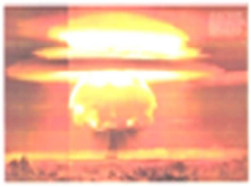
The modelled radiological impact is dominated by the radioactive carbon, C-14, in the source term for normal NPP operation. The dose to the public and non-human species is highly sensitive to the chemical species of C-14 in the environment. In this assessment of the sites, it was conservatively assumed that the chemical form is inorganic $^{14}CO_2$. All discharged C-14 therefore participates in the photosynthesis process, as opposed to organic chemical species. This assumption results in a potentially high dose contribution from ingestion pathways. However, the measured releases of gaseous C-14 from two U.S. and six German commercial pressurised water reactors found that the inorganic release fraction is on average 20 per cent and the organic release fraction is 80 per cent [1.14.16]. A more accurate assessment of the radioactive carbon dioxide fraction, $^{14}CO_{2,}$ of the C-14 source term in the airborne release as well as the liquid release should be used in the radiological assessment when a specific NPP design becomes available.

The discharge of C-14 by the global nuclear power industry and its relative contribution to environmental concentrations are put in perspective in Figure 1-17.

"Carbon - the Fabric of Life"

How much of this fabric is ^{14}C from Nuclear Installations ? (important to know because of its mobility in the environment and long $T_{1/2}$ = 5730 yrs)

Estimates of Global ^{14}C and Reservoirs Note: 1 PBq = 1E15 Bq		
Natural	Production in the upper atmosphere, (PBq/yr)	1.4 PBq/yr
	Atmosphere	220 PBq
	Terrestrial	11 500 PBq
Anthropogenic	Atmospheric A-Bomb testing	220 PBq (up to 1990)
	Nuclear reactor emissions	0.3 PBq



Current ^{14}C estimated levels of 250 Bq/kg C in atmosphere and biosphere correspond to an approximate ratio of :

1 atom of ^{14}C to 7×10^{11} atoms of stable carbon,
or 1.5×10^{-10} % of all carbon present.

Figure 1-17: Sources of radioactive carbon C-14

1.13.2 Atmospheric dispersion

Following the release into the atmosphere of radioactive materials, the subsequent dispersion will depend on radionuclide properties and the weather conditions. The semi-empirical Gaussian plume model is used in *PC-CREAM 08* for assessing the impact of continuous and routine discharges to the atmosphere. The end-points of the calculations are long-term average or time-integrated concentrations in air, as is normally the case in the assessment of dose from continuous releases. The airborne discharge is assumed to be from a single point at ground level. This results in significantly higher radionuclide concentrations at a critical group location than would be the case for multiple stacks discharging at tens of metres above ground level. When more realistic dispersion is performed by taking into account a stack release and building wake effects, smaller dispersion coefficients should be obtained and therefore lower radioactivity concentrations in the environment.

1.13.3 Dispersion in the sea

It is assumed that the liquid discharge is from a single point into a local marine compartment of limited size as described in the *DORIS* model of *PC-CREAM 08*. There are, however, large uncertainties associated with complex behaviour of radionuclides in different marine environments, e.g. sediment distribution coefficients (expressed as Bq/kg in sediment per Bq/ℓ in seawater) and the radionuclide bioaccumulation and biomagnification in marine species at different trophic levels.

A limited sensitivity study was performed using two sets of data from different sources. However, advanced marine dispersion modelling should be used to support optimisation studies during the safety analysis of a specific NPP design.

1.13.4 Public dose and critical groups

Hypothetical critical groups (CGs) were defined at locations adjacent to the sites' owner controlled boundaries and therefore receiving the maximum impact from airborne radioactive discharges to the environment. The basic approach was to choose habit and consumption data to ensure a conservative and bounding result for each CG dose. The formal rules for defining a CG have therefore been forced in a conservative manner in a way that could be viewed as bordering on being implausible or completely hypothetical, e.g. combining farming and fishing family habits for locations close to the site.

The concept of representative person as recommended by ICRP Publication 101 [1.14.10] will be applied in a later nuclear licensing stage that will require a safety assessment report for a specific NPP design. A representative person is then defined specific to a site based on local habit data and less conservative exposure assumptions than for hypothetical critical groups. However, irrespective of the conservative approach followed, adequate margin was demonstrated between critical group's doses and the regulatory dose constraint of 250 µSv/y.

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2 NUCLEAR POWER PLANT ACCIDENTS AND RADIOLOGICAL RISK TO THE PUBLIC

2.1 Introduction

The majority of NPPs operating today were built in the seventies and eighties. They are considered second generation NPP (GEN **II**) and developed from experience gained with NPPs built and operated in the nineteen-fifties and early nineteen-sixties. The environmental impact of nuclear power is largely determined by the radioactive releases in case of severe accidents involving reactor fuel damage and in the extreme cases, melting of the reactor core consisting of the support structures and nuclear fuel inside the reactor vessel. The NPP accidents that have taken place up to now involved GEN **I** and GEN **II** reactor designs, e.g. Windscale, Three Mile Island (TMI), Chernobyl, and Fukushima Dai-ichi.

TMI and Chernobyl forced the nuclear power industry to improve safety features in the designs. Safety objectives were developed that included the significant lowering of the probability for reactor core melt accidents and practically eliminating consequences that result in large releases of radioactivity into the environment. The international nuclear power industry also reviewed currently operating GEN **II** NPP. The Fukushima Dai-ichi accident resulted in further safety reviews and to incorporate lessons learnt in respect of extreme external events such as earthquakes and tsunamis. The reviews have led to actions to further improve safety of new NPP design such as GEN III designs, and emergency response actions.

2.2 Purpose

This section provides an overview of the nuclear safety criteria applicable to accidents and some of the safety assessment methodologies. The safety features of GEN III reactors that practically eliminate large releases of radioactivity are discussed. It is a general and limited overview of a highly technical subject field.

It is important to remember that an actual NPP design that will be selected to be built at a particular site, will be subjected to a rigorous nuclear authorisation process to ensure compliance with the NNR regulations and which are fully aligned with international safety standards, e.g. those developed by the IAEA. The safety analysis report to be submitted to the NNR must describe in detail the specific NNP design to be constructed at the site, its response to a wide range of potential events that may initiate accident sequences, and how safety systems prevent accidents. A structured engineering approach is followed to identify potential events with an internal origin such as reactor system failures, but also external events such as earthquakes and tsunamis. This comprehensive safety analysis report is normally developed in stages with nuclear authorisation hold points [2.6.11]. Full compliance with NNR dose and risk criteria for accidents must be demonstrated before NPP operation may commence.

2.3 Safety principles and criteria

A major part of the process of design and licensing of a NPP is the safety analysis report. The IAEA definition of a safety analysis is stated and a discussion of the terms included in the definition follows [2.6.2]:

> *A safety analysis of the NNP design, applying methods of deterministic and probabilistic analysis, shall be provided which establishes and confirms the design basis for the items important to safety and demonstrates that the overall NNP design is capable of meeting the prescribed and acceptable limits for radiation doses and releases for each plant condition category, and that defence-in-depth (DiD) has been achieved.*

The safety analysis process and its results have to demonstrate to the NNR that the fundamental safety functions of a NPP can be maintained and that a large release of radioactivity is practically eliminated. These fundamental safety functions are [2.6.3]:

- Reactivity control (reactivity is the parameter that describes the “acceleration” and “deceleration” of the nuclear fission processes in reactor fuel);
- heat removal from the reactor core; and
- confinement of radioactivity (c*onfinement* is closely related in meaning to *containment*, but *confinement* is typically used to refer to the *safety function* of preventing the ‘escape’ of *radioactive material*, whereas *containment* refers to the means for achieving that function, e.g. the reactor building [2.6.4].

Public radiological exposure may occur if confinement is lost. The design, operation, and maintenance of a NPP must ensure the highest level of integrity of the physical barriers to contain radioactivity. These physical barriers are the uranium fuel material matrix, the cladding of the fuel element tube containing the fuel material, the reactor vessel, and the NPP containment building that includes irradiated and spent fuel storage. These barriers are illustrated in Figure 2-1 [2.6.5].

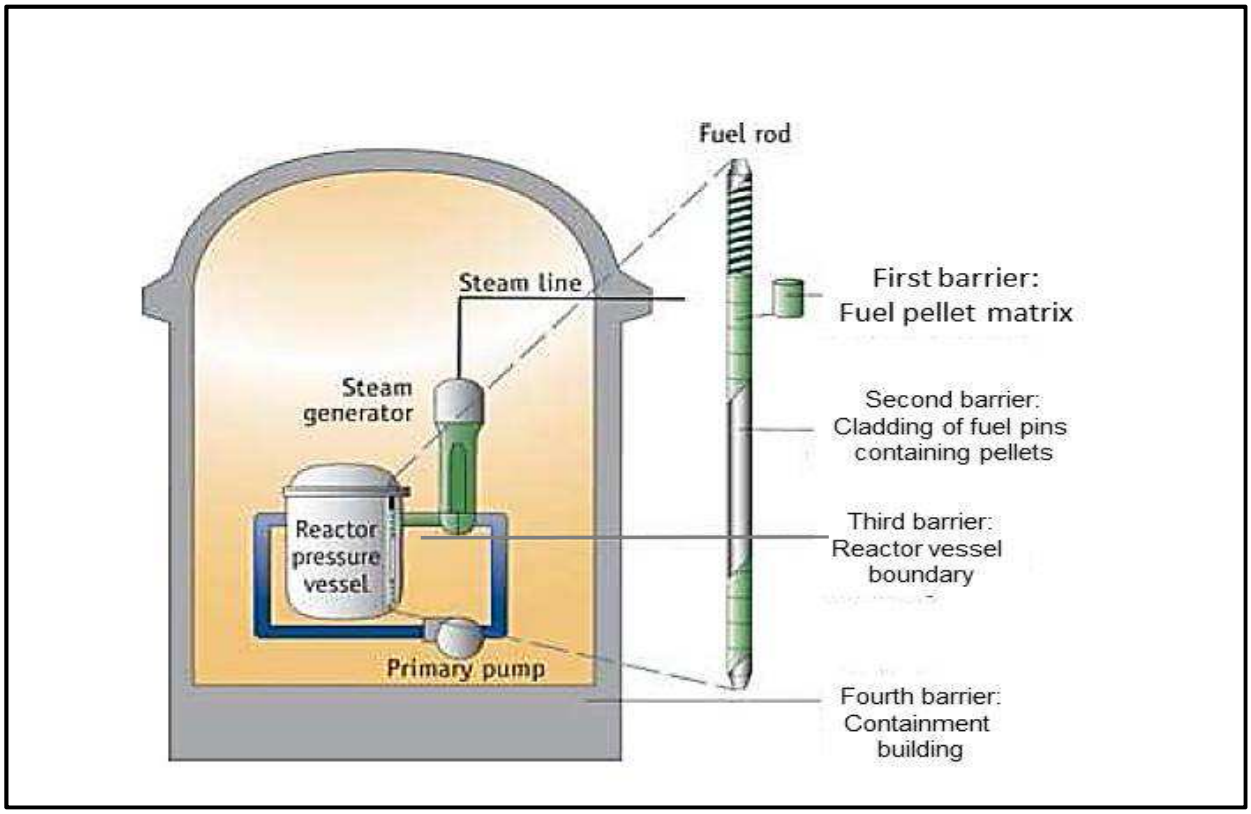

Figure 2-1: Reactor core fission product barriers

The principle of defence-in-depth (DiD) is fundamental to nuclear safety in order to comply with the fundamental safety functions. The objectives of DiD are [2.6.6]:

- to compensate for potential human and component failures;
- to maintain the effectiveness of the barriers by averting damage to the NPP and to the barriers themselves; and
- to protect workers, members of the public, and the environment from harm in accident conditions in the event that these barriers are not fully effective.

The application of the principle of DiD consists in a hierarchical deployment of different levels of structures, systems, components (SSCs), and procedures in order to maintain the effectiveness of physical barriers placed between radioactive materials and workers, the public, or the environment. DiD has to be in place during normal operation, anticipated operational occurrences and, for some barriers such as building containment structures, during severe accidents. Application of the DiD principle results in the following NPP safety features [2.6.3]:

- sufficient independent reactivity control functions;
- sufficient independent heat removal functions; and
- sufficient independent barriers for confinement of fission and activation products.

The safety philosophy underlying DiD is aimed primarily at the prevention of accidents but also gives attention to the mitigation of the consequences of accidents that could give rise to major radioactive material releases.

The DiD concept is illustrated by means of an event tree that shows the possible outcomes of hazardous conditions or of an “initiating event” in Figure 2-2. The scenario is that of a driver travelling in his car at night on a wet road. An initiating event is represented by a truck that

broke down some distance ahead and is parked in an unsafe position, creating a hazardous situation for the driver. At each node (branch) of the event tree, there is a certain probability for entering a safe condition by going “up” in the event tree or entering an unsafe condition by going “down”; i.e. a safety system fails or a driver action is not carried out. Different layers of protection exist to prevent and control conditions so that an accident can be avoided, or if an accident does take place, limiting and mitigating systems exist to ensure that the driver survives the accident. The success or failure of the elements making up the layers of protection determines the outcomes of the possible sequences of events. The elements that constitute the layers of protection are some of the DiD provisions. These must be of high quality and reliability so that the probability of driver fatality is low.

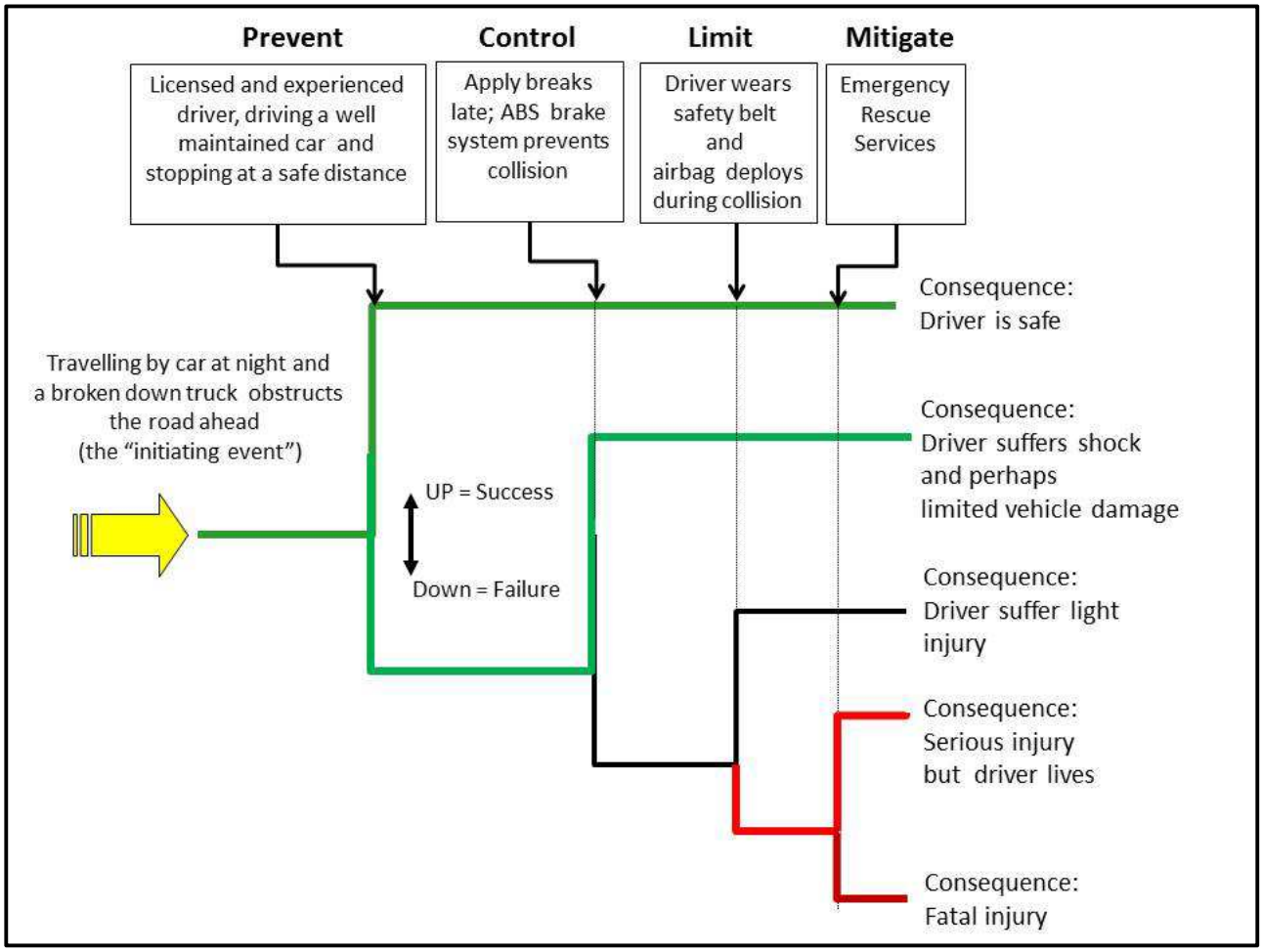

Figure 2-2: An example of an initiating event and potential event sequences illustrating the risk analysis process and systems providing DiD

In the design and operation of a GEN III NPP, these elements providing the layers of protections are of such a high standard that the most serious sequence of events (the bottom sequence in Figure 2-2 when all systems fail and the driver is fatally injured) is practically eliminated, i.e. a large release of radioactivity to the environment. Expressed in nuclear terminology, the aim is to reduce both the probabilities of the potential events beyond normal operation and to consider these events in the design basis, as well as successfully managing extremely low probability events, events that can be considered the design basis of a NPP.

The spectrum of operational states and accident conditions that are considered in NPP designs are illustrated in Figure 2-3 and an explanation of each term is provided.

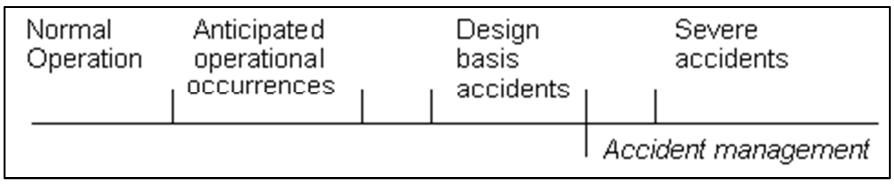

Figure 2-3: Operational states and accident conditions considered in NPP designs

- Operational states: States defined for normal operation or anticipated operational occurrences.
- Normal operation: Operation of a NPP within specified operational limits and conditions including starting up, power operation, shutting down, shutdown state, maintenance, testing, and refuelling.
- Anticipated operational occurrences: All operational processes deviating from normal operation that are expected to occur once or several times during the operating life of the NPP and that, in view of appropriate design provisions, do not cause any significant damage to items important to safety nor lead to accident conditions.
- Accident conditions: Deviations from operational states more severe than anticipated operational occurrences including design basis accidents and severe accidents.
- Design basis accidents: Accident conditions against which the NPP is designed according to established criteria, and for which the damage to the fuel and the release of radioactive material are kept within prescribed limits.
- Severe accidents: NPP states that are beyond-design-basis accidents and may result in significant reactor core degradation.
- Accident management: Accident management is the way of taking a set of actions, during the evolution of an event sequence, before the design basis of the NPP is exceeded, or during severe accidents without reactor core degradation, or after core degradation has occurred to return the NPP to a controlled safe state and to mitigate any consequences of the accident.

DiD is applied at each operational state in the manner described in Table 2-1.

Table 2-1: DiD and operational/accident states

Defence-in-Depth Level	Objective	Essential means of obtaining objective
Level 1: Normal operation	Prevention of NPP abnormal operation	Conservative, high quality and, as far as possible, proven design for NPP systems, structures, and components, as well as high quality in construction and operation.
Level 2: Anticipated	Control of NPP abnormal operation and detection	Process control and limiting systems and other surveillance features and

Defence-in-Depth Level	Objective	Essential means of obtaining objective
operational occurrences	of failures	procedures to enable return the NPP to normal operation.
Level 3: Design basis accidents	Control of accidents within the NPP design basis	Provision of engineered and passive safety features and systems
Level 4: Beyond-design-basis accidents	Control of severe NPP conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Complementary measures, accident management, and on-site mitigation
Level 5: Off-site emergency response	Mitigation of radiological consequences of significant releases of radioactive materials from a NPP	Emergency response plans to protect the public and workers

Risks criteria in the nuclear industry are quantified and expressed as a probability of an event occurring in a certain period of time, also referred to as an event occurrence frequency per reactor-year. Scientific notation is generally used to present quantitative information on event frequencies.

One in a hundred years	1/100 per year	1E-02 y^{-1}
One in a hundred thousand years	1/100,000 per year	1E-05 y^{-1}
One in a million years	1/1,000,000 per year	1E-06 y^{-1}
One in ten million years	1/10,000,000 per year	1E-07 y^{-1}

The IAEA issued its 'Basic Safety Principles for Nuclear Power Plants' in 1988 and revised it in 1999 [2.6.6]. The IAEA recommends that the reactor core damage frequency (CDF) value for advanced reactor designs not exceed 1E-05 y^{-1} (y^{-1} is per reactor year), which is a factor of ten lower than the requirement for the CDF of the majority of current nuclear power reactors. This recommendation has been widely adopted, both by NPP utilities and by manufacturers.

Compliance with regulatory and international acceptable criteria in respect of accident frequencies are demonstrated using mainly two analysis methodologies during the safety analysis of a NPP. One type of safety analysis methodology is deterministic design basis accident analysis. It uses conservative assumptions to demonstrate that events that could result in accidents are adequately considered in the design of a NPP and that the necessary safety systems are included in the design. In this type of analysis only systems with a very high level of quality are credited to terminate an accident sequence. In reality, there are other safety systems that will help to control and limit the progression of accident sequences but these are ignored for purposes of conservatism.

The design basis accident frequency criteria required by the NNR for the PBMR project, for example, were the following. .The postulated design basis accidents with a frequency of less than 1E-02 y^{-1} but more frequently than 1E-06 y^{-1} must not result in a dose of more than 50 mSv to a member of the public [3]. It is internationally accepted that radiation doses below around 100 mSv in a year, the increase in the incidence of health effects such as cancers (referred to

as stochastic effects) is assumed to occur with a small probability. This probability is in proportion to the increase in radiation dose over the background dose, based on the so-called linear-non-threshold (LNT) model. The LNT model is the basis of a practical approach to managing risk from radiation exposure and is commensurate with the 'precautionary principle' [2.6.7]. The design basis accidents are not expected to occur during the life cycle of the plant.

Another safety analysis method, namely probabilistic safety analysis, is carried out in parallel to deterministic safety analysis. It is a more realistic analysis since systems and human actions and their probabilities of failure are considered in postulated accident sequences. The results have to demonstrate that the public radiological fatality risk is 5E-06 y^{-1} peak individual risk and 1E-08 y^{-1} average risk per site [2.6.8], criteria which are stricter than for other hazardous industries. In order to meet these probabilistic safety criteria, a NPP must have a low severe accident frequency involving reactor core melt and a large release of radioactivity. Table 2-2 lists core damage and large release fraction frequencies published in open literature for various types of GEN III reactors [2.6.9]. The frequencies for large releases are all less than NNR's peak individual risk 5E-06 y^{-1}.

Table 2-2: Core damage and large release fraction frequencies for GEN III NPPs

GEN III **Reactor**	**Light Water Reactor Type**	**Core Damage Frequency (events per reactor year)**	**Large Radioactivity Release Frequency (events per reactor year)**	**Mitigation System for Severe Accidents**
ABWR	Boiling Water Reactor (BWR)	1.60E-07	2.50E-08	Core catcher
ESBWR	BWR	6.20E-08	2.00E-09	Core catcher
AES-92	PWR	6.10E-07	1.80E-08	Core catcher
AP1000	Pressurised Water Reactor (PWR)	5.10E-07	3.90E-08	In-vessel retention
APR-1400	PWR	2.70E-06	8.20E-08	In-vessel retention
APWR	PWR	4.60E-06	8.10E-07	Core catcher
EPR	PWR	6.10E-07	3.90E-08	Core catcher
ACR-1000	Pressurised Heavy Water Reactor (PHWR)	1.80E-07	≤ 8E-08	In-vessel retention
EC6	PHWR	<1E-06	<1E-07	In-vessel retention

A measure of scepticism may exist regarding the numerical risk values used in NPP safety analysis, especially following the Fukushima Dai-ichi NNP accident. Also, site-specific frequencies will have to be calculated for the specific design to be built in South Africa. Justification for low-occurrence frequencies for accidents, especially for external events, will have to be provided with high confidence in the safety analysis report that is submitted to the NNR. Also, practical elimination of an accident at a GEN III NPP is not claimed solely based on compliance with accident and fatality frequencies. Regulatory authorities require that, even if the

probability of a condition is very low, additional reasonable design features to lower the risk have to be implemented [2.6.10].

2.4 Safety features of GEN III nuclear power plants

GEN III reactors were developed in the nineties with improved safety features. Additional safety features have been incorporated in the designs following lessons learned from the Fukushima disaster. Safety objectives of GEN III designs include a reduction in the necessity for off-site emergency measures in case of a severe accident and increased protection against external hazards. DiD has been strengthened in GEN III reactors by reducing the frequencies of abnormal events through improved capability to stay within normal operational conditions. Improved control measures have been provided so that abnormal events do not progress to accident situations. In the unlikely situation of an accident, designs include safety features with the following objectives for accidents without reactor core melt:

- Accidents without core melt do not induce off-site radiological impact or only minor radiological impact (in particular, no necessity of iodine prophylaxis, sheltering, nor evacuation).
- The core damage frequency, taking into account all types of hazards and failures and combinations of events, and the releases of radioactive material from all sources, are reduced as far as reasonably achievable.

Severe accidents can potentially result in reactor core melts and the formation of a corium i.e. the molten nuclear fuel and reactor core vessel structures. The core melt of Three Mile Island reactor unit 2 accident in 1979 is illustrated in Figure 2-4 [2.6.11].

Cooling the corium is essential, because the release of fission products and the generation of non-condensable gas stop as the melt/debris temperature drops below approximately 1000°C [2.6.9].

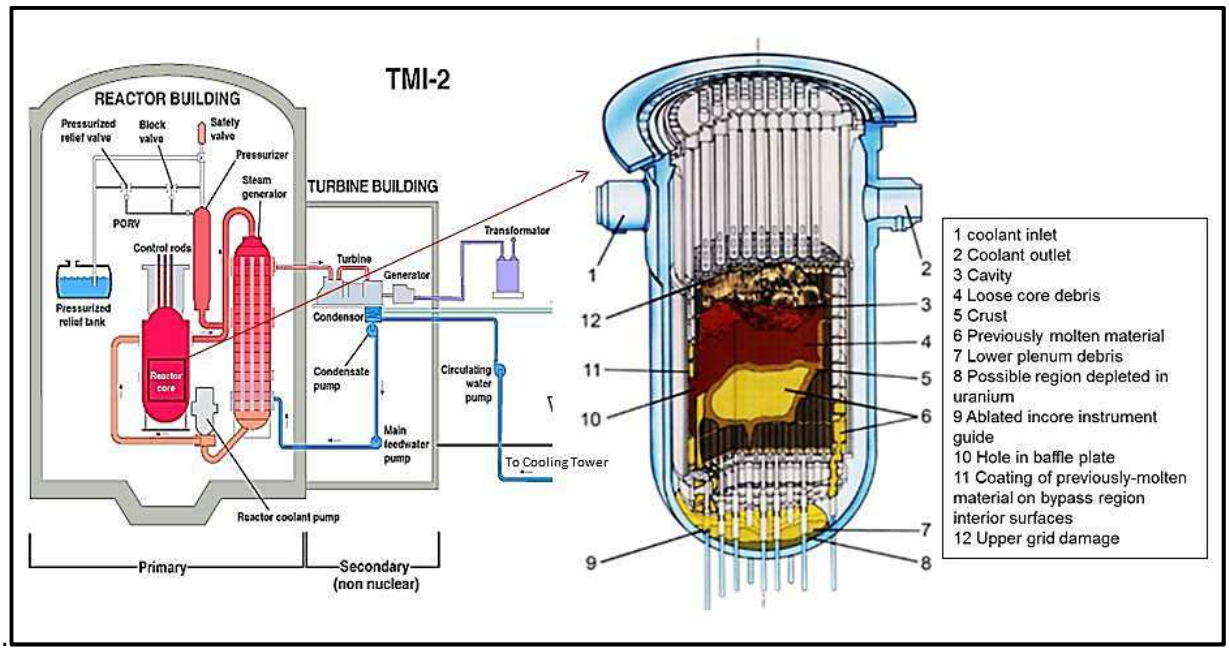

Figure 2-4: Three Mile Island reactor 2 after core meltdown in the reactor vessel

In the case of accidents with core melt, the design objective of GEN III reactors is to reduce potential radioactive releases to the environment, also in the *long term*[1], by following the qualitative criteria below:

- accidents with core melt which would lead to *early*[2] or *large*[3] releases have to be *practically eliminated*[4];
- for accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited protective measures in area and time are needed for the public (no permanent relocation, no need for emergency evacuation outside the immediate vicinity of the plant, limited sheltering, no long-term restrictions in food consumption) and that sufficient time is available to implement these measures [2.6.10].

These objectives in respect of accidents without and with core melt are achieved by having increased reliance in passive systems, when compared with designs of GEN **II** NPPs. The use of passive systems avoids the consequences of events that disrupt external sources of electricity, cooling water, and other essential supplies. The reactor core of some designs, for example, can be cooled by natural convection, radiation, and conduction. No external electricity is required.

A core melt must not lead to a large radioactive release from the reactor building and the IAEA recommended that severe accident management and mitigation measures be used to reduce by a factor of at least ten the probability of large off-site releases. Gen III designs achieve cooling and containment of the corium using ex-vessel (external to the reactor vessel) or in-vessel structures. An example of an ex-vessel structure, also designated core catcher, is illustrated in Figure 2-5; the specific design is for the EPR reactor [2.6.12].

1 Long term: considering the time over which the safety functions need to be maintained. It could be months or years, depending on the accident scenario.

2 Early releases: situations that would require off-site emergency measures but with insufficient time to implement them.

3 Large releases: situations that would require protective measures for the public that could not be limited in area or time.

4 Practically eliminated: the possibility of certain conditions occurring is considered to have been practically eliminated if it is physically impossible for the conditions to occur or if the conditions can be considered with a high degree of confidence to be extremely unlikely to arise.

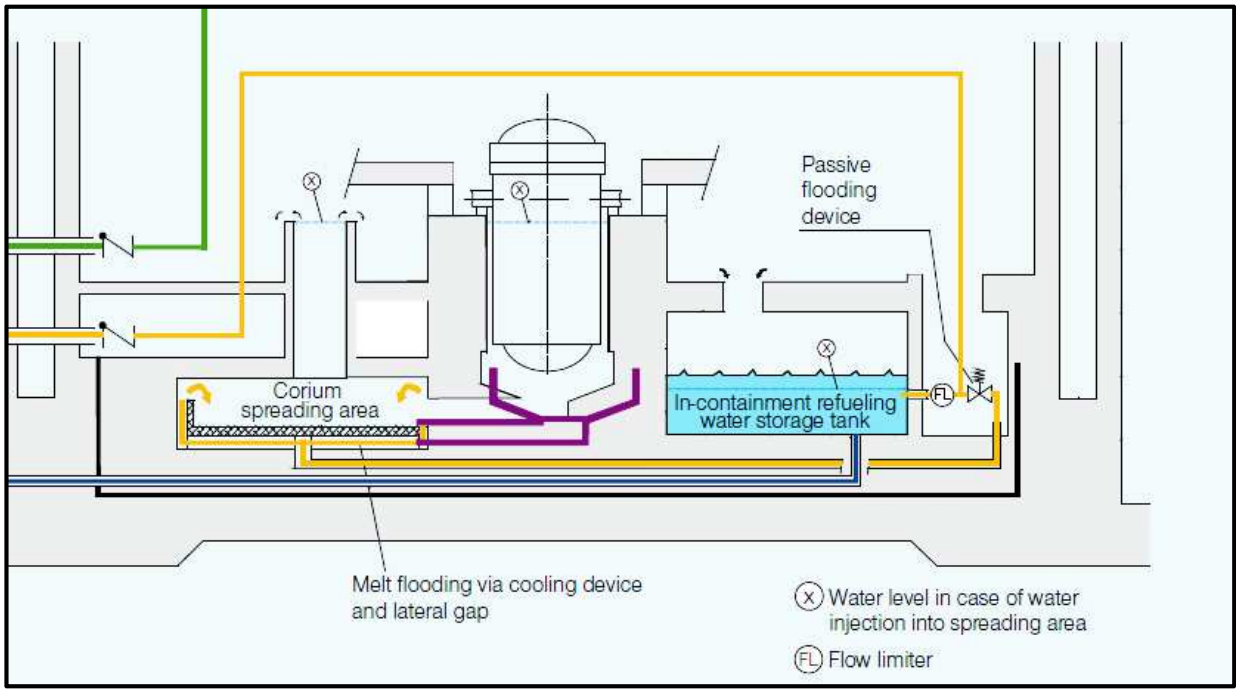

Figure 2-5: Example of a core catcher (EPR reactor)

In the event of a core melt, the corium escaping from the reactor vessel would be passively collected and retained, then cooled passively or actively in a specific area inside the reactor building. The deliberate interaction with sacrificial materials, usually concrete or oxide materials, on a first layer helps to cool the corium and to keep it liquid over a wider temperature range, so that it spreads efficiently. The use of non-limestone aggregate concrete (so called basaltic concrete) minimizes further production of carbon-based non-condensable gases, such as CO and CO_2, which could contribute to an eventual failure of the containment. The main objective of in-vessel retention of the corium is to maintain the reactor pressure vessel as a barrier against the release of fission products, by preventing a melt-through of the vessel. This is achieved by flooding the reactor cavity and transferring the decay heat from the corium on the lower head of the pressure vessel to the water surrounding the vessel. This heat transfer must be efficient so that the vessel wall maintains its structural properties and is able to support the mechanical load that results from the weight of the corium and the lower head, and from a possible pressure increase inside the vessel. The main advantage of this type of corium retention scheme is the fact that all ex-vessel phenomena are avoided, such as direct containment heating, corium-concrete interactions, and eventual steam explosions [2.6.13].

2.5 Radiological consequences of severe accidents – current requirements and past experience

The radiological consequences of severe accidents that involve core melt are assessed against the specific objectives for emergency planning of GEN III NPPs. These are as follows [2.6.14]:

- minimal emergency protection action beyond 800 m from the reactor during early releases from the reactor containment;
- no delayed action such as temporary transfer of people at any time beyond approximately 3 km from the reactor;

- no long-term action involving permanent (longer than 1 year) resettlement of the public at any distance beyond 800 m from the reactor; and
- limited restriction on the consumption of foodstuff and crops in terms of timescale and ground area in order to limit the economic impact.

The source terms for severe accidents provided in the probabilistic risk analysis studies of two NPPs representative of GEN III designs have been used to demonstrate the limited off-site radiological impact at the three sites. The results are provided in the Nuclear-1 EIA Emergency Response Report (Appendix E26 of the Revised Draft EIR Version 2) and shows that the objectives are met at the three sites. Further studies, using the NPP specific design information, will be performed during the nuclear licensing process in order to confirm the results of these initial studies. The detailed safety analysis will include all postulated initiating events to be considered for the design assessment, whether from events external to the NPP or internal events such as human error and failures of structures, systems, and components.

This section on nuclear accidents is concluded with a summary of the radiological consequences of the two light water reactor severe accidents, both belonging to the older generation reactors, GEN **II** (Chernobyl reactors do not belong to the category of light water reactors).

The Three Mile Island Unit 2 (TMI-2) reactor, near Middletown, Pennsylvania in the USA, partially melted down on 28 March 1979. This was the most serious accident in U.S. commercial nuclear power plant operating history. The location of the NPP is shown in Figure 2-6.

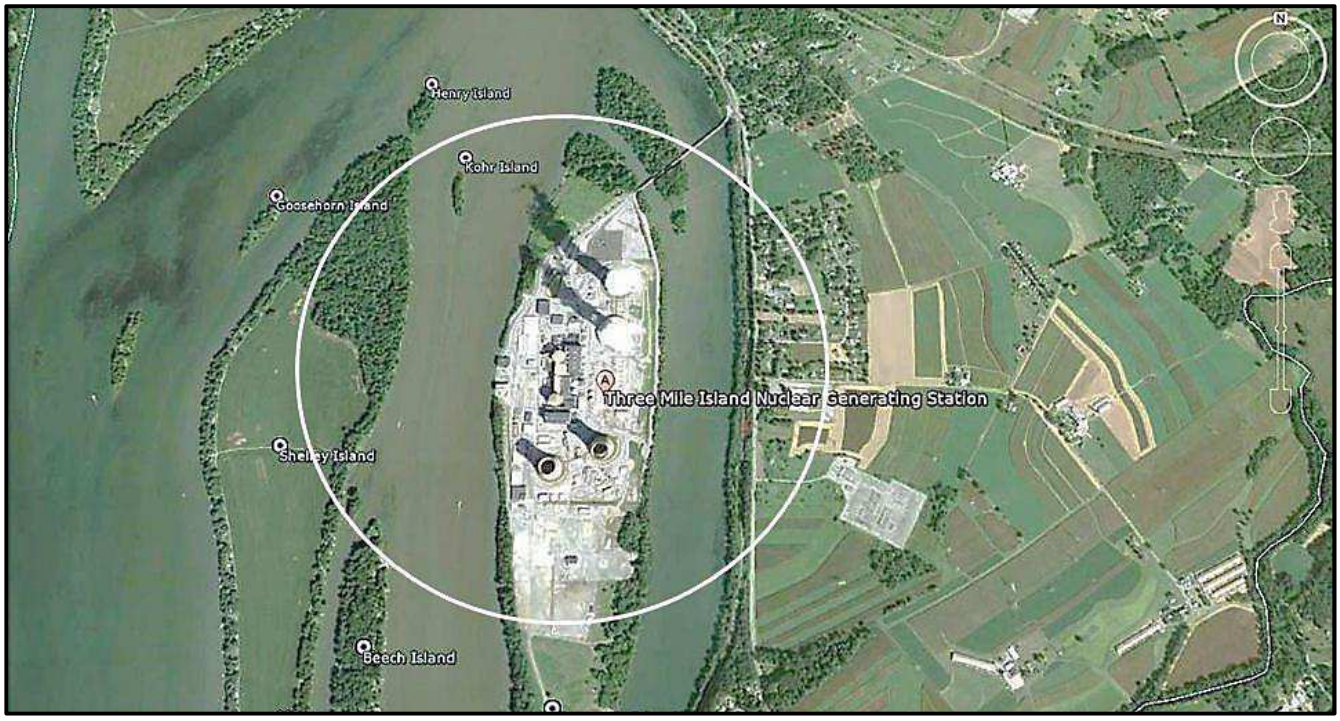

Figure 2-6: Three Mile Island NPP and circle indicating 800 m radius

The Unites States Nuclear Regulatory Commission, the Environmental Protection Agency, the Department of Health, Education and Welfare, the Department of Energy, and the Commonwealth of Pennsylvania conducted detailed studies of the accident's radiological consequences. The approximately 2 million people around TMI-2 during the accident are estimated to have received an average radiation dose of only about 0.010 mSv above the usual

background external radiation dose of 0.100 to 0.125 mSv/y. The accident's maximum dose to a person at the site boundary would have been less than 1 mSv above background [2.6.15].

On 11 March 2011, a tsunami that followed a 9.0-magnitude earthquake flooded over 500 square kilometres of land, resulted in the loss of more than 20,000 lives and destroyed property, infrastructure and natural resources. The loss of off-site and on-site electrical power and compromised safety systems at the Fukushima Dai-ichi NPP resulted in severe core damage to three of the six nuclear reactors on the site. Large quantities of radioactive material were released to the environment. Tsunami waves and NPP damage are shown in Figure 2-7.

Figure 2-7: Tsunami waves approaching the Fukushima Dai-ichi NPP (top) and a view of the damaged reactors 3 and 4 (bottom)

A recent report by UNSCEAR describes the health effects of NPP accidents as follows [2.6.16]:

> *No acute health effects (i.e. acute radiation syndrome or other deterministic effects) had been observed among the workers and the general public that could be*

attributed to radiation exposure from the accident. The most important health effects observed so far among the general public and among workers were considered to be on mental health and social well-being, relating to the enormous impact of the earthquake and tsunami, causing loss of family and friends and loss of livelihood and necessitating evacuation; and the impacts of the nuclear accident, including not only further evacuation and loss of livelihood, but also fear and stigma related to real and perceived health risks associated with ionizing radiation.

Risks for stochastic health effects (such as cancer) are reasonably well quantified for doses that are considerably larger than those estimated for the vast majority of the people (public and workers) irradiated due to the accident at Fukushima Dai-ichi Nuclear Power Station. Where such estimated risks of disease are sufficiently large in a large enough exposed population, compared to the normal statistical variability in the baseline incidence of the disease in that population, an increased incidence due to irradiation may be discernible in the disease statistics. Conversely, when risks are small or may only be inferred on the basis of existing knowledge and risk models, and/or the number of people exposed is small, the Committee has used the phrase "no discernible increase" to express the idea that currently available methods would most likely not be able to demonstrate an increased incidence in disease statistics due to radiation exposure. This does not rule out the possibility of future excess cases or disregard the suffering associated with any such cases should they occur.

The average first-year effective doses to evacuees and to the population in the non-evacuated areas most affected by the accident were estimated to be in the range from about 1 to 10 mSv for adults and about twice as large for a 1-year old. Risk models, by inference, suggest a small increased risk of cancer for such doses; however, any overall increase in disease incidence in the general population due to radiation exposure from the accident would be too small to be observed against the lifetime baseline risk for members of the Japanese population (which, for all solid cancers, is on the average 35%, although this figure is subject to individual variation related to sex, lifestyle and other factors).

Notwithstanding the above, previous experience indicates that the relative risks for certain cancers in certain population groups (notably following exposure as foetus, or during infancy and childhood) are higher than for the population average.

2.6 References for Part 2

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2.6.10 Western European Nuclear Regulator's Association. December 2009. Safety Objectives for New Power Reactors. Study by WENRA Reactor Harmonization Working Group Reference: WENRA

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2.6.15 United States Nuclear Regulatory Commission Office of Public Affairs Backgrounder: Three Mile Island Accident

2.6.16 UNSCEAR 2013, Sources, Effects and Risks of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly with Scientific Annexes VOLUME I. Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami.

3 RADIOLOGICAL RISK TO NON-HUMAN BIOTA

3.1 Regulatory and international framework for the radiological protection of non-human biota

In South Africa, the principal framework legislation governing the protection of the environment is the National Environmental Management Act 107 of 1998 (NEMA) [3.4.1]. NEMA Section 2 set out the principles for environmental protection. The primary legislation for nuclear safety in South Africa is governed by National Nuclear Regulator Act, Act 47 of 1999 (NNRA), that aims at providing the protection of persons, property, and the environment against nuclear damage [3.4.2].

The current international basis for the radiological protection of the environment is derived from work performed by various international scientific organisations. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) provides findings on the sources and effects of ionising radiation that can be used as the authoritative scientific basis for international efforts in environmental radiation protection. The International Commission on Radiological Protection (ICRP) issues recommendations on radiation protection, including specific recommendations for the protection of non-human biota species. The International Atomic Energy Agency (IAEA) establishes appropriate international undertakings, including international standards and mechanisms for their worldwide application to restrict releases of radioactive materials into the environment over time, in order that not only humans but also the non-human component of the environment is protected adequately.

The radiological protection of non-human species has evolved considerably over recent years. Where radiological protection used to focus on human protection based on the assumption that, if humans are protected, non-humans living in the same environment would be sufficiently protected, the explicit consideration of Radiological Protection of the Environment is now recommended by the ICRP [3.4.3].

There are commonalities in the approaches to radiological protection of humans and of non-human biota. This illustrated in Figure 3-1. However, there are also fundamental differences in determining the risk to humans following exposure to radiation and the risks to a radioactively contaminated environment. Human risk analyses largely focus on stochastic cancer risks and acute deterministic effects to individuals and for which the scientific basis is well established. Non-human biota risks are not concerned with individuals but the risk to populations of plants and animals. The focus of environmental management is on a viable population of organisms, not on single individuals within the population. The non-human biota risks are not cancer oriented, but instead include a wide spectrum of effects ranging from chromosomal damage to reduced reproductive success. There are no risk factors that equate dose to the probability of a detrimental health effects as in the case for humans [3.4.4]. There are no defined dose limits for non-human species.

The differences in radiological protection of humans and non-human species are also reflected in the use of the words “reference” and “representative” for the humans and non-human biota radiological protection (plants and animals) [3.4.4]:

- Reference Animal or Plant (RAP): A hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the

generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating radiological exposure to dose, and dose to effects, for that type of living organism.

- Representative Animal or Plant (REPAP): A particular species or group of organisms selected during a site-specific assessment, taking account of their assumed location with respect to the radiation source. In many cases, the actual representative organisms chosen for this purpose may be the same as, or very similar to, the RAP; however, in some cases, they may be very different. The actual animal or plant species in a nuclear site's environment are assigned to the most similar RAP for the purposes of radiation screening dose assessment and environmental radiation protection.
- Reference Person: A hypothetical aggregation of human (male and female) physical and physiological characteristics arrived at by international consensus for the purpose of standardizing radiation dose calculations.
- Representative Person: An individual receiving a dose that is representative of the more highly radiologically exposed individuals in the population. This term is equivalent to and replaces the term "the average member of the critical group".

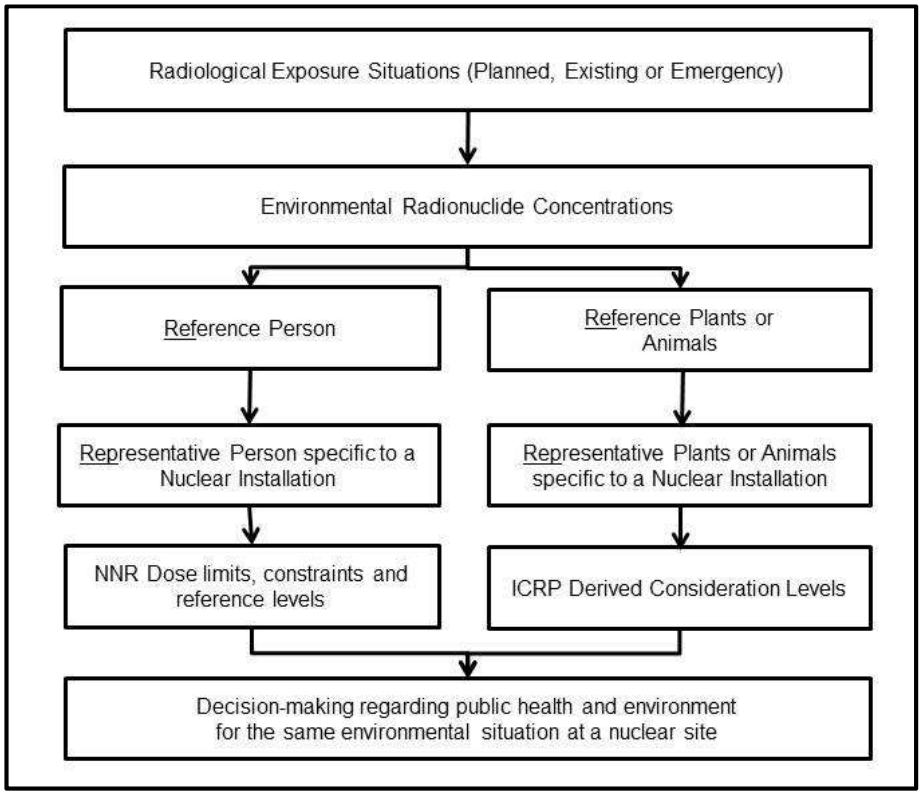

Figure 3-1: Common approach for the radiological protection of humans and non-human species

The ICRP defined RAPs that are a small set of hypothetical entities representative of animals and plants present in different environments (terrestrial, freshwater, marine) [3.4.4]. The RAPs form the basis of a structured approach to the assessment of exposures to, and effects of, ionizing radiation. A range of derived consideration reference levels (DCRLs) of radioactivity in the environment, shown in Figure 3-2, are proposed by the ICRP for each of the RAPs. The DCRLs are expressed in units of absorbed dose per unit time, mGy/d (milligray per day)

whereas human dose rate is expressed as units of effective dose per year that includes weighting factors to account for different human tissues.

The DCRLs serve as numerical guidance for evaluating the level of potential or actual radiological impacts and as an input to decision making. These values are defined in terms of bands of doses within which certain effects have been noted, with a focus on those that may have some impact on the population structures of the animals and plants under consideration.

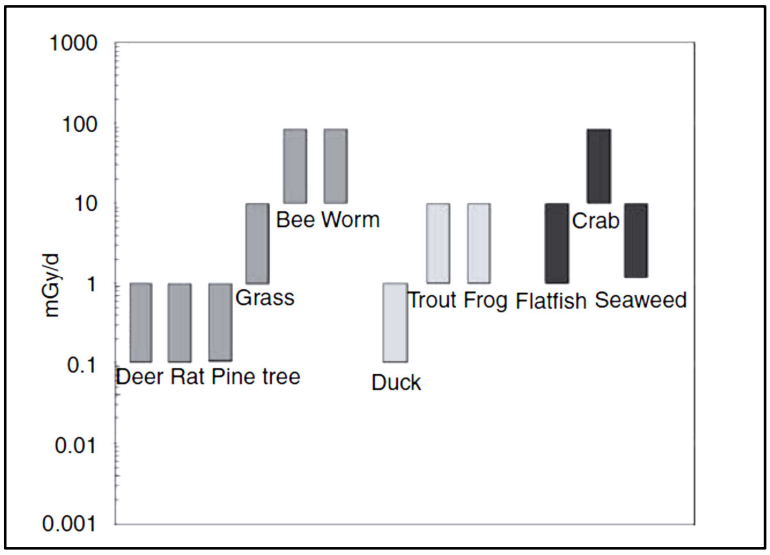

Figure 3-2: Derived consideration reference levels (DCRLs) for environmental protection for each RAP (the RAPs being grouped according to their terrestrial, freshwater, or marine habitat)

3.2 Non-human biota dose assessment for normal operational discharges

The *ERICA* software system [3.4.5] was used to perform a screening assessment of the potential radiological impact on non-human species as a result of NPP normal operational radioactive discharges. The dose rates were estimated for two sets of generic species (RAPs) representing the terrestrial and marine environments.

ERICA is defined as an 'integrated approach to scientific, managerial, and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems'. Appendix 7 provides more information on the *ERICA* system.

Tier 2 assessments (as defined in Appendix 7) were performed using conservative atmospheric and marine radionuclide concentrations. The values were derived as follows using the environmental concentrations calculated with the dispersion models of the *PC-CREAM 08* code system (refer to Part 1 of the report):

- atmospheric concentrations at 100 m distance from a ground level release; and
- radionuclide concentrations in a local marine compartment that was defined and applied to all three sites.

The RAP screening dose rate reference value is 10 µGy/h (approximately 0.25 mGy/d) [3.4.5]. This is the reference value provided in *ERICA* and is defined as a value well below any dose

rate where measureable effects in the organisms would be detected. The results are reported in Table 3-1 for terrestrial organisms and Table 3-2 for marine organisms. Both sets of organisms are in line with the RAPS defined by the IAEA. The results are further illustrated in Figure 3-3 and Figure 3-4.

Table 3-1: Dose rate to non-human species from airborne discharges

Organism Potentially Impacted by Airborne Discharges	Total Dose Rate per Organism (µGy/h)
Amphibian	0.92
Bird	0.95
Bird egg	0.64
Detritivorous invertebrate (e.g. millipedes)	0.35
Flying insects	0.35
Gastropod (e.g. snails)	0.35
Grasses & Herbs	0.64
Lichen and bryophytes (e.g. mosses)	0.64
Mammal (Deer)	0.95
Mammal (Rat)	0.95
Reptile	0.95
Shrub	0.64
Soil Invertebrate (worm)	0.35
Tree	0.92

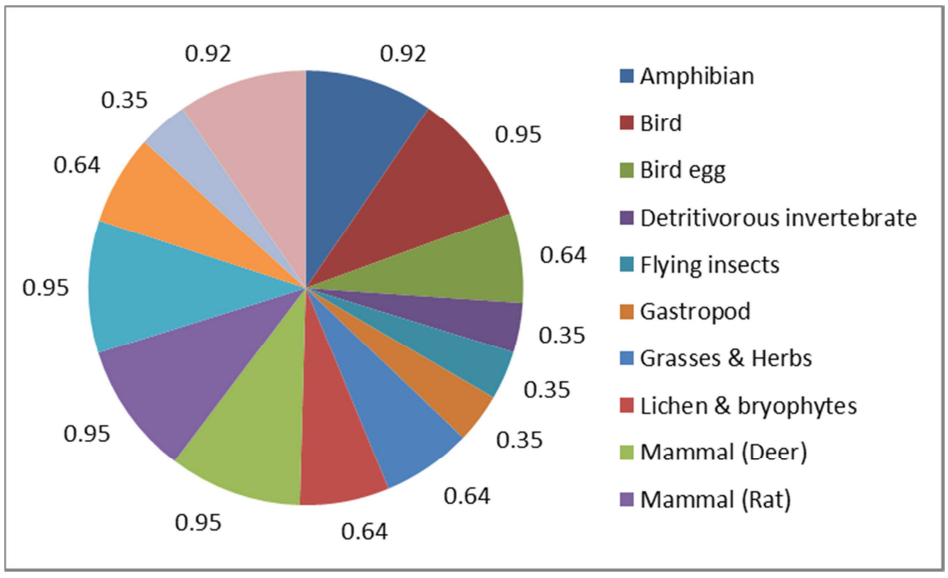

Figure 3-3: Dose rate to non-human species from airborne discharges (µGy/h)

Table 3-2: Dose rate to non-human species from liquid discharges into the sea

Organisms Potentially Impacted by Discharges to the Sea	Total Dose Rate per Organism (µGy/h)
(Wading) bird	0.10
Benthic fish	1.65
Benthic mollusc	1.75
Crustacean	1.62
Macroalgae	1.75
Mammal	0.11
Pelagic fish	0.07
Phytoplankton	0.00
Polychaete worm	3.45
Reptile	0.11
Sea anemones or true corals – colony	1.61
Sea anemones or true corals – polyp	1.75
Vascular plant	1.73
Zooplankton	0.05

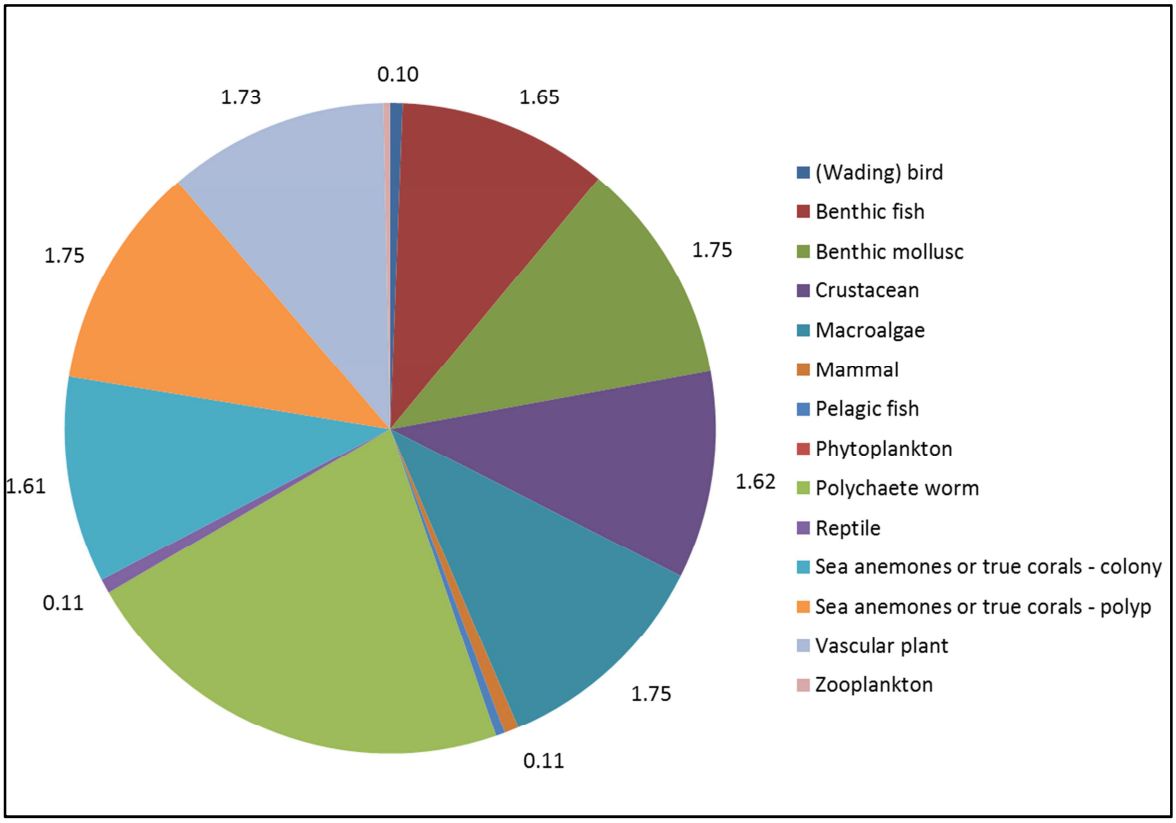

Figure 3-4: Dose rate to non-human species from liquid discharges

Based on the results above none of the organisms exceeds the screening value of 10 µGy/h. Though no significant impact has been identified a more detailed radio-ecological assessment of REPAP's will be performed as the NPP design and building lay-outs are finalised at a later nuclear licensing stage and to confirm the conclusions reached in the screening assessment.

3.3 Radiological risk to non-human biota following nuclear accidents

Radioecology is a complex and evolving scientific field and although useful assessment tools such as *ERICA* are available to assess the effects of normal operational discharges from NPPs, the long-term effects of severe nuclear accidents such as Chernobyl and Fukushima on non-human biota remain uncertain. The accident at Chernobyl released approximately 80E15 Bq of radioactive Cs, Sr, Pu, and other radioactive isotopes into the atmosphere. The radioactive pollution covered 200 000 km^2 of land in Europe. In the exclusion zone environment near Chernobyl, for example, reduced abundance of insects and spiders is linked to radiation twenty years after the accident. Partial albinism has been observed in barn swallows and this is correlated to reduced mating success [3.4.6].

UNSCEAR recently produced an authoritative Fukushima report in which radiological exposures of selected non-human biota were also estimated [3.4.7]. The study area covered by the UNSCEAR report is shown in Figure 3-5.

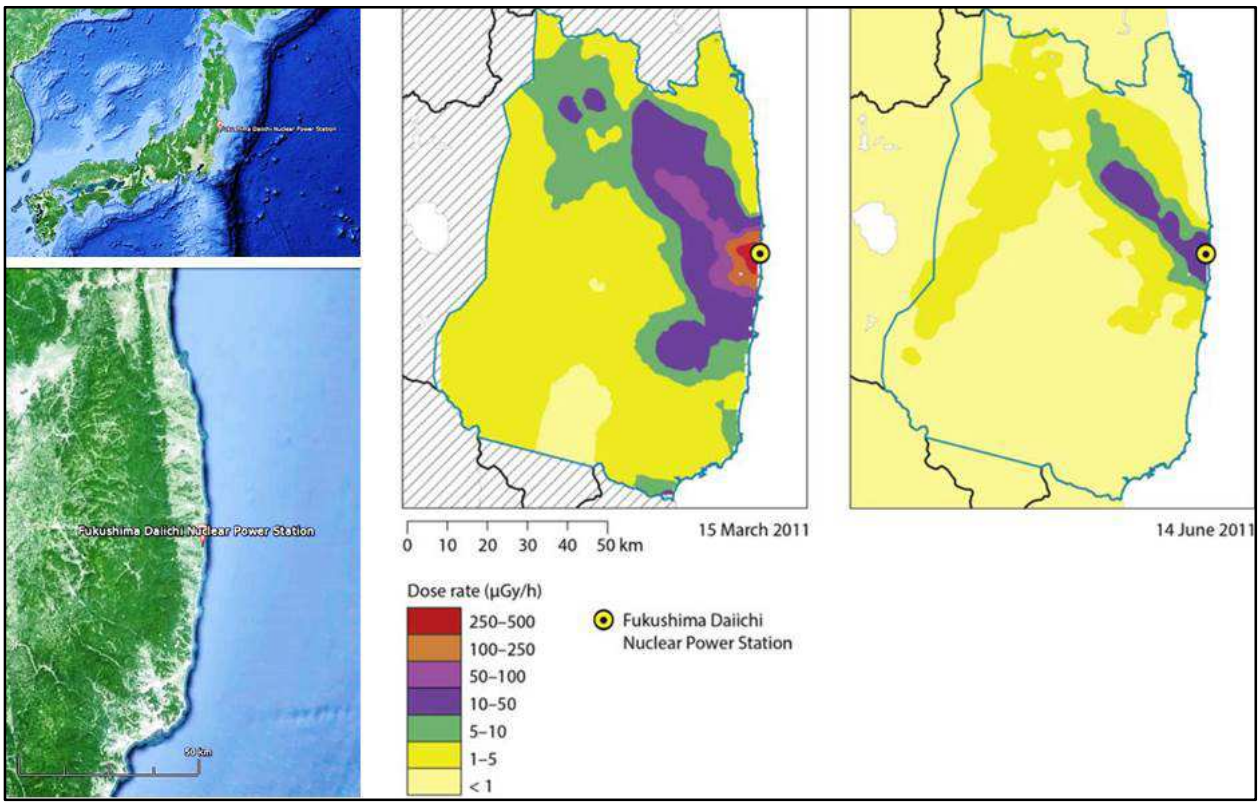

Figure 3-5: Fukushima Dai-ichi NPP and estimates of weighted absorbed dose rates for a large mammal

UNSCEAR concluded that the possibility of effects on non-human biota in both the terrestrial and aquatic (freshwater and marine) environments was geographically constrained and that, in areas outside the constrained area, the potential for effects on biota may be considered

insignificant. Releases to the marine environment were ongoing and this may warrant further follow-up assessment of exposures and trends in the coming years. Excerpts of the UNSCEAR report are provided in the following paragraphs.

> *Exposures of both marine and terrestrial non-human biota following the accident were, in general, too low for acute effects to be observed, though there may have been some exceptions because of local variability:*
>
> *(a) Effects on non-human biota in the marine environment would be confined to areas close to where highly radioactive water was released into the ocean;*
>
> *(b) Continued changes in biomarkers (to measure radiation-induced changes in an organism) for certain terrestrial organisms, in particular mammals, cannot be ruled out, but their significance for population integrity of those organisms is unclear. Any radiation effects would be restricted to a limited area where the deposition of radioactive material was greatest; beyond that area, the potential for effects on biota is insignificant.*
>
> *As for humans, any organism in the natural environment can be exposed both internally and externally to radioactive substances in its habitat. UNSCEAR concluded that chronic dose rates of less than 100[5] μGy/h to the most highly-exposed individual organisms would be unlikely to have significant effects for population integrity of most terrestrial communities, and that maximum dose rates of 400 μGy/h to any individual in aquatic populations of organisms would be unlikely to have any detrimental effects at the population level.*
>
> *The Committee has examined the impact of the Fukushima Dai-ichi NPP (FDNPP) accident on non-human biota inhabiting terrestrial, freshwater and marine ecosystems. Its assessment was largely based upon measured data provided to the Committee, other relevant reports, and published scientific papers. The radiation exposures were considered in terms of the intermediate phase after the accident (approximately the first two months) and the late phase (months to years). The areas considered in detail were some of the more affected areas of Fukushima prefecture and any neighbouring prefectures within approximately 100 km of the FDNPP site, covering a land area of 7 000 km^2 and extending to 30 km off the coast.*
>
> - *Terrestrial ecosystems*
>
> *From measured radionuclide concentrations in animals corresponding to the late phase of the accident (June 2011), terrestrial mammals and birds were estimated to have been exposed to dose rates between 1.2 and 2.2 μGy/h in areas encompassing most of the range of Cs-137 deposition densities.*
>
> *These dose rates are approximately one order of magnitude greater than those from naturally occurring radionuclides in the environment. Dose rates of 300 μGy/h have been estimated for soil-dwelling organisms in areas of high deposition density such as Okuma town during the earlier intermediate phase. Inclusion of the very short-lived radionuclides, Te-132 and I-132, indicates that dose rates may have been as high as 1 mGy/h (1,000 μGy/h) for some*

[5] The ERICA screening value provided further safety margin. For all organisms and ecosystems, ERICA has a screening incremental dose rate of 10 μGy h-1 for chronic exposure to human activities that use radioactive substances and/or increase the levels of ionising radiation in the environment.

organisms over short periods (hours to days). While higher than the benchmark level of 100 μGy/h (10 times higher than the ERICA screening dose rate), these dose rates are unlikely to have resulted in observable effects on populations; and any effects would have been transient in nature.

For the late phase after the accident, a potential risk of effects on individuals of certain species, especially mammals, may exist in areas of relatively high radioactivity deposition density but observable population effects for terrestrial biota are considered unlikely. Changes in biomarkers of various types cannot be ruled out, especially in mammals, and such effects may persist in the late phase for areas of highest deposition density.

A few field studies have reported effects in areas affected by FDNPP releases, such as decreases in bird and insect populations and morphological and genetic disturbances in butterflies. The relationship between exposure and effect has not been unequivocally established in these studies. Furthermore, the observations are not consistent with the Committee's assessment and suggest that further analysis is needed to establish whether radiation exposure was an important factor, among many others, including the impact of the tsunami itself, in causing the environmental effects observed.

- *Freshwater aquatic ecosystem.*

Although dose rates calculated for freshwater fish were in some cases more than an order of magnitude above the natural background level, they did not reach threshold levels pertaining to chronic exposures above which observable effects in freshwater biota are expected.

- *Marine aquatic ecosystem*

For coastal locations where biological samples were available, dose rates in the period 10 May 2011 to 12 August 2012 were low relative to the benchmarks. The highest dose rates, from compiled arithmetic means of dose rates to all organism groups, were in the range of 0.10-0.25 μGy/h. Such levels were commensurate with background dose rates in the marine environment.

The highest dose rates were calculated from estimated concentrations in seawater for the intermediate phase of the accident (before 10 May 2011, when biological samples were not available), using a dynamic model for the northern drainage channel near the FDNPP site. For fish, the maximum estimated dose rate occurred within the first month (approximately 140 μGy/h), and the accumulated dose over 1 year was approximately 0.32 Gy. Maximum calculated exposures for macroalgae (exceeding 20 mGy/h) at the same location occurred at 23 days after the accident, but fell rapidly, with I-131 being the dominant component. The accumulated dose for macroalgae over 1 year was approximately 7 Gy. Comparisons with reported benchmarks indicate that the calculated doses, with the exception of the transient exposures for macroalgae at locations very close to the discharge point, were substantially below those where observable effects on populations would be expected.

As of August 2012, marine fish were still being found with radionuclide concentration levels above the Japanese regulation value of 100 Bq/kg (fresh weight) for sale and human consumption. Although such a level may be of relevance to radiation protection of the public, the corresponding dose rates for non-human biota are insignificant, falling far below any relevant benchmarks.

3.4 References for Part 3

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3.4.2 Republic of South Africa (1999), National Nuclear Regulator Act, 1999. Act No. 47 of 1999. Pretoria.

3.4.3 ICRP (2007), The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103. Ann. ICRP 37(2–4).

3.4.4 ICRP (2014), Protection of the Environment under Different Exposure Situations. ICRP Publication 124.

3.4.5 Björk M and Gilek M (Eds) (2005), Overview of Ecological Risk Characterization Methodologies http://www.erica-tool.com/erica/ERICA software system.

3.4.6 A. P. Møller, T. A. Mousseau. 2006. Biological consequences of Chernobyl: 20 years after the disaster. Trends in Ecology and Evolution, 21: 200-207.

3.4.7 UNSCEAR (2013), Sources, Effects and Risks of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly with Scientific Annexes VOLUME I. Scientific Annex A: Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami.

4 BACKGROUND RADIATION

4.1 Purpose and scope

This section of the report provides the main results of the background radiation surveys at the proposed Nuclear-1 sites; Thyspunt, Bantamsklip, and Duynefontein. The surveys covered the sites and adjacent land and sea areas that could potentially be affected by routine radioactive discharges from a future NPP. The surveys were performed over a period of approximately one year, from August 2012 to November 2013.

The surveys were of a “reconnaissance” nature with the purpose to obtain initial radiological profiles of the sites and potential impact areas. Detailed baseline surveys of a much more extensive nature than the reconnaissance survey discussed here, have to be performed one to two years prior to nuclear operation.

It is important to emphasise that the radioactivity results reported here for foodstuff do not reflect the quality of the products from farms where they were collected. The radioactivity concentrations are low in global terms. Artificial radioactivity concentrations reported in food products are lower than general levels in the northern hemisphere where the impacts of anthropogenic radioactivity are more significant than in the southern hemisphere.

Limited sampling was performed at Duynefontein. The Koeberg NPP has an extensive environmental monitoring programme [1.14.14]. Different sampling locations that are not part of the Koeberg monitoring network were selected for each site reconnaissance survey with the purpose of adding further value to the current data base. Additional radionuclides were included, for example, the naturally occurring radionuclide Po-210 in marine organisms and airborne radon (Rn-222). Po-210 is known to be an important contributor to human dose from naturally occurring radioactivity, especially in areas where seafood is a significant fraction of people’s diet. Radon is normally the main component of human exposure to naturally occurring radioactivity.

The survey measurements included external ionising radiation of terrestrial and cosmic origin and radioactivity concentrations in different environmental media, i.e. air, water (land and sea), soil, sediment from water bodies on land, beach sand, and non-human biota (marine and terrestrial). Each environmental medium has specific characteristics and radioactivity concentrations that determine the background radiation in at a site. The interactions of humans with the different environmental media result in exposure pathways and an amount of lifetime dose.

The main objectives of the surveys were the following:

- Measure external radiation from terrestrial sources and identify any anomalies that may exist at each site and in its immediate region.
- Measure radioactive concentrations in non-human biota that form part of the human ingestion pathways.
- Demonstrate that some artificial radionuclides that will form part of the authorised discharges from a future NPP are already detectable at a site and part of the background radiation.

- Illustrate the relative importance of radioactivity from naturally occurring radioactive material (NORM) in the environment when compared to artificial radioactivity.
- Provide information to be considered in a future pre-operational baseline study and the subsequent operational monitoring programmes.
- Provide information that can be used when communicating radioactivity issues with the public and other interested and affected parties.

4.2 Structure of Part 4

Global values of background radiation dose to humans are described. The reader is introduced to the radionuclides that were measured to determine background radiation in the study area.

The approach to the background radiation surveys is described. The potential impact area (PIA) of a future NPP at each site was considered in the planning of the surveys, e.g. the prevailing wind direction and atmospheric dispersion results.

A brief description is provided of the laboratories that provided analytical services and equipment used for background radiation measurements.

The subsequent sections describe each environmental medium for which background radiation measurements were performed. The environmental media are:

- terrestrial surface and groundwater and seawater;
- soils and sediments;
- beach sand from the intertidal zone on beaches;
- marine biota;
- terrestrial biota with emphasis on the dairy industry; and
- general air quality.

External radiation was also measured over large areas on the sites and adjacent land.

A brief introduction to each set of results aims to provide perspective on the site-specific results. This is followed by a discussion of the results.

A final section presents the main conclusions.

4.3 Background radiation

Exposure to ionizing radiation arises from naturally occurring sources (such as from outer space and radon gas emanating from rocks in the Earth) and from sources with an artificial origin (such as medical diagnostic and therapeutic procedures; radioactive material resulting from nuclear weapons testing; energy generation, including by means of nuclear power; unplanned events such as the nuclear power plant accidents at Chernobyl in 1986 and the east-Japan earthquake and tsunami of March 2011; and workplaces where exposure to artificial or naturally occurring sources of radiation may be increased) [4.16.1].

The main human exposure pathways to sources of naturally occurring radioactive material (NORM) and global values of human dose from each of these exposure pathways are listed in Table 4-1.

Table 4-1: Natural radiation exposure pathways and human dose

Natural Source	Annual Average Dose Worldwide (mSv/y)	Typical Global Range of Individual Doses (mSv/y)	
Inhalation of airborne radio-activity consisting mainly of radon gas, a gaseous decay product in the U-238 decay chain	1.26	0.2 to 10	The radon dose can be much higher in buildings occupied by humans because of higher than typical concentration of NORM in soil and when these buildings are poorly ventilated.
External terrestrial radiation from NORM in soils and rocks	0.48	0.3 to 1	The dose can be significantly higher in some areas because of a particular geology of surface land and its NORM content.
Ingestion of NORM in water and foodstuff	0.29	0.2 to 1	NORM is transferred from soils and the atmosphere to plants and animals.
Cosmic and cosmogenic radiation	0.39	0.3 to 1	The cosmic dose is lowest at sea level because of shielding by the atmosphere and increases with altitude.
Total natural radiation dose	2.4	1 to 13	There are regions in the world where sizeable population groups receive 10 to 20 mSv.

The significant NORM radionuclides are K-40 and the radionuclides in the U-238 and Th-232 decay series, illustrated in Figure 4-1 [4.16.2].

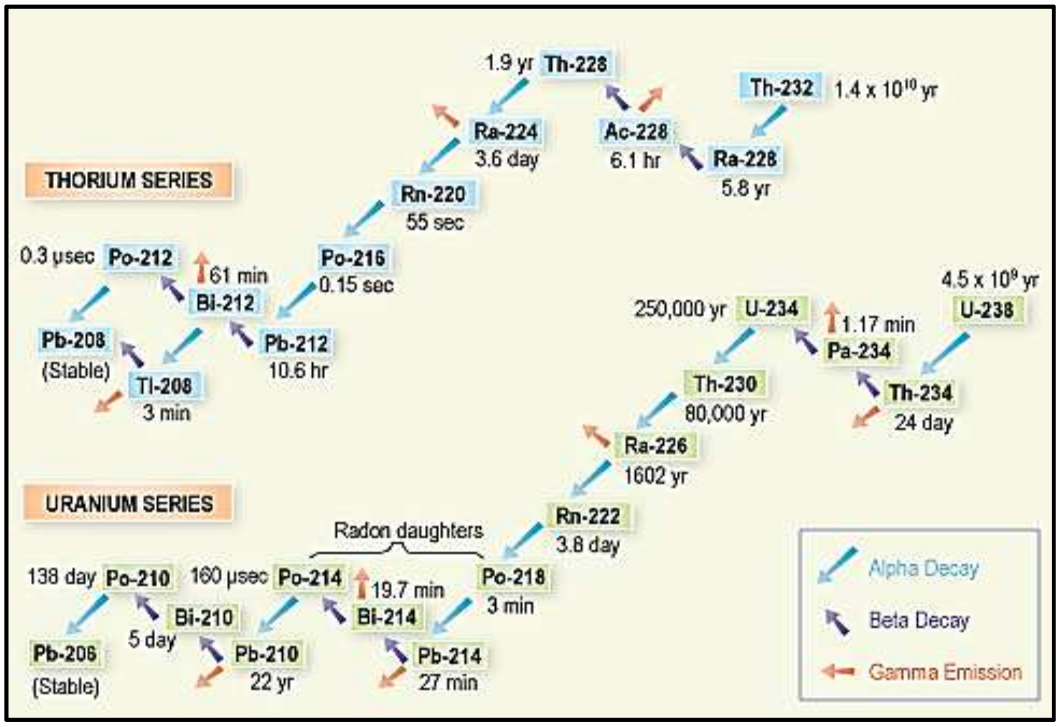

Figure 4-1: Radioactive decay of the Th-232 and U-238 series

These radionuclides are also present in the human body and irradiate organs with alpha and beta particles, as well as gamma rays. Some other terrestrial radionuclides, including those of the U-235 series, Rb-87, La-138, Sm-147, and Lu-176, exist in nature but at such low levels that their contributions to the dose in humans are small [4.16.1].

Figure 4-2 illustrates all the natural human dose components and the increasing contribution from anthropogenic sources especially nuclear medicine that involves radionuclides such as Cr-51, F-18, I-125, I-131, Sr-89, Tc-99m, and Y-90 [4.16.1].

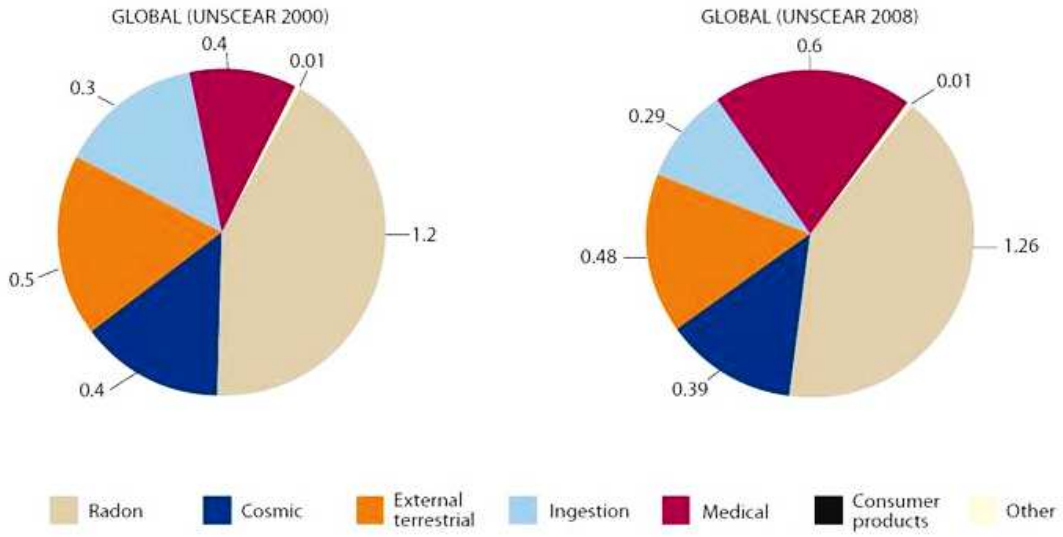

Figure 4-2: Components of average human dose from different exposure pathways reported by UNSCEAR during the period 2000 to 2008

It is important to differentiate between a *background radiation monitoring* programme reported here and a *pre-operational baseline monitoring* for a NPP. Pre-operational baseline monitoring is normally carried out a few years prior to the start of NPP operation when authorised discharges of low levels of radioactivity will commence. It has to be designed to establish a baseline for the public in terms of representative persons (refer to Part 1 of this report) and ecologically sensitive areas that exist at the time just prior to operation. Changes, for example in respect of human settlements and farming practices, that may take place in future when compared to the present conditions, have to be considered in the NPP specific baseline study. Its purpose is therefore to provide a detailed baseline for determining the subsequent radiological impacts of the discharges based on the specific design of a NPP. The pre-operational baseline monitoring programme takes account of all the radionuclides that might be discharged in the liquid and gaseous effluent and the important parameters of design influencing exposure pathways, e.g. the height of a stack for operational airborne discharges.

The key radionuclides in background radiation are listed in Table 4-2. Their radioactivity decay half-lives are listed in a format that illustrates the large range in half-lives. The nuclides are arranged from the highest radiotoxic nuclide to the least radiotoxic nuclide. The table provides reference information to be considered when assessing the survey results, for example when interpreting the radioanalysis results of biota environmental samples in respect of their importance to the ingestion dose received by humans from background radiation.

Table 4-2: Main radionuclides in the background radiation monitoring surveys

Element	Radio-nuclide	Half-life, years (rounded for illustration purposes)	Ingestion Dose Coefficient (mSv/Bq)	Inhalation Dose Coefficient (mSv/Bq)
Radon	Rn-222	0.01	Not applicable	The dose coefficient associated with Rn-222 is discussed separately
Polonium	Po-210	0.4	8.80E-06	1.40E-05
Radium	Ra-228	6	5.70E-06	4.80E-05
Lead	Pb-210	22	3.60E-06	1.80E-05
Radium	Ra-226	1 600	9.60E-07	2.90E-05
Thorium	Th-232	14 000 000 000	4.50E-07	2.20E-04
Thorium	Th-230	77 000	4.10E-07	2.00E-04
Uranium	U-235	704 000 000	1.30E-07	2.60E-05
Uranium	U-234	244 000	1.30E-07	2.90E-05
Uranium	U-238	4 470 000 000	1.20E-07	2.50E-05
Strontium [1]	Sr-90	29	7.30E-08	4.00E-07
Potassium	K-40	1 280 000 000	4.20E-08	1.70E-08
Caesium [1]	Cs-137	30	1.20E-08	1.00E-07
Carbon [2]	C-14	5 730	1.60E-09	1.70E-08
Beryllium [2]	Be-7	0.1	2.4E-10	1.3E-10
Hydrogen [2]	H-3	12.3	1.20E-10	1.00E-09

[1]: Artificial radionuclides
[2]: Natural radionuclides that are also artificially generated during nuclear fission and part of the normal discharges of a NPP

For further information on global background radioactivity, refer to [4.16.1].

4.4 Elements of the site surveys

The programme consisted of the elements listed in Table 4-3.

Table 4-3 Approach to radiation monitoring at each site

#	Monitoring Element	Description of Monitoring in Potential Impact Areas
1	Ambient external radiation	Integrated monitoring during approximately 3 months at ten fixed locations
		Large area mobile surveys
2	Atmospheric radon	Integrated monitoring during approximately 3 months at ten fixed locations
3	Soil radioactivity	Samples collected over a wide area
4	Beach sand radioactivity	Composite samples collected from the main beaches
5	Biota radioactivity	Land and marine biota samples
6	Coastal air quality	Suspended particulate monitoring

The background monitoring programme is of a reconnaissance nature and did not attempt to quantify the radiation in each environmental compartment with high levels of statistical confidence. Financial considerations and the expected long lead time before nuclear operation do not justify a more extensive programme at this early stage of NPP siting.

4.5 Laboratories and equipment

Environmental samples were collected quarterly over a period of one year. Check sheets were completed for each sample to ensure proper identification, storage, and delivery to laboratories. The following sample identification system was used for samples submitted for radioanalysis:

QQ-XXX-YY-ZZ

where:

- QQ = TP for Thyspunt; QQ = BK for Bantamsklip and QQ = DF for Duynefontein
- XXX is either;
    - BIO for biological samples;
    - SS for soil sample;
    - SED for sediment samples;

- BSS for beach sand sample; and
- WS for water sample;

- YY corresponds to the three-month period (quarter) during which the sample was collected, 01 to 04;
- ZZ is the unique numerical sequence of a sample.

The following notation was used for radon and external radiation monitors located at fixed positions:

QQ-RG–YY-ZZ

where:

- QQ is as before;
- RG = radon/gamma;
- YY corresponds to the three-month period (quarter) during which the sample was collected, 01 to 04;
- ZZ is the code for the monitoring location, 01 to 10.

Equipment and radioanalysis services included the following:

- Radioanalytical services were provided by Necsa RadioAnalysis. The laboratory is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO / IEC Standard 17025. All analytical methods are documented in their RadioAnalysis Quality System.
- Water samples were analysed for tritium by the Environmental Isotope Laboratory of iThemba Labs.
- PARC Scientific: RGM monitors measuring time-integrated radon gas concentrations. The monitors and analysis service are accredited by the National Nuclear Regulator.
- External radiation integrated over quarterly periods and at fixed locations was measured using South African Bureau of Standards (SABS) Thermoluminescent Dosimeters (TLD) for environmental radiation.
- Portable radiation monitors were used for monitoring land surface areas. S-230 (2012) Gamma Ray Spectrometer Serial 3402 with BGO crystal, calibrated for K-40, U-238, Th-232, and Inspector 1000 with IPRON 3 NaI probe and internal GM tube. Calibration of equipment was performed at National Nuclear Regulator (NNR) recognised calibration facilities.

Radioactivity concentration levels in samples above and equal to the minimum detectable radioactivity (MDA) are referred to as ‘detects’ in the report. Low levels of radionuclides may cause many samples to yield results below the MDA. Values below the MDA will be referred to as ‘non-detects’. ‘Non-detect’ refers to a sample value that cannot be distinguished statistically from the background level of radiation in the laboratory counting system.

4.6 Terrestrial surface water radioactivity

4.6.1 Introduction

The radiation dose from drinking water obtained from terrestrial sources, e.g. dams and wells, is determined by those radionuclides in NORM that are dissolved from soils and rocks and remain in solution. Uranium tends to remain dissolved in water whereas thorium has an extremely low solubility in natural waters. Groundwater tends to be elevated in NORM concentrations when compared to surface water [4.16.3].

Uranium normally poses a health risk in water because of its chemical toxicity rather than the radiological risk associated with it. In humans, the main toxic effect of short-term exposure to high concentrations of uranium is inflammation of the kidney. The World Health Organization guideline level for drinking water is 10 µg/ℓ uranium [4.16.4]. In most terrestrial surface waters, the elemental uranium concentration ranges from less than 0.1 to 10 µg/ℓ (2.5 to 250 mBq/ℓ). However, in some regions of the world where natural radioactive minerals are particularly abundant, uranium concentration in water can reach much higher values, up to several mg/ℓ.

Radium radioactivity concentrations in surface waters are generally low (0.4 to 40 mBq/ℓ) but elevated levels can be found in groundwater sources. Some mineral and thermal waters exhibit high Ra-226 concentration values up to several Bq/ℓ. Two other important nuclides in the U-238 decay chain and present in water are isotopes of lead and polonium, specifically Pb-210 and Po-210. Po-210 has a high ingestion dose coefficient; however, it is largely insoluble in environmental waters. In the hydrological cycle, Po-210 generally follows its precursor radioactive lead (Pb-210) which is more readily adsorbed than Pb-210 onto particulate matter [4.16.5].

Tritium (H-3) discharged by NPPs to the environment is a contentious issue in many countries. In the United States of America (USA), concerns have been raised by the public in respect of elevated levels of H-3 in groundwater near NPPs. Over the last decade, several nuclear power plants in the USA have detected small quantities of radioactivity in soil and groundwater, also from other inadvertent releases of radioactive material [4.16.6]. The contamination results from operational events and subsurface leaks of fluids contaminated with radioactivity. Investigation has shown that these contamination incidents have an insignificant radiation dose consequence. However, many NPPs have entered into a voluntary initiative to implement groundwater monitoring programmes at all sites in order to assure local stakeholders of the public health and safety. Tritium has been a primary radionuclide of focus in these efforts, as it is a common radioisotope found in airborne and waterborne effluent pathways. Section 4.9 is devoted to H-3 results measured at the sites.

4.6.2 Thyspunt

Different types of water sources were sampled. The water samples that were collected for radioanalysis are described in Table 4-4. The water sampling locations are shown in Figure 4-3 and examples of the different types of water sources are included in Figure 4-4. The table includes the main conclusions on radioactivity concentrations in each sample. Overall, all samples contained low levels of NORM radioactivity and no artificial radioactivity could be detected. Elemental uranium concentration measurements confirmed the low uranium radioactivity levels and are below the WHO guideline value of 10 µg/ℓ.

Table 4-4: Thyspunt terrestrial water samples

Water Sample ID	Location/Water Source	Comments
TP-WS-1-2	Rainwater collected at the Dune Ridge guesthouse (property owned by Eskom)	Samples were analysed for NORM. Very low radionuclide concentrations are reported. Elemental uranium analysis confirmed the low radioanalysis results for U-238.
TP-WS-1-3	Water supplied to households by the municipality in St Francis	
TP-WS-1-4	Eskom dam on the site supplying water to the Eskom office	
TP-WS-2-2	Eskom dam on the site supplying water to the Eskom office	
TP-WS-2-3	Rainwater collected at the Eskom office	
TP-WS-3-5	Water from a dam on Cilliers farm	
TP-WS-3-6	Water from a dune-slack wetland in dunes on the eastern side of the site	
TP-WS-3-9	Eskom dam on the site supplying water to the Eskom office	Slightly higher uranium radioactivity measured in the water compared to the samples above. No artificial radioactivity detects.
TP-WS-3-11	Water from a dune-slack wetland in dunes towards the northern side of the site	
TP-WS-4-1	Small dam at Dune Ridge guesthouse	The highest uranium radioactivity concentrations were measured in these two samples. These levels are still very low and representative of “radioactively clean” water. There were no artificial radioactivity detects.
TP-WS-4-2	Eskom dam on the supplying water to the Eskom office	
TP-WS-4-3	Water supplied by the municipality in St Francis	Slightly higher uranium radioactivity in the water. No artificial radioactivity detects.
Summary of the radioactivity concentrations for some important radionuclide are as follows: U-238: 5.5 – 66.9 mBq/ℓ U-234: 9.1 – 69.6 mBq/ℓ Ra-226: 1.7 – 18.7 mBq/ℓ Uranium chemical concentration: 0.2 – 8.9 µg/ℓ Artificial nuclides, e.g. Cs-137: < MDA (= 16 mBq/ℓ)		

Figure 4-3: Thyspunt terrestrial water sample locations

Figure 4-4: Thyspunt terrestrial water source examples; dune-slack wetland, rainwater tank at the Dune Ridge guesthouse and the Eskom dam on the site

4.6.3 Bantamsklip

Water samples were collected from dams providing water to Pearly Beach and to the Groot Hagelkraal homestead. A large dam and a smaller secondary dam supply water to Pearly Beach. The water sampling locations are shown in Figure 4-5 and the two dams located closest to the site are shown in Figure 4-6.

The radioanalysis results of eleven water samples are summarised in Table 4-5. All samples contained low levels of NORM radioactivity and no artificial radioactivity could be detected. Elemental uranium concentration measurements confirmed the low uranium radioactivity levels. The uranium concentrations are below the WHO guideline value of 10 µg/ℓ.

Table 4-5: Bantamsklip terrestrial water sample radioanalysis results

Water Sample Collected	Location/Water Sources	Comments
BK-WS-1-2 BK-WS-1-4 BK-WS-2-1 BK-WS-3-3 BK-WS-4-2	Groot Hagelkraal dam	Water samples were analysed for NORM and artificial nuclides. Very low NORM concentrations are reported and no detects for artificial radionuclides. Elemental uranium analysis confirmed the low radioanalysis results for U-238. The radioactivity concentrations for some important radionuclide are as follows: • U-238: 13.1 – 36.0 mBq/ℓ • U-234: 17.3 – 58.5 mBq/ℓ • Ra-226: 4.1 – 19.6 mBq/ℓ • U: 1.8 – 0.7 µg/ℓ • Artificial nuclides, e.g. Cs-137: < MDA (= 16 mBq/ℓ)
BK-WS-1-3	Pearly Beach town and water supplied at tap to households	
BK-WS-2-2 BK-WS-3-1 BK-WS-4-1	Pearly Beach secondary dam	
BK-WS-3-9	Pearly Beach large dam	
BK-WS-2-2	Groot Hagelkraal wetland	

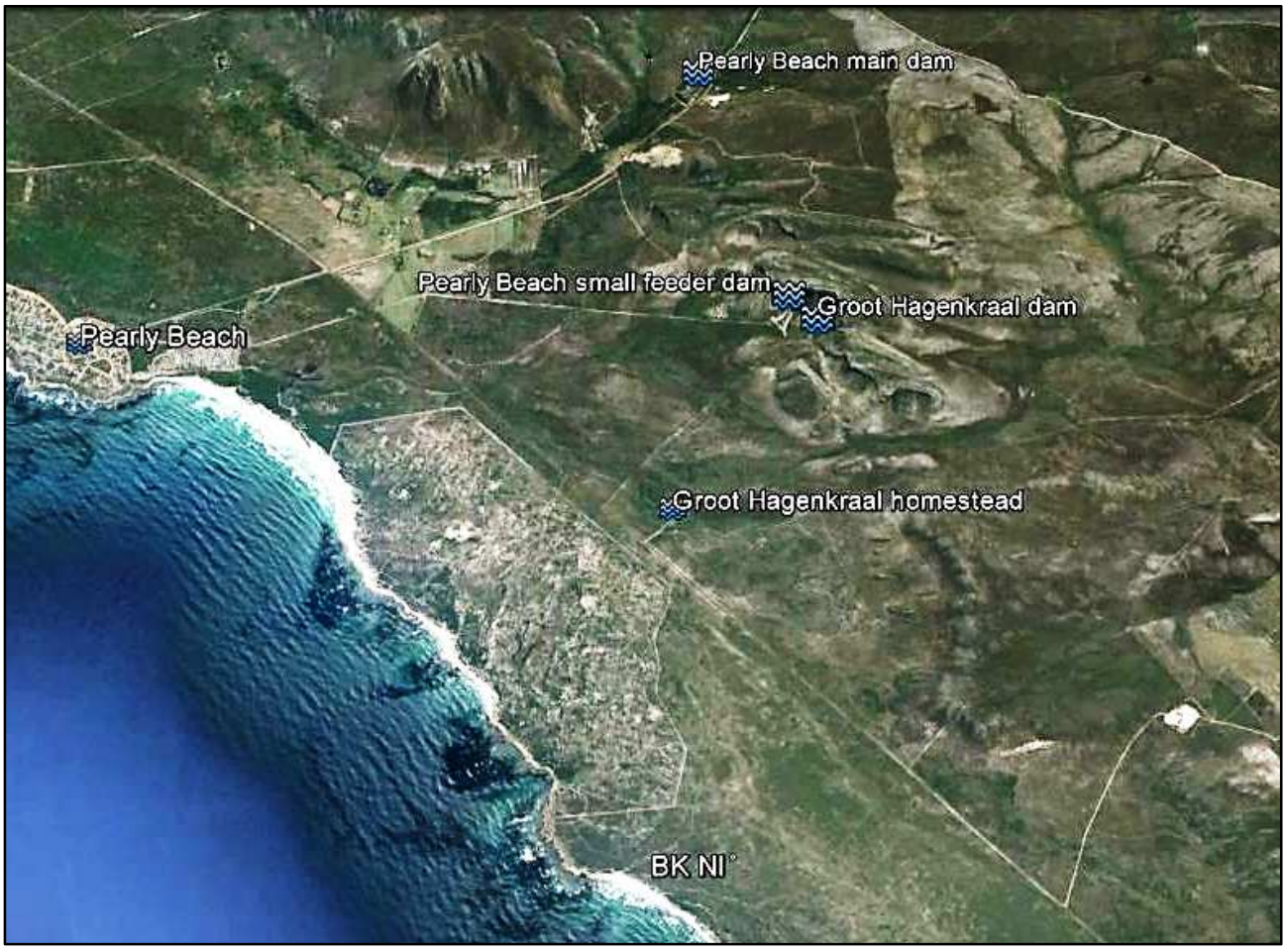

Figure 4-5: Bantamsklip terrestrial water sample locations

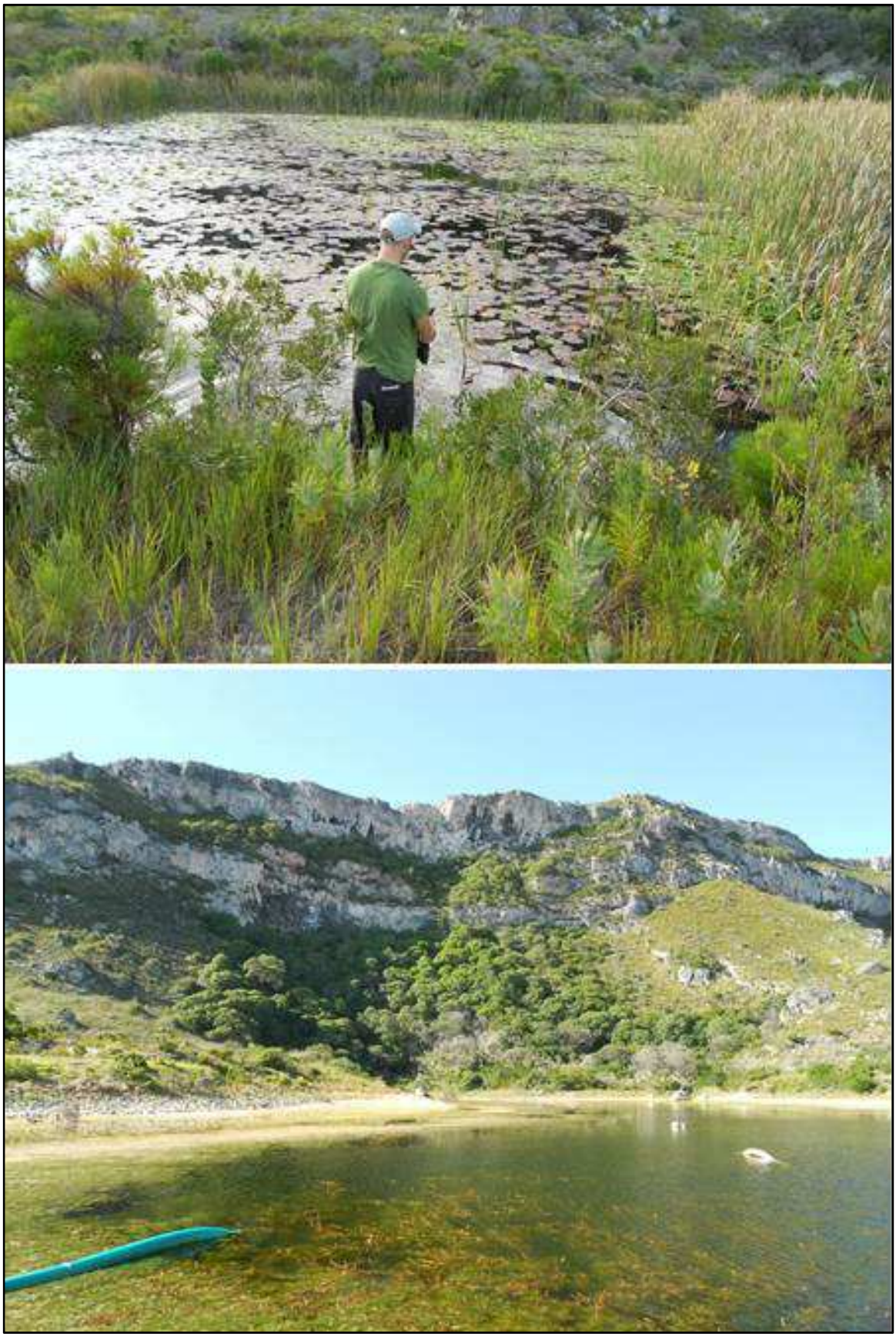

Figure 4-6: Bantamsklip – Groot Hagelkraal dam (top) and the secondary Pearly Beach dam (bottom)

4.6.4 Duynefontein

Water samples were collected from dams on the site, a smallholding in the Duynefontein township, and the Langeberg farm located east of the site. The municipal water supplied to the Duynefontein township was also sampled.

The water sample locations are shown in Figure 4-7. Overall, all samples contained low levels of NORM radioactivity. Extremely low NORM was measured in a sample from a dam on the smallholding in the Duynefontein township, the nearest water body in the public domain to the Koeberg NPP. Elemental uranium concentration measurements confirmed the low uranium radioactivity levels. The results are all below the WHO guideline value of 10 µg/ℓ for drinking water.

Table 4-6: Duynefontein terrestrial surface water samples

Nuclide	DF-WS-3-11 Duynefontein Small Holding		
	mBq/ℓ	**Unc**	**MDA**
^{238}U	7.73	2.73	2.6
^{234}U	12.2	3.5	2.6
U µg/ℓ	*0.181*	*0.02*	*0.05*
^{226}Ra	18.7	2.4	2.8
^{235}U	0.356	0.126	0.12
^{223}Ra	0.99	1.8	1.5
^{224}Ra	10.6	2.6	1.7
Gross alpha	-150	98	360
Gross beta	-72	140	460

Figure 4-7: Duynefontein terrestrial water sample locations

4.7 Groundwater radioactivity

The company SRK Consulting (South Africa) carried out extensive groundwater monitoring at the three sites as part of the siting surveys for Eskom. A summary of the NORM radioactivity in groundwater is provided here.

Radioactivity concentrations were included in the analysis of 15 water samples at Thyspunt, collected during a hydrosensus of farms located near the site. It included gross alpha and beta radioactivity, uranium isotopes, and artificial radionuclides such as Cs-137. The radioactivity levels of U-238 and U-234 were extremely low and the maximum levels reported were 21.9 mBq/ℓ and 29 mBq/ℓ, respectively. No artificial radioactivity was detected.

The groundwater radioactivity levels of U-238 and U-234 were also low at Bantamsklip. However, radioanalysis results reported by Necsa included relatively high results for Th-230 and Th-232 for two boreholes.

NORM levels were low in all borehole water samples at Duynefontein except for Ra-226 in two boreholes. Concentrations equal to 253 mBq/ℓ and 205 mBq/ℓ and an order of magnitude higher than the rest of the samples were reported. However, even higher Ra-226 concentrations can be found in areas in the Northern Cape.

4.8 Seawater radioactivity

4.8.1 Introduction

Oceans cover 70.8 per cent of the total surface of the Earth. The ocean is therefore a major recipient of radionuclides released to the environment by atmospheric as well as aquatic pathways. Rivers and airborne dust carry large quantities of NORM to the oceans. Known sources of anthropogenic radionuclides in the marine environment include global nuclear fallout following atmospheric weapons tests, discharges of radionuclides from operating NPPs, historic dumping of nuclear wastes into the world's oceans and seas, nuclear submarine accidents, loss of nuclear weapons and radioactive sources, and satellite burn-up [4.16.7].

Protection of the marine environment at each site will have to enjoy high priority. Large volumes of cooling water for the NPP will be drawn from the sea and operational liquid discharges will be made to the local marine environment. The background radioactivity levels in seawater is therefore of particular interest.

Cs-137 is a key nuclide measured in water and sediment in the oceans to determine the distribution of anthropogenic sources. An international research project carried out in 2000 [4.16.7] reported that the highest concentrations of Cs-137 were observed in the European seas and the lowest in the southern hemisphere, the Antarctic Ocean in particular. The surface water activity levels were reported as follows:

- Indian Ocean 0.0021 ± 0.0003 Bq/ℓ;
- Central Atlantic 0.0014 ± 0.0002 Bq/ℓ; and
- South Atlantic 0.0006 ± 0.0001 Bq/ℓ.

The studies represent conditions before the Fukushima nuclear accident took place. Results were recently published of a study carried out in the western North Pacific and Sea of Japan to determine the levels of Cs-137 following the Fukushima accident [4.16.8]. Eighty-eight seawater samples were collected. During the period 2011 to 2012, the measured activity concentrations of dissolved Cs-137 ranged from 0.001 Bq/ℓ to 0.034 Bq/ℓ. The pre-Fukushima background level of Cs-137 in seawater was estimated to be 0.0013 ± 0.0003 Bq/ℓ. The lowest Cs-137 concentrations were determined in the western part of the Sea of Japan near the Russian coast, while the maximal levels were observed in the open Pacific Ocean, some 500 to 800 km offshore of the Fukushima Dai-ichi NPP.

Although the oceans contain the majority of the anthropogenic radionuclides released into the environment, the radiological impact of this contamination was demonstrated to be low. Radiation doses from naturally occurring radionuclides in the marine environment (e.g. Po-210) are on the average two orders of magnitude higher than for artificial radioactivity [4.16.9].

4.8.2 Thyspunt

Seawater samples were collected from the surf zone at the Oyster Bay beach and Thysbaai. The results of gamma spectrometric analysis are listed in Table 4-7.

Only two radionuclides were detected above MDA values and at very low concentrations in the large volume samples (25 ℓ) that were collected:

- Th-228: 0.009 1 Bq/ℓ;
- K-40: 9.33 Bq/ℓ.

Both these nuclides are NORM. No detects were reported for artificial radionuclides. Other artificial radionuclides included in the analysis, all below the MDA, are typical of radioactivity discharged by nuclear power plants using seawater as coolant.

Table 4-7: Thyspunt seawater radioactivity

Sample ID	TP-WS-2-1		TP-WS-3-12		TP-WS-4-4	
Nuclide	**Bq/ℓ**	**MDA**	**Bq/ℓ**	**MDA**	**Bq/ℓ**	**MDA**
^{226}Ra	< MDA	0.021	< MDA	0.023	< MDA	0.015
^{210}Pb	< MDA	0.14	< MDA	0.11	< MDA	0.04
^{228}Ra	< MDA	0.038	< MDA	0.05	< MDA	0.033
^{228}Th	0.0091	0.0086	< MDA	0.015	0.0065	0.0095
^{40}K	9.17	0.077	9.33	0.1	0.161	0.067
^{54}Mn	< MDA	0.009 8	< MDA	0.012	< MDA	0.008 9
^{58}Co	< MDA	0.009 2	< MDA	0.012	< MDA	0.017
^{59}Fe	< MDA	0.022	< MDA	0.027	< MDA	0.052

Sample ID	TP-WS-2-1		TP-WS-3-12		TP-WS-4-4	
Nuclide	**Bq/ℓ**	**MDA**	**Bq/ℓ**	**MDA**	**Bq/ℓ**	**MDA**
^{60}Co	< MDA	0.011	< MDA	0.016	< MDA	0.009 7
^{110m}Ag	< MDA	0.009 3	< MDA	0.011	< MDA	0.009 2
^{134}Cs	< MDA	0.008 8	< MDA	0.012	< MDA	0.008 6
^{137}Cs	< MDA	0.01	< MDA	0.012	< MDA	0.008 5

4.8.3 Bantamsklip

Seawater samples were collected from the surf zone at the site. The results of gamma spectrometric analysis are listed in Table 4-8. Only two radionuclides were detected above MDA values and at very low concentrations in the large volume samples that were collected:

- Th-228: 0.0076 Bq/ℓ;
- K-40: 8.13 Bq/ℓ

Both these nuclides are NORM. No detects were reported for artificial radionuclides.

Table 4-8: Bantamsklip seawater radioactivity

Sample ID	BK-WS-2-3		BK-WS-3-6		BK-WS-4-4	
Nuclide	**Bq/ℓ**	**MDA**	**Bq/ℓ**	**MDA**	**Bq/ℓ**	**MDA**
^{226}Ra	< MDA	0.018	< MDA	0.018	< MDA	0.016
^{210}Pb	< MDA	0.08	< MDA	0.078	< MDA	0.079
^{228}Ra	< MDA	0.039	< MDA	0.036	< MDA	0.039
^{228}Th	< MDA	0.011	0.00761	0.0074	< MDA	0.012
^{40}K	7.32	0.097	4.91	0.074	8.13	0.078
^{54}Mn	< MDA	0.009	< MDA	0.0091	< MDA	0.011
^{58}Co	< MDA	0.0094	< MDA	0.0087	< MDA	0.02
^{59}Fe	< MDA	0.022	< MDA	0.02	< MDA	0.075
^{60}Co	< MDA	0.011	< MDA	0.011	< MDA	0.015
^{110m}Ag	< MDA	0.0093	< MDA	0.0083	< MDA	0.011
^{134}Cs	< MDA	0.0094	< MDA	0.0095	< MDA	0.0093
^{137}Cs	< MDA	0.01	< MDA	0.0091	< MDA	0.0096

4.8.4 Duynefontein

Seawater samples were collected from the surf zone north and south of the Koeberg NPP. The results of gamma spectrometric analysis are listed in Table 4-9. No detects were reported for artificial radionuclides.

Table 4-9: Duynefontein seawater radioactivity

Field code	Quarter 1: DF Seawater		Quarter 2: DF-WS -2-1		Quarter 3: DF-WS-3-1	
Nuclide	**mBq/ℓ**	**MDA**	**mBq/ℓ**	**MDA**	**mBq/ℓ**	**MDA**
^{238}U	54	2.4	N.R.*		N.R.	
^{234}U	67.2	2.4	N.R.		N.R.	
^{230}Th	58	25	N.R.		N.R.	
^{226}Ra	3.6	4	< MDA	16	< MDA	24
^{210}Pb	18	1.7	< MDA	110	< MDA	79
^{210}Po	18	1.7	N.R.		N.R.	
^{235}U	2.49	0.11	N.R.		N.R.	
^{227}Th	2.1	6.8	N.R.		N.R.	
^{223}Ra	-1.5	6.2	N.R.		N.R.	
^{232}Th	3.2	4.7	N.R.		N.R.	
^{228}Th	11.3	5.8	8.63	8	14	9.6
^{228}Ra	N.R.		< MDA	31	< MDA	48
^{224}Ra	4.7	5				
^{40}K	N.R.		8200	67	8720	120
^{54}Mn	N.R.		< MDA	7.5	< MDA	11
^{58}Co	N.R.		< MDA	7	< MDA	11
^{59}Fe	N.R.		< MDA	18	< MDA	26
^{60}Co	N.R.		< MDA	9.2	< MDA	14
^{110m}Ag	N.R.		< MDA	7.2	< MDA	11
^{134}Cs	N.R.		< MDA	6.7	< MDA	12
^{137}Cs	N.R.		< MDA	8.2	< MDA	12

*N.I.A.: Radionuclides not included in the analysis

4.9 Tritium in surface water, groundwater, and the sea at the sites

Tritium (H-3) is discharged from NPPs during normal operation and usually at the highest radioactivity quantity when compared to other nuclides discharged. However, its contribution to public dose is small (refer to Part I). H-3 is also produced naturally by the interaction of cosmic radiation with atmospheric components.

Anthropogenic sources, especially from nuclear tests in the atmosphere, overshadowed the natural production for more than a decade from the early 1950s. Peak H-3 concentrations were measured in precipitation (rain/snow) during 1963 following nuclear weapons tests. In the northern hemisphere, the value was 590 Bq/ℓ compared to 13 Bq/ℓ in the southern hemisphere [4.16.1].

Water samples for tritium concentration analysis were collected at the three sites from dams and the sea. Very low H-3 concentrations were measured. The results are included in Table 4-10, Table 4-11, and Table 4-12. A slightly elevated concentration was measured at the Koeberg NPP cooling water discharge to the sea when compared to the rest of the results and a result to be expected. The annual H-3 discharge from Koeberg NPP is well below the authorised discharge quantity, a limit value set by the NNR.

Table 4-10: Thyspunt H-3 in water

Sample ID	Sample Location	Bq/ℓ
TP-WS-3-1	Cape St Francis seawater	0.02
TP-WS-3-2	Oyster Bay seawater	0.04
TP-WS-3-3	Oyster Bay lagoon water	0.11
TP-WS-3-4	Cilliers farm dam	0.08
TP-WS-3-5	Dune-slack wetland – Dune Ridge pool	0.15
TP-WS-3-7	St Francis seawater	0.07
TP-WS-3-8	Eskom dam	0.15
TP-WS-3-10	Dune-slack wetland - Crystal Pool	0.24
TP-WS-3-13	Dune Ridge guesthouse rainwater tank	0.17

Table 4-11: Bantamsklip H-3 in water

Sample ID	Sample Location	Bq/ℓ
BK-WS-3-2	Pearly Beach secondary dam	0.07
BK-WS-3-4	Groot Hagelkraal dam	0.07
BK-WS-3-5	Buffeljags seawater	0.11
BK-WS-3-7	Die Dam holiday resort seawater	0.04
BK-WS-3-8	Pearly Beach large dam	0.08
BK-WS-3-10	Site seawater	0.05
BK-WS-3-11	Pearly Beach seawater	0.05

Table 4-12: Duynefontein H-3 in water

Sample ID	Sample Location	Bq/ℓ (0.118 Bq/T.U.)
1 DF-WS-3-2	Seawater – Koeberg NPP cooling water outfall	2.77
2 DF-WS-3-3	Seawater – Bokpunt	0.11
3 DF-WS-3-4	Seawater – north of Koeberg NPP	0.11
4 DF-WS-3-5	Koeberg NPP bird hide south dam	0.31
5 DF-WS-3-6	Koeberg NPP site office dam	0.28
6 DF-WS-3-7	Duynefontein smallholding dam	0.17
7 DF-WS-3-8	Langeberg farm dam	0.28
8 DF-WS-3-9	Koeberg NPP bird hide north dam	0.15
9 DF-WS-3-10	Duynefontein municipal water (residential tap water)	0.19

All the reported H-3 concentrations are significantly less than the 100 Bq/ℓ screening value used by some countries for drinking water. In the United Kingdom, for example, if the level of tritium is above 100 Bq/ℓ, further investigation is triggered and action may be required [4.16.10].

In reaction to concerns in Canada about tritium in drinking water, the Canadian Nuclear Safety Commission provided assurance that the drinking water near nuclear facilities does not pose a risk to health. The following illustration was provided and shows the radiation dose from drinking water with a H-3 concentration of 18 Bq/ℓ when compared to other source radiation dose [4.16.11].

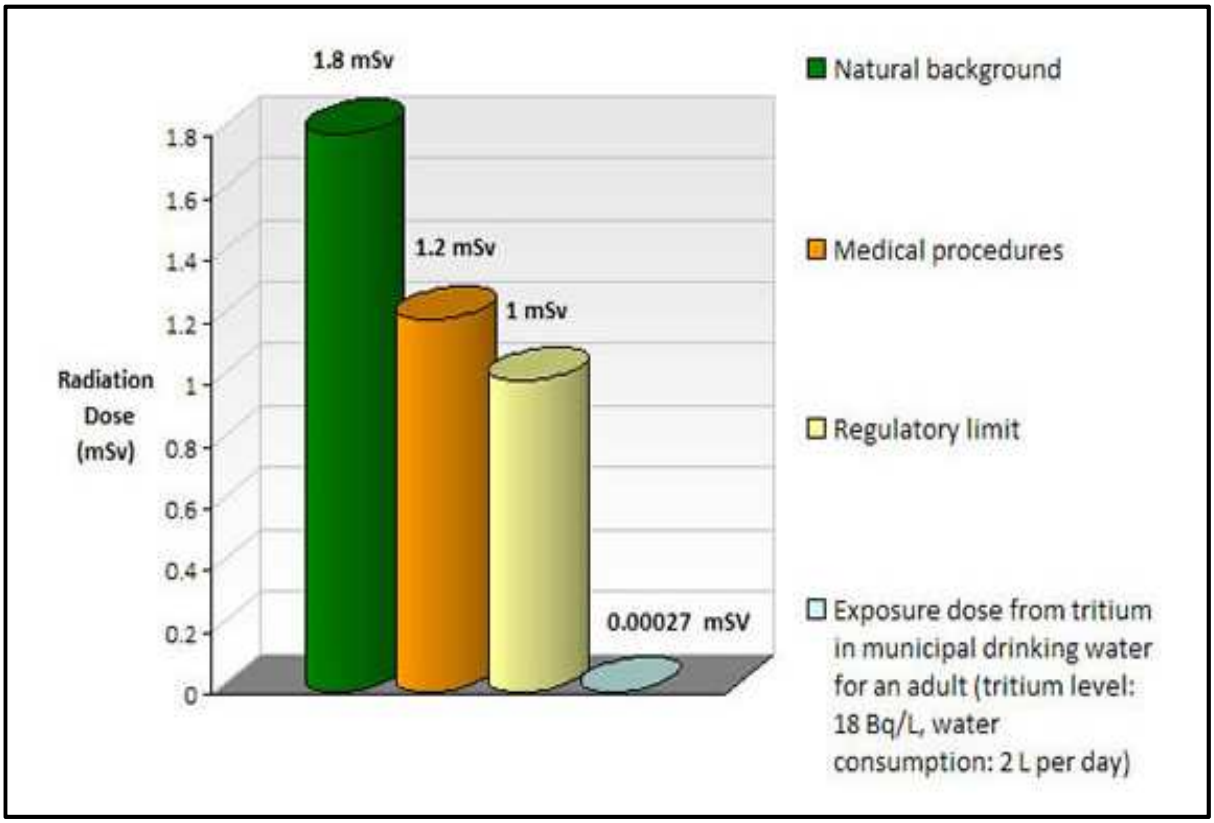

Figure 4-8: Typical annual average dose rate by source

4.10 Soil, sediment, and beach sand

4.10.1 Introduction

Radioactivity in soil is mainly NORM and has its origin in the rock from which it is derived. Typical global values of key NORM concentrations in different rock types and soil are listed in Table 4-13 [4.16.13].

Table 4-13: Typical NORM concentrations in soil and rock

Rock Type		K-40 (Bq/kg)	Th-232 (Bq/kg)	U-238 (Bq/kg)
Igneous rock	Basalt (crustal average)	300	10 to 15	7 to 10
	Mafic	70 to 400	7 to 10	7 to 10
	Salic	1 100 to 1 500	60 to 80	50 to 60
	Granite (crustal average)	> 1 000	70	40
Sedimentary rock	Shale sandstones:	800	50	40
	Clean quartz	< 300	<8	< 10
	Dirty Quartz	400	10 to 25	40
	Arkose	600 to 900	<8	10 to 25
	Beach sands (unconsolidated)	< 300	25	40
	Carbonate Rocks	70	8	25

Rock Type		K-40 (Bq/kg)	Th-232 (Bq/kg)	U-238 (Bq/kg)
Continental upper crust	Average	850	44	36
Soil		400	37	66

Only trace amounts of artificial radioactivity can normally be detected in soils. It can be found on most land surfaces even though sites such as Bantamsklip and Thyspunt are remote from any nuclear facility.

Radioanalysis results of soil and sediment samples reported detects for the two key nuclides Cs-137 and Sr-90. These specific nuclides are indicators of the global presence of artificial radioactivity and the lingering presence of the more than 520 atmospheric nuclear weapons tests conducted between 1945 and 1980 [4.16.13]. These radionuclides are also regarded as being of major importance when assessing the impact areas of accidental releases in the contamination of food and environmental samples, i.e. air, water, milk, meat, other foods, vegetation, and soil.

Bottom sediments of water bodies are often used as indicators of contamination due to past discharges from NPPs [4.16.14]. Many nuclides released into water, whether it be NORM following natural events or NPP discharges, are adsorbed onto particulate material which accumulates with time as bottom sediment. Radioactivity that accumulates over time on intertidal beach sand may result in external exposure of people. Nuclides in sediment are also part of aquatic food chain contamination that can be detected in non-human biota radioanalysis.

4.10.2 Thyspunt: Soil, sediment, and beach sand radioactivity

4.10.2.1 Sampling locations

Samples of soil and sediment were collected on the site, adjacent farms, and the towns of Oyster Bay, Cape St Francis, and St Francis. Composite beach sand samples were collected along the main beaches of these towns. The samples were collected during low tide and from the intertidal zone. The sample locations are indicated in Figure 4-9.

4.10.2.2 Soil

Soil samples were collected during each of the four quarterly periods of the background radiation survey. Four specific samples were collected during quarters 2 and 3 to investigate areas where elevated gamma radiation was detected during the mobile gamma screening surveys.

Three composite soil samples were collected from pasture areas on three farms. A final sample was from rock at the edge of a farm dam. This specific rock sample provided the most interesting and highest radioactivity results of all samples.

Figure 4-9: Thyspunt soil, sediment, and beach (indicated by a red line) sampling locations

Figure 4-10 shows examples of surface areas where external radiation levels are significantly different from one another. Radioanalysis results of the soil samples demonstrate the large variations that can be found in a relatively small area such as the Thyspunt site and its adjacent towns and farm areas.

Figure 4-10: Thyspunt – An illustration of surface areas with very different radioactivity concentrations

A dark aggregate material is shown in Figure 4-10 (top left). It appears to be shale and is being used on some farm roads as a top cover and to fill potholes. Surfaces covered with this material represent the highest NORM activity and external radiation levels of large surface areas that were surveyed. The source of this material is a small quarry located next to the road leading from Oyster Bay to Humansdorp, just after crossing the Krom River; refer to Figure 4-11.

Figure 4-11: Thyspunt – Quarry where shale aggregate is sourced, also showing the material when in-situ

Sand dunes that make up most of the site and nearby town areas have the lowest radioactivity concentrations. Higher levels can be measured in farm soil samples. The use of phosphate-rich fertilizers on farms is known to result in higher K-40 radioactivity than found in most natural soils.

The aggregate used for bitumen-surfaced roads, in contrast to the shale used on dirt roads, has a very low external radiation level and therefore very low NORM levels. The tarred top layer shields higher radiation levels from the natural soils underneath. This can be observed at the transition from a dirt road to a tarred road shown in Figure 4-10. In the Northern Cape, for example, where road construction uses granitic aggregate with higher natural uranium content, the situation is the opposite and road surfaces have higher radiation levels than most of the surrounding soils.

The highest nuclide radioactivity concentrations in the site region were found in a rock sample collected from the edge of a farm dam and shown in Figure 4-12. It is assumed that the geological formation became exposed during the construction of the dam. The nuclide radioactivity concentrations are at levels that, should the material be mined for use as aggregate or building material, nuclear authorisation from the NNR for radiation protection purposes would be required. The material appears to include heavy mineral sand deposits that have high natural occurrence of thorium and uranium minerals.

Figure 4-12: Thyspunt – Location of natural rock with elevated levels of NORM

The conclusions based on the radioanalysis results, are as follows:

- Samples TP-SS-1-7 and TP-SS-1-8 had elevated levels of U-238 (63.1 Bq/kg) and Th-232 (51.5 Bq/kg) when compared to the other samples.
- All samples had detects for Cs-137 and the highest concentration was reported for TP-SS-1-6 (4.93 Bq/kg). The results confirm its global occurrence as a result of earlier atmospheric weapons tests. No detects above MDA were reported for Sr-90. A Sr-90 concentration at 3.2 Bq/kg, just above the MDA of 2.4 Bq/kg, was reported for a

composite sample collected during Quarter 3 at Gerber's farm, from a cereal production land area.

- The mobile gamma radiation screening survey carried out during Quarter 2 observed areas on dirt roads covered with dark shale as discussed earlier. The U-235 and Th-232 decay chain nuclides measured in a sample of this material are higher than those measured in most other soil samples in the region. It also has an exceptionally high K-40 radioactivity concentration (1 070 Bq/kg), the highest of all soil samples.
- The radioanalysis results for NORM activities were all at low levels for soil samples. All samples had C-137 detects with the maximum levels at TP-SS-4-7 (1.87 Bq/kg). There were three detects for Sr-90; TP-SS-4-4 (3.66 Bq/kg), TP-SS-4-7 (3.29 Bq/kg) and TP-SS-4-9 (4.06 Bq/kg).
- The high NORM radioactivity concentrations in the rock sample from the area shown in Figure 4-12 are listed in Table 4-14. Levels for a number of the listed radionuclides exceed the 500 Bq/kg, a regulatory level defined by the NNR above which material is defined as radioactive. Any human activity involving such material has to be regulated by the NNR. The Th-232 decay chain nuclides have exceptionally high concentrations when compared to the soils in the area.

Table 4-14: Thyspunt – 'Rock' material at grassy ridge farm dam

Nuclide	Necsa Radioanalysis Report: RA-14892X004		
	Bq/kg	Unc	MDA
^{238}U	835	37	1.3
^{234}U	842	38	1.3
^{226}Ra	440	10	5.4
^{210}Pb	351	27	31
^{235}U	38.4	1.7	0.06
^{232}Th	2 110	60	11
^{228}Ra	2 030	50	6.8
^{228}Th	1 910	30	2.9
^{40}K	583	16	25
^{90}Sr	0.57	0.73	2.4
^{137}Cs	< MDA		3.5

4.10.2.3 Sediment

Sediment samples were collected from farm dams and from the small Eskom dam on site that supplies water to the Eskom environmental site office. The maximum nuclide specific activities measured in any of the samples are summarised in Table 4-15.

Table 4-15: Thyspunt – Maximum nuclide-specific activity measured in sediment

Nuclide	Bq/kg	Sample Location	Sample ID
^{238}U	83	Eskom dam	TP-SED-3-2
^{234}U	83.7		
^{226}Ra	73.1		
^{210}Pb	76.4		
^{235}U	3.82		
^{232}Th	38.2		
^{228}Ra	65.3	Grassy Ridge farm dam	TP-SED-4-2
^{228}Th	40.3	Eskom dam	TP-SED-3-2
^{40}K	389	Grassy Ridge farm dam	TP-SED-4-2
^{90}Sr	6.76	Eskom dam	TP-SED-2-1
^{137}Cs	< MDA	All sampling locations	TP-SED-2-1

The sediment samples contained slightly elevated concentrations of NORM when compared to the soil samples from areas adjacent to the dams.

Whereas Cs-137 was detected in all surface soil samples, no Cs-137 was reported for the sediment samples.

Strontium was reported in one sediment sample (TP-SED-2-1 from the Eskom dam). The activity reported is the highest of all soil and sediment samples collected at Thyspunt.

4.10.2.4 Beach sand

Radioactivity concentrations in beach sand are significantly lower than for soil and sediment. The maximum radionuclide specific activities measured in beach sand are summarised in Table 4-16.

Table 4-16: Thyspunt – Maximum radionuclide specific activity measured in beach sand

Nuclide	Bq/kg	Sample I.D.
^{238}U	14.1	TP-BSS-1-2
^{232}Th	4.63	TP-BSS-1-2
^{226}Ra	16.6	TP-BSS-3-3
^{210}Pb	26.4	TP-BSS-3-3
^{228}Ra	8.24	TP-BSS-3-3
^{228}Th	8.47	TP-BSS-3-3
^{40}K	40.1	TP-BSS-3-3
^{54}Mn	< MDA	All beach sand samples
^{58}Co	< MDA	
^{59}Fe	< MDA	
^{60}Co	< MDA	
^{110m}Ag	< MDA	

Nuclide	Bq/kg	Sample I.D.
^{134}Cs	< MDA	
^{137}Cs	< MDA	
^{90}Sr	< MDA	

4.10.3 Bantamsklip: Soil, sediment, and beach sand radioactivity

4.10.3.1 Sampling locations

The locations where samples of soil, sediment, and beach sand were collected as part of the site background radiation survey are indicated in Figure 4-13. The sediment sample locations SED01 and SED02 refer to the Pearly Beach secondary dam and the Groot Hagelkraal dam respectively.

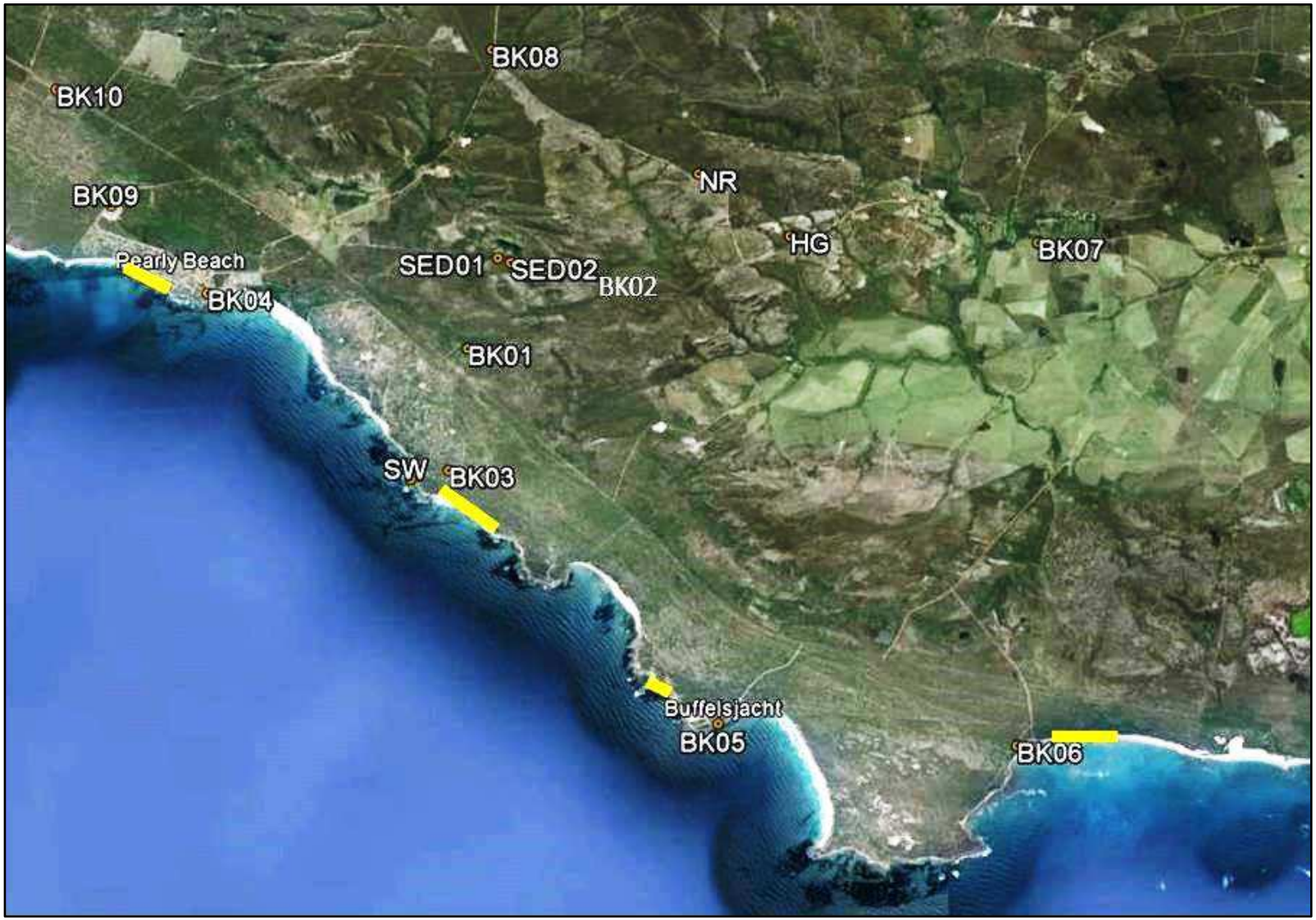

Figure 4-13: Bantamsklip – Soil, sediment, and beach (indicated by a yellow line) sampling locations

4.10.3.2 Soil

The ten composite soil samples collected during the first quarter were from areas identified as BK01 to BK10 shown in Figure 4-13. Three composite soil samples were collected during the second quarter. Two of these samples represent soil from a flat terrain with sparse natural vegetation south of sampling location BK02 and where biota samples (sour fig) were also collected. The relationship between Cs-137 and Sr-90 concentrations in soil and biota in this area is discussed in the biota radioanalysis section (sections 4.11.6 and 4.11.7).

The third sample was of a rocky outcrop on a dirt road located at the position '***HG'*** in Figure 4-13 and Figure 4-14. Elevated gamma radiation was detected at this location during the mobile gamma screening surveys. This soil sample provided the highest radioactivity results of all samples collected in the Bantamsklip site region.

Figure 4-14: Bantamsklip – Soil and rock collected on a road where high gamma radiation was detected

Further samples were collected during the fourth quarter from the site's coastal area and at the Groot Hagelkraal homestead. The maximum and minimum values of the radionuclide specific activities relative to the values of the sample from '***HG***', are summarised in Table 4-17. The last column shows the ratio between the '***HG'*** sample and the maximum radioactivity for the other samples. The ratios for Th-232 decay chain nuclides are particularly high. The Sr-90 concentration at '***HG'*** is also notably higher than for any other soil sample whereas no Cs-137 is reported for '***HG'***.

Table 4-17: Bantamsklip – Radionuclide specific activities measured in soil

Radionuclide	Maximum Bq/kg	Minimum Bq/kg	HG (Sample BK-SS-2-3) Area with high gamma radiation Bq/kg	Ratio HG: Maximum
^{238}U	37.70	3.05	92.40	2.5
^{234}U	38.00	3.07	93.10	2.5
^{226}Ra	35.40	2.07	93.70	2.6
^{235}U	1.73	0.14	4.25	2.5
^{210}Pb	27.80	13.40	55.40	2.0
^{232}Th	48.70	1.31	442.00	9.1
^{228}Ra	54.50	2.10	588.00	10.8
^{228}Th	52.90	2.16	588.00	11.1
^{40}K	270.00	6.17	85.20	0.3
^{90}Sr	1.60	<MDA	9.05	5.7
^{137}Cs	3.05	0.35	< MDA	--

The soil sample results confirm the ubiquitous nature of artificial radionuclides such as Cs-137 and Sr-90.

Sandy soils that make up most of the site and nearby town areas have the lowest radioactivity concentrations.

4.10.3.3 Sediment

Sediment samples were collected during quarters 2, 3, and 4 from the Pearly Beach secondary dam, the Groot Hagelkraal dam, and a wetland at the Groot Hagelkraal homestead. The maximum and minimum values of nuclide specific activities measured are summarised in Table 4-18.

Table 4-18: Bantamsklip – Radionuclide specific activities measured in sediment

Radionuclide	Maximum Bq/kg	Minimum Bq/kg
^{238}U	38.00	5.11
^{234}U	38.30	5.15
^{226}Ra	58.50	3.23
^{210}Pb	96.20	5.80
^{235}U	1.75	0.24
^{232}Th	39.60	2.57
^{228}Ra	49.70	2.96
^{228}Th	41.90	2.11
^{40}K	473.00	5.74
^{90}Sr	7.01	<MDA
^{137}Cs	<MDA	<MDA

A comparison of the sediment radioactivity concentrations of the two dams yields an interesting result. The maximum radioactivity levels are all found in the Pearly Beach secondary dam. Sr-90 concentration was also measured in the sediment of this dam. The differences in radioactivity levels are significant, even though the two dams are located close to each other, approximately 0.25 km distance and illustrated in Figure 4-15. They serve as catchments of water from the same mountain. A determining factor in radioactivity concentrations in sediment could be the size of the dams with the larger dam allowing more time for settling of imported radionuclides.

Figure 4-15: Bantamsklip – The two adjacent dams where sediment samples were collected

4.10.3.4 Beach sand

The lowest radioactivity concentrations in all samples collected were reported for beach sand. The maximum and minimum values of nuclide specific activities are summarised in Table 4-19. Radionuclides such as Mn-58, Co-58, Co-60, Fe-59, Ag-110m, and Cs-134 should only be detectable close to an operating NPP.

Table 4-19: Bantamsklip – Maximum radionuclide specific activity measured in beach sand

Radionuclide	Max Bq/kg	Min Bq/kg
^{226}Ra	5.94	1.43
^{210}Pb	13.9	8.92
^{228}Ra	4.89	1.08
^{228}Th	4.39	1.42
^{40}K	144	24.5
^{54}Mn	< MDA	
^{58}Co	< MDA	
^{59}Fe	< MDA	
^{60}Co	< MDA	
^{90}Sr	< MDA	
^{110m}Ag	< MDA	
^{134}Cs	< MDA	
^{137}Cs	< MDA	

4.10.4 Duynefontein: Soil, sediment, and beach sand radioactivity

4.10.4.1 Sampling locations

Soil samples were collected during the first quarter at monitoring locations DF01 to DF07 indicated in Figure 4-16. A further soil sample was collected just east of the Koeberg NPP weather station at the same location where a biota sample consisting of sour figs was collected. Sediment and beach sand from the intertidal zone were collected at the locations indicated in Figure 4-17 as DF01 to DF10.

Figure 4-16: Duynefontein – Soil sampling locations

Figure 4-17: Duynefontein – Sampling locations of dam sediment (indicated by yellow circles) and beach sand (indicated by yellow lines north and south of the Koeberg NPP)

4.10.4.2 Soil

The radioanalysis results indicate low levels of NORM for the dunes and sandy soils at the Duynefontein site. No artificial radionuclide detects were reported for the soil samples. Note that the results represent a limited number of soil samples. The environmental monitoring programme of the Koeberg NPP has reported low concentrations of artificial radionuclides at levels typical of global background levels and similar to the levels measured at the Bantamsklip and Thyspunt sites.

The maximum nuclide specific activities measured in any of the samples are summarised in Table 4-20.

Table 4-20: Duynefontein – Maximum radionuclide specific activity measured in soil

Radionuclide	Bq/kg
^{238}U	15.8
^{234}U	15.9
^{226}Ra	14.2
^{210}Pb	15.5
^{235}U	0.728

Radionuclide	Bq/kg
^{232}Th	8.4
^{228}Ra	13.4
^{228}Th	13.4
^{40}K	101
^{54}Mn	< MDA
^{58}Co	< MDA
^{59}Fe	< MDA
^{60}Co	< MDA
^{90}Sr	< MDA
^{110m}Ag	< MDA
^{134}Cs	< MDA
^{137}Cs	< MDA

The wide range in natural soil radioactivity in different regions of South Africa is illustrated by the results of a soil sample collected at mineral hot springs in the Karoo. The sample was collected during the same time the background radiation survey was carried out for the Duynefontein site. The Ra-226 radioactivity concentration in the sample is particularly high and more than two orders of magnitude higher than the maximum concentration found in the soils at the sites. The radioanalysis results are shown in Table 4-21. Soils with this level Ra-226 radioactivity will result in high levels external gamma radiation and radon concentrations should a building be located on it. People occupying such a building will have an annual dose rate significantly higher than the global average.

Table 4-21: Radioactivity in soil at a mineral hot spring

Radionuclide	DF-SS-1-8	Soil at Mineral Hot Springs
	Bq/kg	MDA
^{238}U	48	0.42
^{234}U	48.4	0.42
^{226}Ra	*2 220*	*8*
^{235}U	2.21	0.019
^{232}Th	< MDA	3.9
^{228}Ra	< MDA	18
^{228}Th	4.25	3.4
^{40}K	65.2	39
^{137}Cs	<MDA	4.8

4.10.4.3 Sediment

Sediment samples were collected during quarters two and three from three small dams shown in Figure 4-17. The sediment samples contained low levels of NORM and at levels similar to the soil radioactivity levels. A detect for Cs-137 was reported for only one sediment sample.

The maximum radionuclide specific activities measured in any of the samples are summarised in Table 4-22.

Table 4-22: Duynefontein – Maximum radionuclide specific activity in sediment

Nuclide	Bq/kg
^{238}U	12.60
^{234}U	12.70
^{226}Ra	10.50
^{210}Pb	22.60
^{235}U	0.58
^{232}Th	17.90
^{228}Ra	18.20
^{228}Th	18.70
^{40}K	222.00
^{90}Sr	3.50
^{54}Mn	< MDA
^{58}Co	< MDA

Nuclide	Bq/kg
^{59}Fe	< MDA
^{60}Co	< MDA
^{110m}Ag	< MDA
^{134}Cs	< MDA
^{137}Cs	0.47

4.10.4.4 Beach sand

The lowest radioactivity concentrations in all samples collected were reported for beach sand. The maximum radionuclide specific activities measured in any of the samples are summarised in Table 4-23. No artificial radionuclide was detected in the beach sand. The NORM radioactivity levels are also extremely low. This is in contrast to some areas further north along the West Coast where beach sand contains elevated levels of NORM, e.g. at Strandfontein and Brand-se-Baai where heavy mineral sands are being mined. Heavy mineral sands contain higher than normal uranium and thorium soil concentrations. Mining of these sands requires authorisation from the NNR and radiation protection management plans.

Table 4-23: Duynefontein – Maximum radionuclide specific activity measured in beach sand

Nuclide	Bq/kg
^{226}Ra	13.3
^{210}Pb	14.8
^{228}Ra	3.74
^{228}Th	3.51
^{40}K	104
^{54}Mn	< MDA
^{58}Co	< MDA
^{59}Fe	< MDA
^{60}Co	< MDA
^{90}Sr	< MDA
^{110m}Ag	< MDA
^{134}Cs	< MDA
^{137}Cs	< MDA

4.11 Biota radioactivity

4.11.1 Introduction

The global average dose to humans from food and water reported by UNSCEAR [4.16.1] is listed in Table 4-24.

Table 4-24: Global annual ingestion dose rate

Ingestion	Annual Effective Dose (mSv)		Comment
	Average	Range	
K-40	0.17	0.2 to 1.0	The dose is dependent on radionuclide concentrations in food and drinking water
Uranium and thorium decay series radionuclides	0.12		
Total	**0.29**		

The ingestion dose between population groups in a country can vary greatly. The dose is a function of the fraction of foodstuff obtained from the area where a group resides. Seafood is an example since most radionuclides in seawater bio-accumulate in marine organisms to a higher degree than soil radioactivity in terrestrial food. The ratio of radioactivity concentrations in soil and water to radioactivity concentration in biota is defined as a concentration ratio (CR). It is expressed in units of Bq/kg (fresh weight of an organism) per Bq/kg (soil or water). CR is mostly greater than one for seawater and less than one for soils and accounts for the potentially high ingestion dose to populations with a high seafood diet [4.16.9].

4.11.2 Thyspunt marine biota

The fishing industry is an important contributor to the local economy and public concerns in respect of liquid discharges from a future NPP are of special importance. Chokka squid and fish are harvested in the sea where liquid discharges from a future NPP will occur. Figure 4-18 illustrates samples from the local marine environment submitted for radioanalysis.

The radioanalysis results are summarised in Table 4-25. The results show the high concentrations of Po-210 in marine biota when compared to the other nuclides, whether NORM or artificial. Only one positive detect is reported for artificial radioactivity at the site, i.e. Cs-137 in a chokka squid sample (TP-BIO-1-4). The squid does not show the same bioaccumulation for Po-210 as the black mussel.

The Po-210 results for fish in Table 4-25 shows the large difference in radioactivity concentration between the muscle tissue of fish and the intestines. This result corresponds to results of a study performed on tuna [4.16.15]. The study reported that Po-210 concentrations in tuna muscle were 3.0 ± 0.1 Bq/kg, while in the liver it was 268 ± 9.

The study also makes the following interesting statement:

Due to overexploitation of fishing resources, human populations are increasingly fishing smaller size fish and catching species in lower trophic levels of marine food chains, which implies that current seafood trends are likely to increase ^{210}Po ingestion and the collective radiation dose. An example is the consumption of krill, the usual whales' food in the Antarctic Ocean, in processed food which may increase Po-210 intake by humans.

Figure 4-18: Thyspunt – Fishing vessels at Oyster Bay and samples of carpenter fish and chokka squid collected from these vessels for radioanalysis

Table 4-25: Thyspunt – Radioactivity concentrations in marine biota

Marine Biota		Sample ID	Radioactivity Concentration (Bq/kg (f.w.))					
			Ra-226	**Pb-210**	**Po-210**(1)	**K-40**	**Cs-137**	**Sr-90**
Black Mussel	Choromytilus meridionalis	TP-BIO-1-3	< 0.95	8.4	212.2	45.7	N.I.A.(2)	N.I.A.
Chokka Squid (Loligo)		TP-BIO-1-4	< 0.53	0.7	38.4	114.0	0.6	N.I.
		TP-BIO-2-2	< 0.074	1.01	47.1	63.5	< 0.043	2.56
		TP-BIO-4-8	< 0.048	0.483	135.4	117.0	< 0.033	< 0.13
Fish – pelagic muscle tissue	Carpenter/ (Argyrozona argyrozona)	TP-BIO-3-3(A)	< 0.083	< 0.35	3.3	90.5	< 0.037	0.09
		TP-BIO-4-9	< 0.12	< 0.58	4.7	130.0	< 0.086	< 0.11
Fish – pelagic intestines	Carpenter/ (Argyrozona argyrozona)	TP-BIO-3-3(B)	< 1.1	< 3.5	84.6	83.2	< 0.54	< 0.82
		TP-BIO-4-10	< 0.9	< 3	336.3	121.0	< 0.51	< 1.5

(1): Po-210 was decay-corrected to reflect the radioactivity concentration at the time of sample collection as opposed to the time the radioanalysis was carried out. The half-life of Po-210 is 138 days, significantly shorter than the other nuclides for which decay-correction is not required.
(2): N.I.A = Nuclide not included in the radioanalysis.

In population groups defined as ‘heavy seafood consumers’, Po-210 is the most important contributor to public ingestion dose due to its large dose coefficient. This situation is illustrated by the results of a study done on consumption of seafood from the North East Irish Sea that receives liquid discharges from various nuclear installations. The Sellafield nuclear fuel reprocessing plant was the biggest contributor to radioactive liquid discharges to the sea at the time the study was carried out [4.16.9]. The results of the annual dose estimate for seafood from the Irish Sea is shown in Table 4-26. Po-210 contributes more than 90 per cent to the dose, and anthropogenic sources that included the nuclear industry, less than 2 per cent.

Table 4-26: Seafood annual dose estimate example

North Irish Sea	Annual Consumption	NORM (µSv/y)		Anthropogenic Source e.g. NPPs (µSv/y)
	kg/y	Total	Po-210	
Fish	73	26.72	***24.5***	0.68
Crustacean	3.65	23.04	***22.8***	0.28
Molluscs	3.65	43.89	***41.2***	0.21
	Total dose =	93.65	***88.5***	1.17

4.11.3 Bantamsklip marine biota

Fishing and marine aquaculture are important contributors to the local economy. Public concerns in respect of liquid discharges from a future NPP are therefore of special importance. An abalone farm currently under construction at Buffeljags is located approximately 6 km away from where liquid effluent will be discharged from a future NPP. Another abalone farm is operational at Gansbaai.

Figure 4-19 illustrates samples collected at the beachfront of the site and submitted for radioanalysis. The samples were restricted to the main marine organisms found at the site and harvested by local people. Kelp was included because it is an important component in abalone communities. The abalone farm at Buffeljags is shown in Figure 4-20. Unfortunately, no abalone samples could be obtained because of environmental permit and security restrictions. *Turbo sarmaticus*, a species of marine gastropod mollusc and also known as *alikreukel* by the locals, was collected and should have a bioaccumulation ratio similar to abalone.

The radioanalysis results are summarised in Table 2-1. The results show the high concentrations of Po-210 in marine biota when compared to the other radionuclides, whether NORM or artificial. Only one positive detect is reported for artificial radioactivity at the site, i.e. Sr-90 in kelp.

Figure 4-19: Bantamsklip – Marine samples collected: alikreukel (top left), removed from their shells (top right), kelp (bottom left) and black mussels before and after removal from their shells (bottom right)

Figure 4-20: Bantamsklip **–** Buffeljags abalone farm and seawater intake area with pump station

Table 4-27: Bantamsklip – Maximum radioactivity concentrations measured in marine biota

Nuclide	Black Mussel	Kelp	Alikreukel
	Bq/kg f.w.	Bq/kg f.w.	Bq/kg f.w.
^{7}Be	< MDA	< MDA	< MDA
^{226}Ra	< MDA	0.30	< MDA
^{210}Pb	2.23	0.28	13.7
^{210}Po	57.80	5.41	67.1
^{228}Ra	0.00	0.29	< MDA
^{228}Th	0.13	0.17	0.0562
^{40}K	414.00	378.00	89
^{90}Sr	< MDA	0.73	< MDA
^{54}Mn	< MDA	< MDA	< MDA
^{58}Co	< MDA	< MDA	< MDA
^{59}Fe	< MDA	< MDA	< MDA
^{60}Co	< MDA	< MDA	< MDA
^{110m}Ag	< MDA	< MDA	< MDA
^{134}Cs	< MDA	< MDA	< MDA
^{137}Cs	< MDA	< MDA	< MDA

4.11.4 Duynefontein marine biota

Monitoring of marine biota at the site was limited to white mussel (*donax serra*), a species that also serves as an indicator organism for Koeberg NPP in terms of operational discharges to the sea (Figure 4-21). The radioanalysis results are summarised in

Biota Sample	Sample ID	Sampling Date	Radioanalysis Date	Time between sampling and radioanalysis; days	Radionuclide	Reported Radioactivity, Bq/kg (f.w.)	Radioactivity at time of sampling; Bq/kg (f.w.)
Adult Mussel; size >60 mm	DF-BIO-1-2	10/11/2012	1/2/2013	82	Po-210	28.7	43.3
				82	Ag-110m	2.2	2.8
Juvenile Mussel; size < 40 mm	DF-BIO-1-3	10/11/2012	1/2/2013	82	Po-210	12.0	18.1
				82	Ag-110m	< MDA (= 0.088)	
Mussel - Mixed age groups	DF-BIO-2-2	31/1/2014	25/3/2013	53.0	Po-210	16.9	22.1
				53.0	Ag-110m	2.0	2.3

Table 4-29. The results show the high concentrations of Po-210. The results also suggest a significant difference in Po-210 concentration between adult and juvenile white mussel.

The only artificial nuclide detected was Ag-110m. Koeberg NPP is allowed to discharge radioactive liquid at very low and safe radioactivity quantities in accordance with its nuclear licence conditions. The environmental surveillance programme regularly reports key nuclides in respect of allowable discharges such as Co-58, Co-60, and Ag-110m in the local marine biota.

The method that is required for the quantification of Po-210 is alpha spectrometry analysis. Po-210 emits energetic alpha particles (> 5 MeV), has a half-life of 138 days.

Biota Sample	**Sample ID**	**Sampling Date**	**Radioanalysis Date**	**Time between sampling and radioanalysis; days**	**Radionuclide**	**Reported Radioactivity, Bq/kg (f.w.)**	**Radioactivity at time of sampling; Bq/kg (f.w.)**
Adult Mussel; size >60 mm	DF-BIO-1-2	10/11/2012	1/2/2013	82	Po-210	28.7	43.3
				82	Ag-110m	2.2	2.8
Juvenile Mussel; size < 40 mm	DF-BIO-1-3	10/11/2012	1/2/2013	82	Po-210	12.0	18.1
				82	Ag-110m	< MDA (= 0.088)	
Mussel - Mixed age groups	DF-BIO-2-2	31/1/2014	25/3/2013	53.0	Po-210	16.9	22.1
				53.0	Ag-110m	2.0	2.3

Table 4-29 shows the adult dose (committed effective dose) when 1 kg of fresh white mussel collected from the intertidal zone on the beach south of Koeberg NPP, is consumed in a year. The dose from Po-210 is more than 5 000 times greater than the Ag-110m released by Koeberg NPP as measured in white mussel.

Figure 4-21: Duynefontein – White mussel collected south of the Koeberg NPP

Table 4-28: Duynefontein – Radioactivity concentrations in white mussel

Biota Sample	Sample ID	Sampling Date	Radioanalysis Date	Time between sampling and radioanalysis; days	Radionuclide	Reported Radioactivity, Bq/kg (f.w.)	Radioactivity at time of sampling; Bq/kg (f.w.)
Adult Mussel; size >60 mm	DF-BIO-1-2	10/11/2012	1/2/2013	82	Po-210	28.7	43.3
				82	Ag-110m	2.2	2.8
Juvenile Mussel; size < 40 mm	DF-BIO-1-3	10/11/2012	1/2/2013	82	Po-210	12.0	18.1
				82	Ag-110m	< MDA (= 0.088)	
Mussel - Mixed age groups	DF-BIO-2-2	31/1/2014	25/3/2013	53.0	Po-210	16.9	22.1
				53.0	Ag-110m	2.0	2.3

Table 4-29: – Radiological dose associated with white mussel

Ingestion Committed Effective Dose (CED) per Unit Intake; µSv/Bq		Bq/kg	CED; µSv	Ratio of committed effective doses CED (Po-210):CED (Ag-110m)
Ag-110m	2.80E-03	2.2	0.006	5591
Po-210	1.20E+00	28.7	34.440	

4.11.5 Thyspunt terrestrial biota

A major agricultural activity in the region is dairy farming. Biota samples collected for radioanalysis included fresh milk collected on the same day the cows were milked, grass in pasture areas, and maize and wheat grown mainly for cattle fodder. Figure 4-22 illustrates some of the farming activities, namely dairy and cereal production. Samples were collected in the areas shown in Figure 4-23.

Table 4-30 lists NORM nuclide concentrations that showed high variability between samples. Detects were reported for Sr-90 and Cs-137. The results for Po-210 illustrate its low levels terrestrial biota when compared to marine biota.

The radionuclide Be-7 that is reported is a cosmogenic radionuclide. It is deposited from the atmosphere and high concentrations can occur in grasses and cereals.

A high value for K-40 was detected in a wheat sample. This could be the result of using fertiliser with a high potassium concentration.

A sample of sour fig (c*arpobrutus edulis*) was collected in the dune areas near the Dune Ridge guesthouse, east of the site. Its fruit is harvested by local people and it is regarded as a traditional delicacy. It can also be used as a herbal medicine [4.16.16]. The fig occurs at all three Eskom sites and samples have been collected at each site.

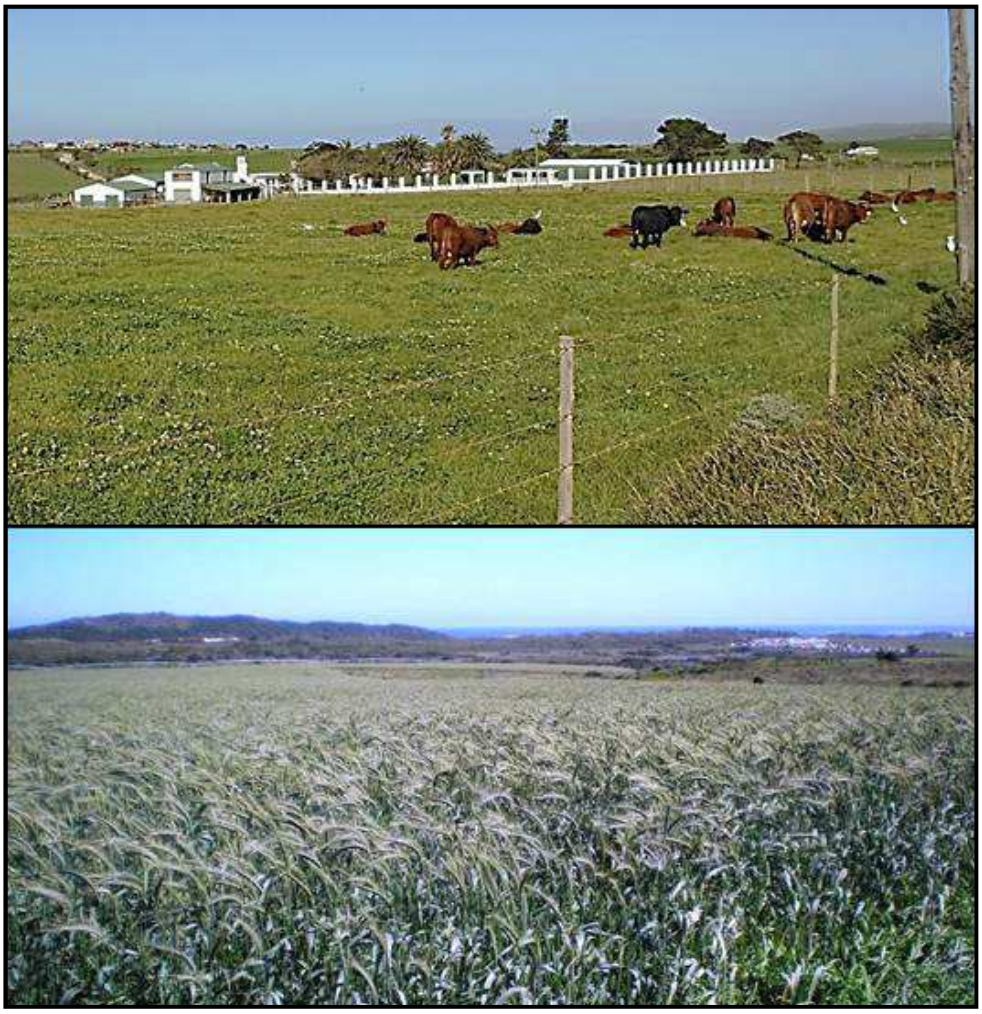

Figure 4-22: Thyspunt – Dairy farming and cereal production near Oyster Bay

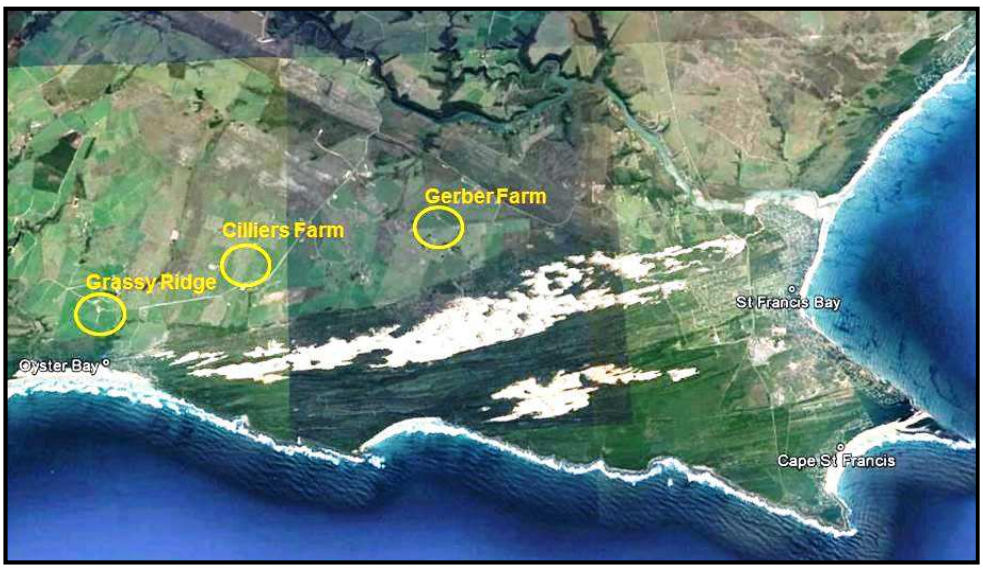

Figure 4-23: Thyspunt – Areas where terrestrial biota samples were collected

A summary of the detailed radioanalysis results is included in Table 4-30.

Table 4-30: Thyspunt – Summary results of terrestrial biota radioactivity concentrations

Milk, Bq/ℓ	**Nuclide**	**TP-BIO-1-2**	**TP-BIO-2-1**	**TP-BIO-3-1**	**TP-BIO-3-2**	**TP-BIO-4-2**	**TP-BIO-4-1**	**TP-BIO-4-3**
		Gerber Farm	**Gerber Farm**	**Cilliers Farm**	**Gerber Farm**	**Grassy Ridge Farm**	**Gerber Farm**	**Cilliers Farm**
	K-40	59.7	46.3	39.0	30.6	72.3	85.4	91.8
	Po-210	N.I.A	0.007	0.033	0.023	0.039	0.026	0.028
	Cs-137	0.24	0.044	< MDA	0.032	< MDA	< MDA	< MDA
	Sr-90	N.I.A	0.056	< MDA	< MDA	< MDA	< MDA	< MDA
Cereal and grass, Bq/kg	**Nuclide**	**TP-BIO-1-1**	**TP-BIO-3-4**	**TP-BIO-4-4**	**TP-BIO-4-5**	**TP-BIO-4-6**	**TP-BIO-4-7**	**TP-BIO-2-3**
		Wheat (Cilliers Farm)	**Maize/fodder (Cilliers Farm)**	**Pasture grass (Grassy Ridge)**	**Pasture grass (Gerber Farm)**	**Wheat (Gerber Farm)**	**Pasture grass (Cilliers Farm)**	**Sour figs**
	K-40	2 810.0	1 300.0	282.0	86.0	213.0	243.0	144.0
	Po-210	0.750	0.690	0.734	0.609	1.300	1.310	0.368
	Be-7	N.I.A[1]	534.0	37.1	241.0	46.6	46.3	2.5
	Cs-137	N.I.A	1.460	< MDA	0.117	< MDA	< MDA	< MDA
	Sr-90	N.I.A	< MDA	< MDA	0.440	< MDA	< MDA	< MDA

[1]: N.I.A = Not Included in the radioanalysis.

4.11.6 Bantamsklip terrestrial biota

Biota samples collected for radioanalysis included fresh milk and cattle fodder produced on a dairy farm, wild watermelon, sour fig, and honey. Figure 4-24 shows the locations where samples were collected; BK-BIO-01 (milk), BK-BIO-02 (cattle fodder), BK-BIO-03 (wild melon) and BK-BIO-04 (sour fig).

A milk sample was collected during each quarter and a honey sample was collected during quarters 3 and 4. Honey from the region is produced on a commercial scale.

A composite sample was collected of each of following biota types; cattle fodder (Quarter 1), wild melon (Quarter 3) and sour fig (Quarter 2). The melons and figs are used on a small scale by local people for manufacturing fruit preserves (jams).

A summary of the radioanalysis results is provided in Table 4-31.

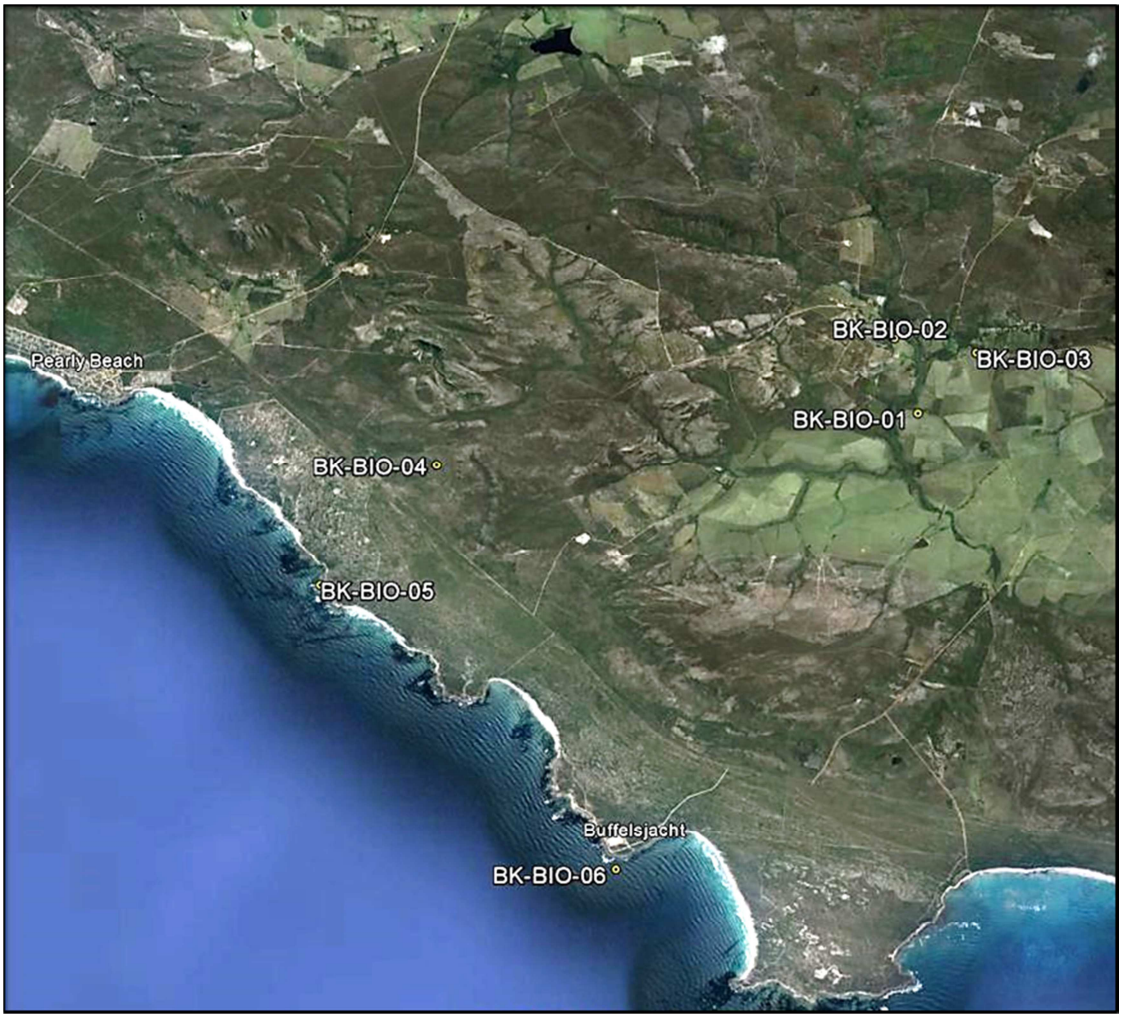

Figure 4-24: Bantamsklip – Terrestrial and marine foodstuff/biota sample locations

Figure 4-25: Bantamsklip – Milk, wild melon, and sour fig

Figure 4-26: Bantamsklip – Honey factory near Stanford

Table 4-31: Bantamsklip – Summary results of terrestrial biota radioactivity concentrations

Nuclide	Cattle Fodder	Milk	Wild Melon	Sour Fig	Honey
	Bq/kg f.w.	Bq/kg f.w.	Bq/kg f.w.	Bq/kg f.w.	Bq/kg f.w.
^{7}Be	50.3	< MDA	< MDA	2.61	< MDA
^{226}Ra	N.I.A.[1]	< MDA	< MDA	< MDA	< MDA
^{210}Pb	N.I.A.	0.296	< MDA	< MDA	< MDA
^{210}Po	5.98	0.036	0.142	0.888	1.99
^{228}Ra	N.I.A.	< MDA	0.045	< MDA	< MDA
^{228}Th	N.I.A.	< MDA	0.012	0.024	0.474
^{40}K	N.I.A.	87.9	42.9	121	44.3
^{90}Sr	N.I.A.	< MDA	< MDA	2.67	11.6
^{137}Cs	< MDA	< MDA	< MDA	1.34	< MDA

[1]: N.I.A = Not included in the radioanalysis.

An indication of the CR values of sour figs can be obtained by comparing the radioactivity in two soil samples collected in the same area where the sour fig sample was collected. Table 4-32 lists the radioactivity concentrations. The artificial nuclides of Cs-137 and Sr-90 are of particular interest since the results suggest that sour fig can be used as an indicator species for a future NPP. The CR value for Sr-90 is more than one and that of Cs-137 slightly less than one.

Table 4-32: Concentration factors of sour fig

Nuclide	BK-SS-2-1			BK SS-2-2			BK-BIO-2-4		
	Soils at sour fig area with low external radiation			Soils at sour fig area with slightly higher external radiation			Sour fig biota analysis		
	Bq/kg	Unc.	MDA	Bq/kg	Unc.	MDA	Bq/kg	Unc.	MDA
^{238}U	3.05	0.31	0.9	11.2	0.5	0.9	–		
^{234}U	3.07	0.32	0.91	11.3	0.5	0.91	–		
^{226}Ra	2.07	0.22	0.93	11.3	0.4	0.97	< MDA		0.093
^{210}Pb	13.4	2.4	7	17.8	2.5	7	< MDA		0.66
^{235}U	0.14	0.014	0.041	0.514	0.022	0.042	–		
^{232}Th	2.26	0.21	0.59	4.63	0.37	0.77	–		
^{228}Ra	3.06	0.36	0.94	8.3	0.56	1.3	< MDA		0.21
^{228}Th	3.24	0.13	0.41	8.1	0.29	0.44	0.024	0.014	0.05
^{40}K	6.17	1.27	3.8	11.8	1.6	4.5	121	5	0.38
^{90}Sr	0.42	1.2	4	1.5	1.2	3.9	2.67	0.72	1.9
^{137}Cs	2.41	0.15	0.33	2.59	0.13	0.27	1.34	0.08	0.042

4.11.7 Duynefontein terrestrial biota radioactivity

Farming activities comprising mainly wheat and milk production occur beyond 6 km of the site, towards the east and south-east. Samples were collected in the areas shown in Figure 4-27. Table 4-33 lists the maximum nuclide concentrations and the results demonstrate the high variability in terrestrial food samples. Detects were reported for Sr-90 and Cs-137. Be-7 was again measured at a relatively high concentration in wheat samples.

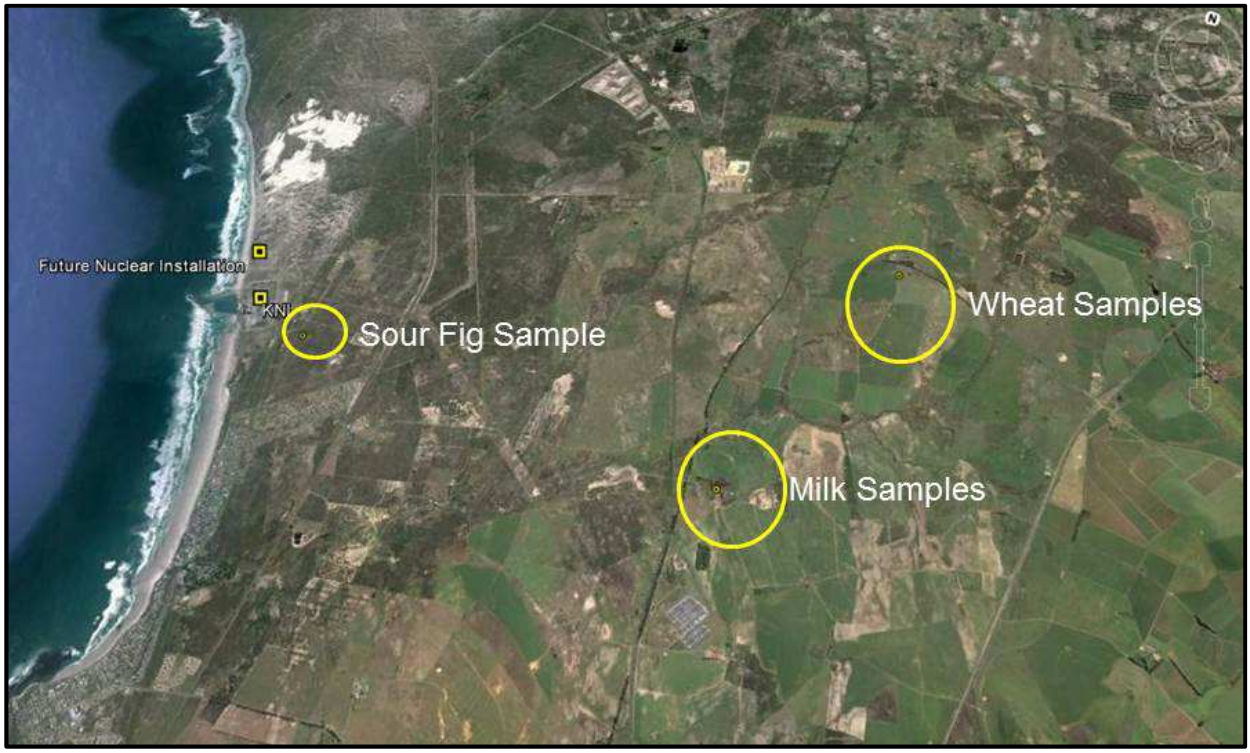

Figure 4-27: Duynefontein – Areas where terrestrial biota samples were collected

A sample of sour fig (c*arpobrutus edulis*) was collected on the site. A comparison of the radioactivity concentrations in sour fig samples from all three sites and for a limited set of nuclides that include Sr-90, is shown in is provided in Table 4-34.

Table 4-33: Duynefontein – Terrestrial biota maximum radioactivity concentrations

Nuclide	Maximum Concentration in Wheat and Fig Samples; Bq/kg	Maximum Concentration in Milk Samples; Bq/ℓ
^{7}Be	38.80	3.50
^{226}Ra	3.70	1.70
^{210}Pb	0.91	0.23
^{210}Po	2.00	0.42
^{228}Ra	1.20	0.32
^{228}Th	0.04	0.01
^{40}K	217.00	7.00
^{54}Mn	< MDA	0.51

Nuclide	Maximum Concentration in Wheat and Fig Samples; Bq/kg	Maximum Concentration in Milk Samples; Bq/ℓ
^{58}Co	< MDA	0.00
^{59}Fe	< MDA	0.00
^{60}Co	< MDA	0.00
^{90}Sr	1.95	0.03
^{110m}Ag	< MDA	0.00
^{134}Cs	< MDA	0.00
^{137}Cs	< MDA	0.00

Table 4-34: Sour fig radioactivity comparison of samples from the three sites, Bq/kg (f.w.)

Nuclide	Duynefontein Fig	Bantamsklip Fig	Thyspunt Fig
^{7}Be	0.93	2.61	2.51
^{210}Po	0.213	0.888	0.368
^{40}K	122	121	144
^{90}Sr	*1.95*	*2.67*	*0.81*
^{137}Cs	< MDA	1.34	< MDA

4.12 Radon

4.12.1 Introduction

Radon (Rn-222) is an inert radioactive gas produced by the decay of natural uranium in rocks and soils throughout the Earth's crust. Rn-222 is the only isotope of radon with a sufficiently long half-life to migrate through rocks and soils to the atmosphere where people can inhale it. Rn-220, another isotope of radon, is a daughter product in the Th-232 decay series and has a short half-life of 55.6 seconds. Rn-219 is a daughter product in the U-235 decay series and has an even shorter half-life of 3.92 seconds. Rn-222 is normally the most significant component of human exposure from NORM and constitutes most of the dose from inhalation as is reported in Table 4-35 [4.16.1].

Table 4-35: Global average public dose from inhalation (dust and radon)

Inhalation	Annual Effective Dose (mSv)		Comments
	Average	Typical Range	
Uranium and thorium decay series radionuclides in airborne dust	0.006	0.2 to 10	Indoor concentrations of Rn-222 can vary considerably. High concentrations can exist in poorly ventilated spaces.
Radon, Rn-222	1.15		
Thoron, Rn-220	0.1		
Total	1.26		

Long-term average global concentrations of radon vary significantly. It can range from approximately 1 Bq/m^3 to more than 100 Bq/m^3. Low concentrations are typical of isolated small islands or coastal regions and the high value is typical of sites where high radon exhalation occurs over large areas. In confined and unventilated underground mining areas, it can reach levels as high 100 000 Bq/m^3 [4.16.1].

4.12.2 Radon concentrations at the sites and adjacent areas

4.12.2.1 The outside environment

Radon concentrations were measured during a period of approximately one year. Passive radon monitors, shown in Figure 4-28, were used to gather four sets of data at fixed locations at each site.

The monitoring locations covered wide areas and are shown in Figure 4-29.

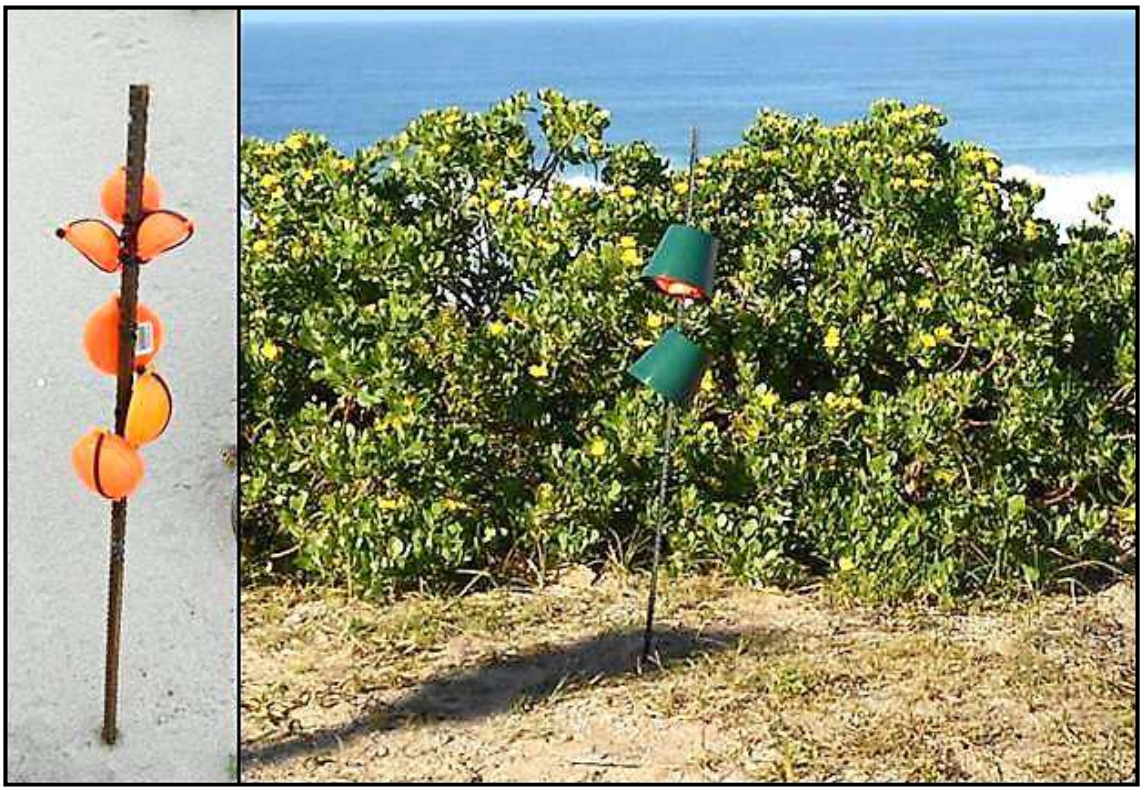

Figure 4-28: Radon monitors (three monitors at top) and TLD external radiation monitors (three monitors at bottom) deployed in the environment

Figure 4-29: Radon and external radiation monitoring locations

Three monitors were deployed at a time at the same location. Each data set provides information on the integrated radon concentration over a period of approximately three months. A summary of the results at each site is provided in Table 4-36, Table 4-37, and Table 4-38.

Table 4-36: Thyspunt environmental radon concentrations

Monitoring Position	Monitoring Period Average Rn ($Bq.m^{-3}$)				Average Rn ($Bq.m^{-3}$)
	Q1	Q2	Q3	Q4	
TP-01	19.3	12.9	5.8	14.8	13.2
TP-02	17.5	7.4	3.3	14.6	10.7
TP-03	18.2	8.7	3.9	17.4	12.1
TP-04	25.5	(lost)	7.2	15.2	15.9
TP-05	22.4	10.9	4.9	15.4	13.4
TP-06	25.6	10.4	4.7	15.7	14.1
TP-07	23.0	14.5	6.5	17.4	15.3
TP-08 (in Jeffreys Bay	23.6	15.4	6.9	17.4	15.8
TP-09	13.9	7.2	3.2	15.4	9.9
TP-10	21.4	10.3	4.6	16.3	13.2

Table 4-37: Bantamsklip environmental radon concentrations

Monitoring Position	Monitoring Period Average Rn ($Bq.m^{-3}$)				Average Rn ($Bq.m^{-3}$)
	Q1	Q2	Q3	Q4	
BK01	23.3	19.7	9.6	9.2	15.4
BK02	34.1	7.7	3.8	10.1	13.9
BK03	31.6	11.3	5.5	10.1	14.6
BK04	50.5	11.1	5.4	9.6	19.2
BK05	24.6	9.6	4.7	10.6	12.3
BK06	20.3	9.1	4.5	15.0	12.2
BK07	23.2	16.9	8.3	11.5	15.0
BK08	17.5	14.0	6.8	9.6	12.0
BK09	27.6	11.4	5.6	9.5	13.5
BK10	22.7	8.2	4.0	8.7	10.9

Table 4-38: Duynefontein environmental radon concentrations

Monitoring Position	Monitoring Period Average Rn ($Bq.m^{-3}$)				Average Rn ($Bq.m^{-3}$)
	Q1	Q2	Q3	Q4	
DF-01	15.4	10.3	4.8	10.7	10.3
DF-02	22.4	18.9	8.8	9.0	14.7
DF-03	21.1	11.6	5.4	8.3	11.6
DF-04	25.5	13.0	6.0	7.7	13.0
DF-05	26.4	13.5	6.3	9.5	13.9

Monitoring Position	Monitoring Period Average Rn ($Bq.m^{-3}$)				Average Rn ($Bq.m^{-3}$)
	Q1	Q2	Q3	Q4	
DF-06	28.5	15.3	Damaged	7.3	17.0
DF-07	18.1	10.1	4.7	8.0	10.2
DF-08	21.4	11.9	5.5	8.5	11.8
DF-09	16.4	10.0	4.7	8.6	9.9
DF-10	19.7	10.7	5.0	8.1	10.9

The radon concentrations are low and typical of coastal environments. The IAEA provides the following relationship to derive a dose conversion factor [4.16.17]:

Dose per unit m^3 concentration, E_{Rn}, [(µSv/y) per (Bq/m^3)]

= 5.56E-03[(µJ/m^3)/(Bq/m^3)EEC] × F × 8 760 [h/y] × occupancy × 1.1 [(µSv)/(µJ.h/m^3)]

The parameter values and assumptions normally used are:

$F_{(indoors)}$ = 0.4

$F_{(outdoors)}$ = 0.8

$Occupancy_{(fraction\ of\ time\ indoors)}$ = 0.8

$Occupancy_{(fraction\ of\ time\ outdoors)}$ = 0.2

Using these factors in the equation gives the following dose conversion factor:

E_{Rn} = 25.7 µSv per Bq/m^3

The dose conversion factor is only used to provide a comparison between radon concentration results for the different locations and sites. The exact radon dose per location will depend on factors such as occupancy and the degree of equilibrium between radon and its short-lived decay products.

The locations where maximum radon concentrations were measured and estimated doses are as follows:

- Thyspunt: TP04 – 0.409 mSv/y
- Bantamsklip: BK04 – 0.493 mSv/y
- Duynefontein: DF06 – 0.438 mSv/y

These values are significantly less than the global average of 1.15 mSv/y.

4.12.2.2 Radon concentrations measured indoors

Rn-222 can reach high concentrations inside buildings when compared to the outside environment. This is caused by the underlying geology and/or when building material has a high NORM content, especially Ra-226, the precursor of Rn-222. Diffusion of Rn-222 into a building and poor ventilation allow it and its decay products to reach high concentrations in the air.

The Rn-222 air quality inside a number of houses was measured as part of the background radiation monitoring of the three Eskom sites proposed for NPPs. The results are listed in Table 4-39.

Table 4-39: Radon concentrations measured in houses

Buildings Inside Environment	RGM Monitor	Bq.m^{-3}
St Francis House (Diane Str):	39297	11.1
	39299	9.9
	39342	13.4
	39352	12.8
	39357	8.4
	39368	8.4
House used as Eskom office on Thyspunt Site	39291	37.0
	39292	18.9
	39295	29.1
	39339	17.8
	39349	19.2
	39351	25.3
	39359	18.1
	39360	22.1
	39402	30.9
Bantamsklip house on Site: Groot Hagelkraal	39296	14.1
	39298	6.9
	39325	12.8
	39327	15.4
	39328	9.7
House 1 – Duynefontein property	39373	11.9
	39386	12.7
	39397	9.5
House 2 – Duynefontein property	39370	8.7
	39405	9.5
	39372	7.2

The highest concentration was measured in the Eskom house on the Thyspunt site. The Rn-222 concentration is more than double that of the house in St Francis. The difference in average radon concentrations between the two houses could be as a result of the building material used. Clay bricks used for the Eskom house generally have a higher NORM content than cement bricks used for the St Francis house. The radon doses for the two houses are:

- House 1: 274 µSv/y;
- House 2: 624 µSv/y;

Although the radon dose in House 2 is more than double that in House 1, both values are significantly below the global average.

4.13 External radiation

4.13.1 Introduction

Cosmic radiation and the primordial radionuclides in rocks that were synthesised during the creation of the Earth are the main sources of external radiation to humans from the natural background.

Cosmic radiation consists mainly of high-energy particles from the sun and outer space. It interacts with the Earth's atmosphere and gives rise to a secondary radiation of particles and gamma rays at the Earth's surface. Cosmic ray intensity increases with altitude, doubling about every 2 000 m above sea level. Cosmogenic radionuclides such as C-14 and H-3 are produced through the interaction of these cosmic rays with atoms in the atmosphere. These two radionuclides are also released by NPPs [4.16.1.

Spectrometric measurements indicate that the three main components of the external radiation field from NORM, namely from the gamma-emitting radionuclides in the U-238 and Th-232 series and K-40, contribute more or less equally to the externally incident gamma radiation dose to individuals [4.16.13]. The differences in external radiation in a region are attributable to variation in the terrestrial sources, i.e. the concentrations of gamma-emitting radionuclides in the top soil layers. Gamma rays from uranium-rich rock at deeper layers are effectively attenuated by the top soil and rock, such that the dose rate above the soil surface generally arises almost entirely from radionuclides in the top metre of cover.

The global average external radiation dose reported by UNSCEAR is listed in Table 4-40 [4.16.1].

Table 4-40: Cosmic and external terrestrial radiation dose

Dose from External Radiation (mSv/y)			
Cosmic Radiation	**Average**	**Typical Range**	**Comment**
Directly ionizing	0.28	0.3 to 1.0	The range of values is from sea level to high-altitude ground levels
Neutron component	0.1		
Cosmogenic radionuclides	0.01		
Total	0.39		
External terrestrial radiation from NORM	**Average**	**Typical Range**	**Comment**
Outdoors	0.07	0.3 to 1.0	The level of external terrestrial radiation is dependent on the radionuclide composition of soil and building material
Indoors	0.41		
Total	0.48		

The following two types of external radiation surveys were performed at each site:

- TLD monitors at fixed locations, as for the radon monitors, to obtain a quarterly integrated dose.
- Gamma radiation surveys of large surface areas carried out on foot and mounted on vehicles using portable radiation monitoring equipment.

4.13.2 Fixed location time-integrated external radiation results

4.13.2.1 The outside environment

Three TLD monitors were deployed together with the three radon monitors at each monitoring location. Each data set provided information on the integrated gamma/beta radiation exposure (external to the human body) over an approximate three-month period. A summary of the results for the three sites is provided in Table 4-41. The results include both the terrestrial and cosmic radiation components.

Table 4-41: Thyspunt external radiation

Monitoring Location	Monitoring Period (mSv)				Annualised Dose ($mSv.y^{-1}$)
	Q1	Q2	Q3	Q4	
TP-01	0.12	0.21	0.23	0.10	0.56
TP-02	0.13	0.21	0.34	0.11	0.68
TP-03	(monitors damaged)	0.15	0.26	0.12	0.56
TP-04	0.13	0.52	0.30	0.12	0.98
TP-05	0.16	0.26	0.37	0.14	0.81
TP-06	0.13	0.25	0.26	0.14	0.69
TP-07	0.18	0.22	0.31	0.14	0.69
TP-08 (Jeffreys Bay)	0.27	0.36	0.34	0.18	0.93
TP-09	0.18	0.26	0.31	0.15	0.76
TP-10	0.15	0.26	0.31	0.10	0.70

Table 4-42: Bantamsklip external radiation

Monitoring Location	Monitoring Period (mSv)				Annualised Dose ($mSv.y^{-1}$)
	Q1	Q2	Q3	Q4	
BK-01	0.127	0.243	0.283	0.093	0.19
BK-02	0.110	0.173	0.187	0.090	0.14
BK-03	0.135	0.190	0.230	0.090	0.16
BK-04	0.190	0.250	0.270	0.113	0.21
BK-05	0.120	0.193	0.193	0.100	0.15
BK-06	0.185	0.203	0.283	0.127	0.20
BK-07	0.225	0.327	0.330	0.167	0.26
BK-08	Monitors damaged	0.250	0.243	0.093	0.20
BK-09	0.180	0.197	0.190	0.073	0.16
BK-10	0.200	0.190	0.210	0.083	0.17

Table 4-43: Duynefontein external radiation

Monitoring Location (***Figure 4-9***)	Monitoring Period (mSv)				Annualised Dose ($mSv.y^{-1}$)
	Q1	Q2	Q3	Q4	
DF-01	0.11	0.25	0.20	0.12	0.17
DF-02	Monitors damaged	0.20	0.18	0.09	0.16
DF-03	0.28	0.18	0.19	0.11	0.19
DF-04	0.13	0.24	0.23	0.09	0.17
DF-05	0.19	0.23	0.21	0.10	0.18
DF-06	0.18	0.21	0.36	0.09	0.21
DF-07	0.24	0.27	0.31	0.11	0.23
DF-08	0.22	0.25	0.23	0.12	0.21
DF-09	0.17	0.27	0.27	0.13	0.21
DF-10	0.18	0.23	0.18	0.09	0.17

4.13.2.2 Indoor environments

The radiation levels inside four houses were monitored during Quarter 3. The TLD monitors were deployed in different rooms for a period of 3 432 hours. The results are listed in Table 4-44.

Table 4-44: Radiation dose measured inside houses

Inside environment	TLD Dosimeter	Dose for period (mSv)	Annualised dose (mSv/y)
Thyspunt House 1: Dianne Street in St Francis	8100102	0.44	1.12
	8079362	0.30	0.77
	8072092	0.40	1.02
	8508084	0.30	0.77
	8036656 (above granite kitchen top)	0.58	1.48
Thyspunt House 2: Eskom Site Office	8019028	0.31	0.79
	8080367	0.39	1.00
	8533625	0.41	1.05
	8207355	0.39	1.00
	8007584	0.37	0.95
	8305727	0.39	1.00
Duynefontein House 1: Kemp Crescent	8096507	0.39	1.00
	8056921	0.38	0.97
	8315690	0.48	1.23
Duynefontein House 2: Charles Hoffe Street	8096259	0.71	1.80
	8089723	0.38	0.96
	8077340	0.35	0.89
	8310807	0.41	1.04

Gamma radiation measurements using portable equipment were also carried out in all the rooms of each house. The average dose rate was ≤ 1 µSv/h and corresponds with the annual dose derived from the TLD results obtained inside the houses. The relatively high dose rate of 1.48 mSv/y in Thyspunt House 1 was obtained by locating a TLD just above a granite worktop in the kitchen. This higher than typical reading for the granite top illustrates how different building materials can result in different radiation exposures. Other elevated but localised gamma radiation levels were measured in House 2. Ceramic tiles in bathrooms and porcelain toilets, for example, can have more than double the dose rate on contact than other surface areas in a house.

The dose expressed in mSv/y is only applicable to a person who spends 100 per cent of the time inside the house.

4.13.3 Area gamma radiation surveys using portable monitoring equipment

Extensive gamma radiation surveys were carried out using portable monitoring equipment on the sites as well as in the adjacent land areas.

The radiation levels are generally low (< 0.14 µSv/h) when compared to regions in South Africa at higher altitudes and with a different geology, for example Gauteng (altitude) and the Northern Cape (granites). The thicker atmospheric layer at the coast provides more shielding against cosmic radiation and the sandy soils at the three sites and adjacent land areas contain low NORM concentrations. The exceptions at Thyspunt are some localised areas discussed earlier and shown Figure 4-10, Figure 4-11, and Figure 4-12. Contact dose rates as high as 1 µSv/h

could be measured. At Bantamsklip, the highest contact dose rate measured was 0.34 µSv/h on the road surface shown in Figure 4-14.

At Duynefontein, the aggregate used for bitumen-surfaced roads near the site delivers a higher external radiation dose rate than the natural land surface adjacent to the road. This can be ascribed to the aggregate used for road construction that contains higher NORM, e.g. granitic rock. The same type of aggregate is also being used to stabilise the dirt roads that provide access to different areas on the site and Koeberg nature reserve. Although the radiation levels measured on road surfaces are significantly higher than the natural and undisturbed sandy soils in the immediate vicinity of the roads, the levels are still low in absolute terms. The highest dose rate measured on the nature reserve dirt roads is 0.15 µSv/h compared to 0.01 µSv/h on the dunes. The dunes represent the undisturbed environment on the Duynefontein site. Figure 4-30 and Figure 4-31 show the numerous tracks and dirt roads on the Duynefontein site and nature reserve, and two small areas where the highest radiation levels were measured as a result of imported aggregate.

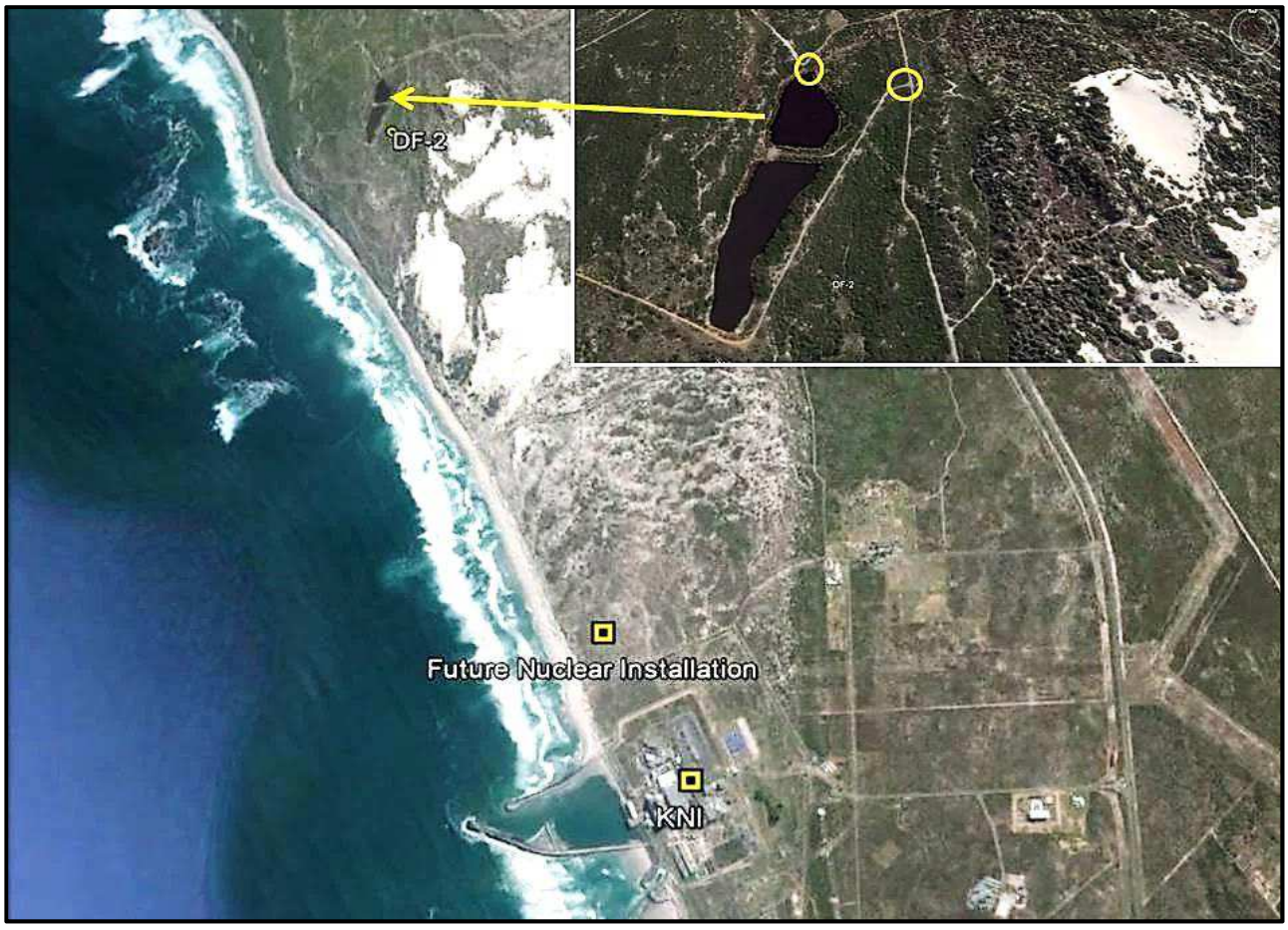

Figure 4-30: Dirt roads in the Koeberg nature reserve and two specific areas with elevated radiation levels indicated

Figure 4-31: Aggregate used for dirt road construction on the dune surfaces of the Duynefontein site

4.14 Airborne particulates

Exposures to high levels of airborne particulate matter (PM) are experienced by many urban populations in both developed and developing countries. People in the Witwatersrand areas in Gauteng residing close to some mine tailings dams are exposed to high PM concentrations. Radioactivity is also associated with the dust from some of these tailings dams due to the elevated levels of NORM in some gold reefs.

At the coastal areas where the three sites are located the situation is different. Sea spray is the most important source of PM at locations within a few hundred metres from the shoreline. Sea spray can contribute up to 80 per cent of particle levels in the air in coastal areas. Sea spray aerosols containing sea salt are finely dispensed particles formed by the action of the wind on the sea and waves breaking on a rocky coastline [4.16.18]. Particulate matter consisting of sea spray is considered not to have similar detrimental health effects as particulate matter in urban and industrial environments.

Sea spray is of particular interest at coastal NPPs since it can act as a carrier of radioactivity in liquid discharge to the sea. Studies have shown that radioactivity concentrations in seawater can be enriched in sea spray [4.16.19]. Airborne particulate monitoring carried out at the sites focused on airborne sea spray particulates concentrations. The atmospheric dispersion of sea spray is illustrated in Figure 4-32. Wave action at a small island (Seal Island) located close to the Koeberg nature reserve shoreline (shown inside the circle) creates airborne sea spray that is observable as a sliver of mist against the setting. It travels in a light breeze for some distance as indicated by the arrow.

Figure 4-32: Atmospheric dispersion of sea spray

The maximum PM concentrations at the Thyspunt site were measured when the wind blew onshore and therefore consisted mainly of sea spray. The concentration dropped significantly when the wind direction changed from an onshore south-westerly direction from the sea to a westerly direction when the wind is mainly over land surfaces. The total suspended particulate (TSP) concentrations measured at homes close to the shore ranged from a low value of 7 µg/m3 to a fairly high value of 134 µg/m3.

TSP measured at a residence in Duynefontein, located approximately 300 m from the seashore, ranged from a very low value of 5 µg/m^3 during light south-south-easterly wind conditions (5 km/h) to TSP spikes as high as 250 µg/m^3 when the wind direction changed to westerly onshore conditions (5 km/h). A monitoring programme for a future NPP at the site should include an initial assessment of the sea spray to determine whether artificial radioactivity can be detected in sea spray and whether it could pose a measureable exposure pathway for humans. This exposure pathway should make a minor contribution to public dose when compared to the other exposure pathways (refer to Part 2 of the report).

4.15 Conclusions based on the results of the reconnaissance surveys

The average doses for people living near the sites are typical of the low background radiation dose for people living at the coast and away from industrial areas. Results for radioactivity concentrations in water, soils, and the air are low when compared to global average values.

Elevated radiation levels from NORM, when compared to the NORM of most soils at the sites, were measured on man-made constructions such as roads and buildings. Aggregate imported into for construction typically contains higher NORM than the natural soils and dunes. This was especially notable for road surfaces at Duynefontein.

An interesting radiation anomaly was identified during mobile gamma radiation surveys of farm areas at Thyspunt. The high NORM concentrations were found in rock samples from an area next to the Grassy Ridge farm dam, and should be investigated further. The radioactivity profile is typical of a heavy mineral sand deposit. It is also recommended that the owner of the farm be aware that the material not be removed, for example to be used as aggregate. A small quarry is

located in the immediate vicinity of the outcrop where the material is found and the possibility exists that the material may be distributed if the quarry increases in size.

The only radiation anomaly that was identified at Bantamsklip during the mobile gamma radiation surveys was on a dirt road from Pearly Beach to Viljoenshof. Radioanalysis of a soil sample confirmed the high NORM concentrations when compared to most of the soils in the area.

Of all the naturally occurring radionuclides measured in samples, Po-210 is probably the most significant. High Po-210 concentrations, a decay product of radon gas (Rn-222) were measured in the marine biota. People whose regular diet includes large amounts of freshly harvested seafood receive a significantly higher dose from ingestion than does the average person.

Radioanalysis of white mussel samples collected Duynefontein indicated one detect of a nuclide that can be attributed to the Koeberg NPP with hundred per cent certainty. It is an isotope of silver, Ag-110m. A comparison of the radiotoxicity of the two nuclides Ag-110m and Po-210 indicates that people whose regular diet includes large amounts of freshly harvested seafood receive a significantly higher dose from Po-210 than from Ag-110m.

The potential radiological impact on abalone farming near Bantamsklip could be a sensitive environmental issue for a future NPP. There is an abalone farm near Gansbaai and another abalone farm is under construction at Buffeljags. It will be important to obtain baseline data on abalone should a NPP be constructed at the site

The two key artificial radionuclides, Cs-137 and Sr-90, could be detected in samples. It is unlikely that the radioactivity discharged during normal operations by a future NPP at either Thyspunt or Bantamsklip, will significantly inflate these ambient levels.

People living near the sites receive a background radiation dose that is estimated to be less than 2 mSv/y and therefore lower than the average global dose.. The annual dose reported by the operating Koeberg NPP and based on allowable discharges of artificial nuclides, is a small fraction of the natural background dose, i.e. < 0.010 mSv/y.

Monitoring of environmental radioactivity prior to commissioning of the NPP will be conducted to establish a baseline. It will include further investigation of site-specific values for important parameters in the dose assessment model of which examples were discussed in this report. This will be followed by on-going monitoring of operational radionuclide discharges and actual levels of radioactivity in environmental media and food commodities. Periodic surveys of demographical changes and habits will also be carried out to determine a realistic critical group for which the annual doses from normal operations have to be reported to the NNR.

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Appendices

Appendix 1:
Environmental Modelling of Radioactive Discharges during Normal Operations – An Overview of the Software Program PC-CREAM 08

Environmental Modelling of Radioactive Discharges during Normal Operations – An Overview of the Software Program PC-CREAM 08

This appendix outlines the methodology employed by the CREAM (Consequences of Releases to the Environment Assessment Methodology) software for the assessment of the radiological consequences of routine releases of radioactive effluents as applied in the computer system, *PC-CREAM 08.*

The first version of *PC-CREAM*, which was completed in 1997, was a PC implementation of a main-frame program for the assessment of radiation doses resulting from routine NPP discharges of radionuclides to the environment. The program was originally designed for use in European countries, where it has been widely used, but copies have also been sold to many other countries world-wide. As a result, there has been considerable feedback from users through training courses and user group meetings regarding many aspects of the system. In response to this feedback and to recent model developments, a revised version of the software has been developed. This new version of *PC-CREAM* known as *PC-CREAM 08* has been used for this site feasibility assessment.

The program has been significantly improved in comparison with earlier versions. It can be used to estimate individual and collective doses arising from discharges of radionuclides to the atmosphere and aquatic environments. It is particularly useful for performing prospective assessments as input to discharge authorisations, such as the AADQs.

PC-CREAM 08 is a complex model that is divided into several parts for ease of use; the principal parts being 'Models' and 'ASSESSOR'. The Models part includes a series of mathematical models that predict the transfer of radionuclides through the environment and provide estimates of activity concentrations in various environmental media following a continuous discharge. The output of these models is then used as input to the dose assessment part of the program, namely ASSESSOR. Exposures to humans can be compared with the dose limits or constraints as required by regulatory criteria.

The models represent the transfer of a wide range of radionuclides through atmospheric, terrestrial, and aquatic pathways. These models enable the spatial and temporal distribution of radioactivity in the environment to be predicted. Default values have been given for many parameters and have been used to determine illustrative results. The choice of such values is necessarily a compromise taking into account the range of possible values. For specific sites and applications, it will often be appropriate to choose alternative values. The models adopted in CREAM are those considered appropriate for routine releases. They have generally been subject to extensive verification and validation.

An overview of each of the models included within *PC-CREAM 08* and the dose assessment part of the program is given in the following sections.

1. PLUME

PLUME is the atmospheric dispersion model used within *PC-CREAM 08*. It is a Gaussian plume model that takes into account the meteorological conditions during the discharge, the roughness of the land surface, and the physical characteristics of the radionuclides being discharged. The model calculates activity concentrations in air, deposition rates, and external gamma dose rates from radionuclides in the cloud (cloud gamma) at various distances downwind of the discharge point. The output from the model can be used as input to ASSESSOR, which combines these

results with site-specific meteorological data and actual discharge rates to calculate actual activity concentrations in air, deposition rates, and cloud gamma dose rates downwind of the discharge point. The deposition rates from PLUME are used to scale the results from the other models, namely RESUS, GRANIS, and FARMLAND, to estimate doses from various exposure routes arising from the discharge of radionuclides to the atmosphere.

2. RESUS

RESUS can be used to estimate activity concentrations in air arising from the resuspension of previously deposited radionuclides. The activity concentrations calculated for a user defined deposition rate, are input to ASSESSOR, which scales them by the actual deposition rate at various locations downwind of the discharge point and combines them with habit data to calculate doses from inhalation of resuspended material.

3. GRANIS

External exposure to gamma radiation from radionuclides deposited on the ground is calculated using the GRANIS model. GRANIS models the transfer of radionuclides through the soil and takes into account the shielding properties of the soil when estimating doses one metre above the soil surface. The doses are calculated based on a user-defined deposition rate. GRANIS is the only model in *PC-CREAM 08* that includes some organ doses as well as effective dose. Effective doses are input to ASSESSOR, which scales them by the actual deposition rate at various locations downwind of the discharge point and combines them with habit data to estimate actual exposures.

4. FARMLAND

FARMLAND is a suite of models that can be used to predict the transfer of radionuclides into terrestrial foods following deposition onto the ground. The food categories considered are those that are most important in the human diet, namely, green vegetables, root vegetables, fruit, grain, cow milk, cow milk products, beef, cattle liver, mutton, and sheep liver. Activity concentrations in each food item are calculated for a user-defined deposition rate. These activity concentrations are input to ASSESSOR, which scales them by the actual deposition rate at various locations downwind of the discharge point and combines them with habit data to calculate ingestion doses.

5. DORIS

The marine dispersion model used in *PC-CREAM 08* is based closely on the MARINA II model. The model can be used to predict the activity concentrations in seawater, sediments, and marine biota for user-defined discharge rates. These activity concentrations are input to ASSESSOR, which scales them by the actual discharge rate and combines them with habit data to calculate doses from ingestion of marine foods, external exposure to beach sediments, and inhalation of sea spray.

6. ASSESSOR

Once activity concentrations in environmental media have been calculated using the various models they can be used in ASSESSOR, the dose assessment part of *PC-CREAM 08*, to calculate effective doses. There are five parts of ASSESSOR to calculate individual and collective doses from discharges to the atmosphere and sea and individual doses from discharges into rivers. Each part of ASSESSOR displays all the model runs that are available for use including the default set. The results of these models are combined with actual discharge rates, site-specific data, habit data, and dose coefficients to calculate effective doses

for the most important exposure pathways. The dose coefficients used are provided in the data tables.

To calculate external effective dose from exposure to beta radiation in the plume (cloud beta), ASSESSOR uses a set of dose coefficients that give the skin-equivalent dose rate per unit air concentration assuming total immersion in the contaminated air. Similarly, the external effective dose from exposure to beta radiation on the ground (deposited from atmosphere or as part of aquatic sediments) is calculated using a set of dose coefficients that give the skin equivalent dose rate per unit deposition at 80 cm above a uniformly contaminated surface. A slightly different approach is used to estimate the external beta and gamma exposures to radionuclides in contaminated fishing gear; these are calculated using empirical formulae and the mean energy of the beta and gamma radiation. The same mean gamma energies are also used to calculate the external gamma dose above aquatic sediments.

The radiological consequences of routine releases of radionuclides are determined using the framework of the system of dose limitation recommended by the International Commission on Radiological Protection (ICRP). The recommendations of ICRP have been issued in Publication 60 (ICRP, 1991). ICRP has since published updated recommendations in Publication 103 and the impact of these have been considered. At the levels of individual dose typically encountered from routine discharge, only the stochastic effects of radiation need to be considered. These comprise fatal and non-fatal cancers in the exposed population and hereditary effects in its descendants.

Appendix 2:

Nuclear Power Plant

Potential Impacts on Groundwater

Nuclear Power Plant Potential Impacts on Groundwater

1 Purpose

The public dose as a result of radioactive discharges during normal operation of a NPP and assessed in the site safety reports, do not include groundwater related exposure pathways. The justification for excluding groundwater is provided in this document.

2 Introduction

General considerations of radioactive discharges from a nuclear installation that may contaminate groundwater systems are discussed in the IAEA Safety Standard Series No. NS-G-3.2 [A2.1]. It states that a discharge of radioactive material from a nuclear power plant may contaminate the groundwater system in the region either directly or indirectly, via earth, atmosphere, or surface water, in the following three pathways:

- Pathway No. 1

  Indirect discharge to the groundwater through seepage and infiltration of surface water that has been contaminated by radioactive material discharged from the nuclear power plant;

- Pathway No. 2

  Infiltration into the groundwater of radioactive liquids from a storage tank or reservoir;

- Pathway No. 3

  Direct release from a nuclear power plant; an accident at the plant might induce such an event, and radioactive material could penetrate into the groundwater system. The protection of aquifers from such events should be considered in the safety analysis for postulated accident conditions, and a geological barrier to provide protection should be considered.

These pathways are discussed in the following sections.

3 Pathway No. 1

The impacts on ground and surface water are generally not included as an exposure pathway during a prospective assessment of public dose for normal operational releases in the case of a nuclear power plant located at the coast. For these plants, the normal liquid discharges are made into the sea. The groundwater exposure pathway for a coastal plant from the deposition of airborne discharges has a negligible contribution to the critical group dose. It has therefore not been included in the *PC-CREAM* code. The types of nuclear facilities where groundwater exposure pathways are important, involve radioactive waste storage facilities or nuclear waste repositories such as Vaalputs.

The negligible contribution from the groundwater exposure pathway is substantiated by information from the sources discussed below.

3.1 EPA Soil Screening Method

A methodology for calculating soil screening levels (SSL) for the migration to groundwater pathway was developed by the U.S. Environmental Protection Agency (EPA) [A2.2]. It allows one to identify radionuclide concentrations levels in soil that have the potential to contaminate

ground water. Migration of radionuclides from soil to groundwater can be envisioned as a two-stage process:

- release of contaminant in soil leachate (e.g. airborne discharge deposition defined by the IAEA as an indirect discharge); and
- transport of the contaminant through the underlying soil and aquifer to a receptor well.

The SSL methodology considers both of these fate and transport mechanisms. These SSLs, expressed as radioactivity concentration per unit mass of soil, are derived from equations combining exposure information assumptions with radiotoxicity data. The methodology provides a framework for screening soils contaminated with radionuclides that encompasses both simple and more detailed approaches for calculating site-specific SSLs, and generic SSLs for use where site-specific data are limited. In identifying and managing risks at sites, EPA considers a spectrum of radionuclide concentrations. SSLs identify the lower bound of the levels of radioactivity concentrations in soil below which no further study is warranted because of the negligible human risk.

Dilution and attenuation factors (DAFs) were developed with groundwater dispersion codes and these form the basis of SSLs. As radionuclides in soil leachate move through soil and ground water, they are subjected to physical, chemical, and biological processes that tend to reduce the eventual contaminant concentration at the receptor point (i.e. drinking water well). These processes include adsorption onto soil and aquifer media, chemical transformation (e.g. hydrolysis and precipitation), biological degradation, and dilution due to mixing of the leachate with ambient groundwater. The reduction in concentration can be expressed by a DAF, which is defined as the ratio of radionuclides concentration in soil leachate to the concentration in groundwater at the receptor point. When calculating SSLs, a DAF is used to back-calculate the target soil leachate concentration from an acceptable groundwater concentration. For example, if the acceptable groundwater concentration is 10 mBq/ℓ and the DAF is 10, the target leachate concentration (SSL) in the soil would be 100 mBq/ℓ.

The highest deposition rates and soil radioactivity concentrations for the important radionuclides from normal airborne discharges, i.e. those with a half-life that can result in build-up in soil radioactivity over a service life of 60 years, are listed in Table A2-1. The radioactivity concentrations per unit mass are very low. A comparison with EPA SSLs clearly demonstrates that the soil radioactivity levels are orders of magnitude less than the SSLs and it can be concluded that there will be a negligible impact on groundwater.

Table A2-1: Soil Radioactivity Concentrations and SSL

Nuclide	Deposition rate; Bq/m^2-s	Soil radioactivity concentration; Bq/kg following 60 y of operation	SSL Bq/kg	Factor by which the actual soil activity is less than the SSL
				20 DAF
Co-60	2.06E-08	1.10E-02	22.2	2011
Cs-137 (+D)	2.82E-08	5.22E-02	1509.6	28936
Sr-90	1.17E-10	2.27E-04	7.1	31298

3.2 Canadian Public Dose Methodology

A comprehensive document for public dose assessment in respect of CANDU reactors provides further detail on the limited transfer of airborne-deposited radioactivity to groundwater Table A2-

3 [A2.3]. This document gives guidance for COG-member facilities (CANDU Operating Group) for calculation of derived release limits for radionuclide releases to the atmosphere and to surface water. The derived release limits are a regulatory requirement and are defined as release rates that are considered to be protective of the public.

The document lists values for transfer parameters between various environmental compartments for a large number of radionuclides. One of these parameters is for transfer from surface soil to a typical groundwater well (30-metre deep). The parameter is designated as P3area2w (Surface Soil to a Groundwater Well; $Bq.L^{-1}$ per $Bq.m^{-2}$) Table A2-2 lists typical values of this parameter for a range of radionuclides. When considering the principal radionuclides in the NPP discharges, it is clear that their transfer parameter values are extremely small or zero. Those radionuclides for which the transfer parameters are not zero, are mainly for extremely long half-life radionuclides, a factor that is important when considering the slow movement of groundwater contamination plumes.

Table A2-2: Transfer parameter values for soil to well water

Radionuclide	$P_{3area2w}$ (m2•L-1)	Radionuclide	$P_{3area2w}$ (m2•L-1)	Radionuclide	$P_{3area2w}$ (m2•L-1)
H-3*	0	Tc-99m	0	Gd-159	0
Be-7	0	Ru-103	0	Tb-160	0
N-13	0	Ru-106	0	Hf-175	0
C-14*	1.64E-04	Ag-110m	0	Hf-181	0
Na-22	0	Sn-113	0	Hg-203	0
Na-24	0	Sb-122	0	Pa-233	0
P-32	0	Sb-124	0	Ra-224	0
S-35	0	Sb-125	0	Ra-225	0
Cl-36	6.68E-04	Te-132	0	Ra-226	0
Sc-46	0	I-125	0	Ra-228	0
Sc-47	0	I-129	2.12E-04	Th-228	0
Cr-51	0	I-131	0	Th-229	0
Mn-54	0	I-132	0	Th-232	1.17E-06
Fe-55	0	I-133	0	Th-234	0
Fe-59	0	I-134	0	U-232	0
Co-58	0	I-135	0	U-233	3.06E-04
Co-60	0	Cs-134	0	U-234	3.09E-04
Ni-63	0	Cs-135	8.57E-07	U-235	3.16E-04
Zn-65	0	Cs-136	0	U-236	3.16E-04
Se-75	0	Cs-137	0	U-238	3.16E-04
As-76	0	Cs-138	0	Np-237	2.92E-04
Br-82	0	Ba-140	0	Np-239	0
Rb-88	0	La-140	0	Pu-238	0
Sr-89	0	Ce-141	0	Pu-239	7.70E-08
Sr-90	0	Ce-143	0	Pu-240	3.40E-12
Y-90	0	Ce-144	0	Pu-241	0
Y-91	0	Pr-143	0	Pu-242	2.52E-06
Zr-95	0	Pm-147	0	Am-241	0
Nb-94	1.88E-06	Eu-152	0	Am-243	1.02E-26
Nb-95	0	Eu-154	0	Cm-242	0
Mo-99	0	Eu-155	0	Cm-244	0
Tc-99	1.51E-02	Gd-153	0		

3.3 Tritium as an Exception

Airborne discharges that comply with annual allowable discharge quantities such as those from a ventilation stack, cooling tower, or condenser air ejectors, may result in measurable atmospheric deposition of nuclear installation related radionuclides (including tritium) near the nuclear installation(s) and mainly inside the owner-controlled area.

Over the last ten years, several nuclear power plants in the United States of America have detected small quantities of radioactivity in soil and groundwater, also from other inadvertent releases of radioactive material [A2.4]. The contamination results from operational events and subsurface leaks of fluids contaminated with radioactivity. Investigation has shown that these contamination incidents have an insignificant radiation dose consequence. However, the USA nuclear power industry has entered into a voluntary initiative to implement groundwater monitoring programmes at all sites in order to assure local stakeholders that the public health and safety are being protected. Tritium has been a primary radionuclide of focus in these efforts, as it is a common radioisotope found in airborne and waterborne effluent pathways. In recent years, tritium in water vapour and rainwater around power reactors have been detected as a result of normal airborne discharges complying with permitted annual allowable discharge quantities. Tritium can be recaptured in water vapour downwind of the nuclear power reactor, including rainwater samples. It has been found that these tritium concentrations from nuclear power reactors do not present health and safety risks.

During surface water monitoring for tritium concentrations as part of the site's ambient radiation monitoring programme, no significant difference could be detected between tritium levels in surface water dams located close to Koeberg NPP in the prevailing wind direction, and those fairly distant from Koeberg NPP and on the Thyspunt and Bantamsklip sites. The only high concentration relative to the other samples was for a sample collected from the Koeberg NPP cooling water outfall (seawater sample). The results are shown in Table A2-3 and Figure A2-1. The results relevant to Koeberg NPP are highlighted. Note that one tritium unit (T.U.) is equivalent to 0.11 Bq/ℓ). No surface water ponds near Koeberg NPP that were sampled indicate elevated H-3 concentrations. The dose from any of these fresh water sources is trivial.

Table A2-3: H-3 in surface water at the three sites (iThemba LABS)

Laboratory	Sample	Sample Description	Tritium	
Number	Identification		(T.U.)	
PSI 001	1 DF-WS-3-2	H-3 Seawater (KNPS Outlet)	23.5	±0.9
PSI 002	2 DF-WS-3-3	H-3 Seawater (Bokpunt)	0.9	±0.2
PSI 003	3 DF-WS-3-4	H-3 Seawater (KNPS North)	0.9	±0.2
PSI 004	4 DF-WS-3-5	H-3 KNPS Bird Hide Dam (South Section)	2.6	±0.3
PSI 005	5 DF-WS-3-6	H-3 KNPS Site's Office Dam	2.4	±0.3
PSI 006	6 DF-WS-3-7	H-3 Duynefontein Plot Dam	1.4	±0.3
PSI 007	7 DF-WS-3-8	H-3 Langeberg Farm Dam	2.4	±0.3
PSI 008	8 DF-WS-3-9	H-3 KNPS Bird Hide Dam (North Section)	1.3	±0.3

Laboratory	Sample	Sample Description	Tritium	
PSI 009	9 DF-WS-3-10	H-3 Municipal Water Duynefontein (tap)	1.6	±0.3
PSI 010	10 BK-WS-3-2	H-3 Dam Pearly Beach Upper - 5 L	0.6	±0.2
PSI 011	11 BK-WS-3-4	H-3 Dam KD	0.6	±0.2
PSI 012	12 BK-WS-3-5	H-3 Buffelsjacht Seawater	0.9	±0.2
PSI 013	13 BK-WS-3-7	H-3 Die Dam Seawater	0.3	±0.2
PSI 014	14 BK-WS-3-8	H-3 Dam Pearly Beach Lower - 5 L	0.7	±0.2
PSI 015	15 BK-WS-3-10	H-3 Bantamsklip Seawater	0.4	±0.2
PSI 016	16 BK-WS-3-11	H-3 Pearly Beach Seawater	0.4	±0.2
PSI 017	17 TP-WS-3-1	H-3 Cape St Francis Seawater	0.2	±0.2
PSI 018	18 TP-WS-3-2	H-3 Oyster Bay Seawater	0.3	±0.2
PSI 019	19 TP-WS-3-3	H-3 Oyster Bay Lagoon Water	0.9	±0.2
PSI 020	20 TP-WS-3-4	H-3 Cilliers Farm Dam	0.7	±0.2
PSI 021	21 TP-WS-3-5	H-3 Duneslack Wetland – Dune Ridge Pool	1.3	±0.3
PSI 022	22 TP-WS-3-7	H-3 St Francis Seawater	0.6	±0.2
PSI 023	23 TP-WS-3-8	H-3 Eskom Dam	1.3	±0.3
PSI 024	24 TP-WS-3-10	H-3 Duneslack Wetland - Crystal Pool	2.0	±0.3
PSI 025	25 TP-WS-3-13	H-3 Dune Ridge Guest House Rain Water Tank	1.4	±0.3

Note: TP = Thyspunt; DF = Duynefontein; BK = Bantamsklip

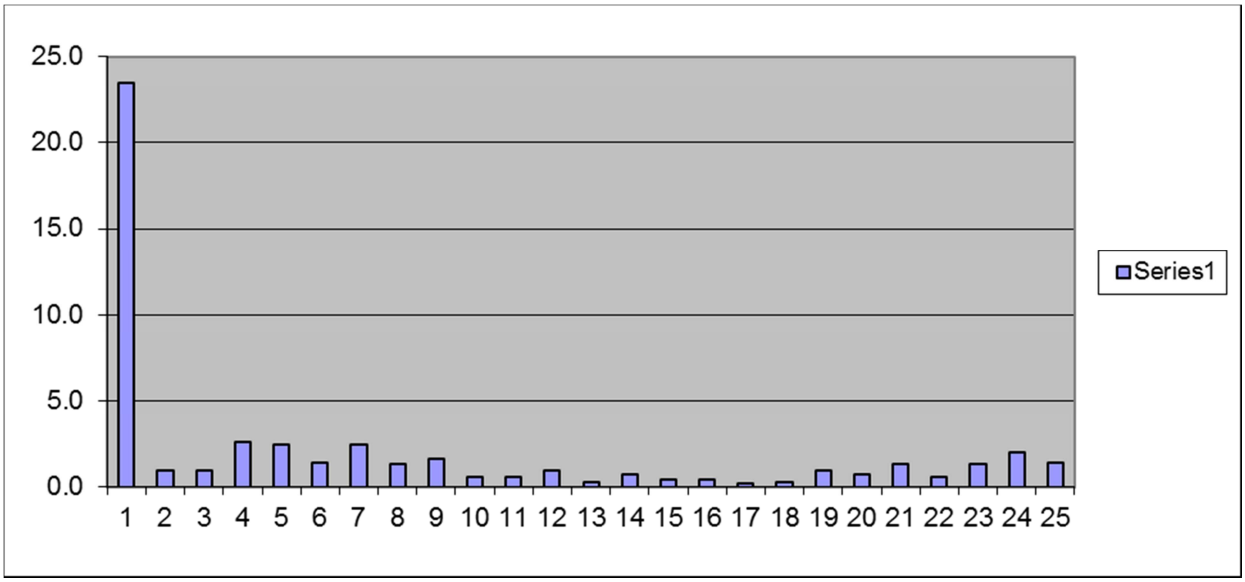

Figure A2-1: H-3 concentrations in surface water (T.U.)

4 Pathways No. 2 and No. 3

Groundwater contamination is of particular importance at nuclear waste and other radioactive material disposal facilities, e.g. geological isolation of high-level nuclear waste, shallow land burial of low- and intermediate-level waste, and uranium mining and milling waste [Reference A2.5]. Consideration given to nuclear power reactor accident releases to groundwater differs from those of nuclear waste disposal and other fuel cycle events in several important respects:

- The risk of contamination will exist only for the lifetime of the nuclear power plant. Administrative controls would be in effect during this period; therefore mitigative measures could presumably be taken should an accidental release occur.
- The radioisotopes of importance in nuclear power plant liquid pathway accidents are generally those with high dose coefficients and/or half-lives of years to tens of years. These notably are H-3, Cs-134, Cs-137, Sr-89, Sr-90, and Ru-106. Unlike nuclear waste, long-lived radionuclides, actinides, and transuranics have been shown to be of much lower importance [Reference A2.5].

Potential contamination of water resources from abnormal operational occurrences (AOOs) and accidents at nuclear power plants do not have a significant contribution to the radiation dose when compared to the other exposure pathways.

Several GEN III nuclear power reactor types have been assessed for a postulated accidental release of radioactive effluent [Reference A2.6]. The radioactive liquid effluent with the highest potential exposure consequences to off-site water users is associated with the liquid waste management system and comprises a mixture of fission and activation products with a wide range of half-lives. The liquid effluent-containing tanks postulated to fail are located below ground level such that a liquid release would enter the groundwater and then be subject to groundwater transport off-site with radionuclide concentrations being attenuated by the processes of radioactive decay, adsorption, and dispersion. Evaluations of these postulated releases have been completed and included in the licence applications for 17 new nuclear power reactor sites. Results of these analyses indicate that groundwater travel times vary widely from site to site and that groundwater to surface water pathways are present for many of the sites. Comparisons of predicted radionuclide concentrations at off-site receptor locations to regulatory limits indicate compliance with the dose limits for an individual member of the public, with tritium having the potential for the greatest dose contribution. One of the GEN III designs did not include this accident in their design assessment and stated that the design features would preclude an accidental release.

Further evidence was provided by the Chernobyl accident that, for a given accident, consequences of release to the groundwater pathway typically present smaller risks than release to the airborne pathway. Findings on water resources following the Chernobyl accident support this assumption [Reference A2.7]. Activity concentrations of soluble radionuclides measured in drinking water showed that their contribution to internal dose was usually negligible compared with that associated with the intake of food. Drinking water contributed approximately 1 per cent to the dose of critical groups in some of the worst affected areas compared to external radiation from soil (50 per cent) and food ingestion (24 per cent). Short-lived radionuclides do not affect groundwater supplies, because groundwater dwell times are much longer than their physical decay time. In most of the studied areas, the activity concentration in groundwater was significantly lower than in most river and lake systems. Radionuclides in irrigation water did not add significantly to radioactivity in crops in comparison with that which

had been initially deposited in atmospheric fallout and subsequently taken up in situ from the soil.

A book recently published deals comprehensively with the radioactivity impact on the environment of the Fukushima accident [Reference A2.8]. All environmental compartments are discussed extensively except for groundwater impact, which is dealt with only briefly because of the limited impact on groundwater. The following section, in which the limited impact on groundwater is discussed, is quoted:

> ***5.1.6 Radionuclides in Groundwater***
>
> *The MEXT conducted emergency monitoring of groundwater in Fukushima prefecture during the period of June/July 2011. All the measurement data for groundwater was less than the detection limit (10 Bq/ℓ). These data suggest that levels of the Fukushima-derived radionuclides in groundwater in Fukushima prefecture were less than the provisional limit value for restriction of drinking water, although actual levels of the Fukushima-derived radionuclides are still unknown.*
>
> *Radionuclides in 41 spring samples collected in the period 21 to 24 June were measured. Both I-131 and radiocesium concentrations were < 10 Bq/ℓ. The data suggest that levels of the Fukushima-derived radionuclides in spring in Fukushima prefecture were less than the provisional limit value for restrict of drinking water, although actual levels of the Fukushima-derived radionuclides are still unknown.*

Irrespective of the information provided here, the next licensing phase involving the safety analysis of a specific nuclear installation design will include an assessment of a postulated accidental release of radioactive liquid effluent in ground and surface waters. It will have to be demonstrated that the dose to an individual member of the public does not exceed regulatory limits when considering all postulated initiating events that can lead to AOOs and accidents.

References specific to Appendix 2

A2.1 IAEA Safety Standard Series No. NS-G-3.2, 2002. Dispersion of Radioactive Material in Air and Water and Consideration of Population Distribution in Site Evaluation for Nuclear Power Plants. Vienna.

A2.2 Unites States Environmental Protection Agency, 2000. Soil Screening Guidance for Radionuclides: Technical Background Document EPA/540-R-00-006. Washington.

A2.3 CANDU Owners Group Inc. 2008. Derived Release Limits Guidance Report COG-06-3090-R2-I. Derived Release Limits Guidance. Quebec

A2.4 Electric Power Research Institute, 2008. Groundwater Protection Guidelines for Nuclear Power Plants. Report No. 1016099. Palo Alto, California USA.

A2.5 U.S. Nuclear Regulatory Commission 1983. Radiological Assessment – A Textbook on Environmental Dose Analysis. NUREG/CR-3332 ORNL-5968. Washington, D.C. 20555 .

A2.6 S.W. Taylor, G.A. Day, A.N. Findikakis, G.A. McLane, and L.E. Young. Assessing Postulated Accidental Releases of Radioactive. A presentation at Liquid Effluents from Nuclear Power Plants. World Environmental and Water Resources Congress 2009: Great Rivers © 2009 ASCE.

A2.7 International Atomic Energy Agency (2006), Environmental Consequences of Chernobyl Accident and their Remediation: Twenty Years of Experience. Report of the Chernobyl Forum Expert Group ‘Environment’. Vienna.

A2.8 Pavel et al. 2013. Fukushima Accident: Radioactivity Impact on the Environment (ISBN 978-0-12-408132-1)

Appendix 3:
Source Term for Normal Operational Discharges

Source Term for Normal Operational Discharges

The procedure used to estimate a bounding source term for the site that represents 33 000 MWth energy to be generated by the nuclear installation, is as follows:

1. The normal operation and continuous annual discharges, liquid and airborne, by the two reference reactors types that constitute source terms to the environmental.
2. AP1000 Source Term: Normal Continuous Annual Discharge (Bq/y)
    a. EPR Source Term: Normal Continuous Annual Discharge (Bq/y)
3. The radionuclide specific discharges, liquid and airborne, are then expressed as source terms per unit energy, MWth:
    a. AP1000 Radionuclide Specific Source Term per MWth (3415 MWth/Reactor Unit)
    b. EPR Radionuclide Specific Source Term per MWth (4500 MWth/Reactor Unit)
4. The total source term for each radionuclide discharged as liquid or airborne when generating 33000 MWth by either the AP1000 or EPR Source Term is calculated.
5. A maximum radionuclide specific source term for the site is compiled by selecting the maximum radionuclide value when comparing the two reactor types should the total energy of 33 000 MWth be generated by either the AP1000 or EPR.

The results of the procedure are shown in Table A3-1 and Table A3-2.

Table A3-1: Site enveloping source term for normal continuous discharges:

Liquid

Radionuclide	AP1000 Source Term: Normal Continuous Annual Discharge (Bq/y)	EPR Source Term Normal: Continuous Annual Discharge (Bq/y)	AP1000 Radionuclide Specific Source Term per MWth (3415 MW_{th}/Reactor Unit)	EPR Radionuclide Specific Source Term per MWth (4500 MW_{th}/Reactor Unit)	AP1000 Source Term for total energy of 33000 MW_{th}	EPR Source Term for total energy of 33000 MW_{th}	Maximum Source Term when comparing two Reactor types for equivalent energy of 33000 MW_{th}
Cr-51	2.40E+05	–	7.03E+01	–	2.32E+06	–	2.32E+06
Mn-54	1.60E+05	–	4.69E+01	–	1.55E+06	–	1.55E+06
Co-58	8.50E+06	8.67E+07	2.49E+03	1.93E+04	8.21E+07	6.36E+08	6.36E+08
Co-60	3.20E+06	1.02E+08	9.37E+02	2.27E+04	3.09E+07	7.48E+08	7.48E+08
Sr-89	1.10E+06	–	3.22E+02	–	1.06E+07	–	1.06E+07
Sr-90	4.40E+05	–	1.29E+02	–	4.25E+06	–	4.25E+06
Zr-95	3.70E+05	–	1.08E+02	–	3.58E+06	–	3.58E+06
Nb-95	9.30E+05	–	2.72E+02	–	8.99E+06	–	8.99E+06
Cs-134	8.50E+05	7.96E+07	2.49E+02	1.77E+04	8.21E+06	5.84E+08	5.84E+08
Cs-137	1.30E+06	7.14E+07	3.81E+02	1.59E+04	1.26E+07	5.24E+08	5.24E+08
Ba-140	1.60E+05	–	4.69E+01	–	1.55E+06	–	1.55E+06
Kr-85m	2.40E+10	–	7.03E+06	–	2.32E+11	–	2.32E+11
Kr-85	3.10E+12	3.13E+12	9.08E+08	6.96E+08	3.00E+13	2.30E+13	3.00E+13
Kr-87	1.90E+10	–	5.56E+06	–	1.84E+11	–	1.84E+11
Kr-88	2.70E+10	–	7.91E+06	–	2.61E+11	–	2.61E+11
Xe-131m	1.40E+12	6.75E+10	4.10E+08	1.50E+07	1.35E+13	4.95E+11	1.35E+13
Xe-133m	1.10E+11	–	3.22E+07	–	1.06E+12	–	1.06E+12
Xe-133	1.30E+12	1.42E+13	3.81E+08	3.16E+09	1.26E+13	1.04E+14	1.04E+14

Radionuclide	AP1000 Source Term: Normal Continuous Annual Discharge (Bq/y)	EPR Source Term Normal: Continuous Annual Discharge (Bq/y)	AP1000 Radionuclide Specific Source Term per MWth (3415 MW_{th}/Reactor Unit)	EPR Radionuclide Specific Source Term per MWth (4500 MW_{th}/Reactor Unit)	AP1000 Source Term for total energy of 33000 MW_{th}	EPR Source Term for total energy of 33000 MW_{th}	Maximum Source Term when comparing two Reactor types for equivalent energy of 33000 MW_{th}
Xe-135m	1.90E+11		5.56E+07	–	1.84E+12	–	1.84E+12
Xe-135	4.40E+11	4.46E+12	1.29E+08	9.91E+08	4.25E+12	3.27E+13	3.27E+13
Xe-137	4.80E+10	–	1.41E+07	–	4.64E+11	–	4.64E+11
Xe-138	8.90E+10	–	2.61E+07	–	8.60E+11	–	8.60E+11
Ar-41	1.30E+12	6.53E+11	3.81E+08	1.45E+08	1.26E+13	4.79E+12	1.26E+13
I-131	1.90E+08	1.82E+08	5.56E+04	4.04E+04	1.84E+09	1.33E+09	1.84E+09
I-133	3.10E+08	2.18E+08	9.08E+04	4.84E+04	3.00E+09	1.60E+09	3.00E+09
H-3	1.80E+12	3.00E+12	5.27E+08	6.67E+08	1.74E+13	2.20E+13	2.20E+13
C14	2.70E+11	9.00E+11	7.91E+07	2.00E+08	2.61E+12	6.60E+12	6.60E+12

Table A3-2: Site enveloping source term for normal continuous discharges: Airborne

Radionuclide	AP1000 Source Term: Normal Continuous Annual Discharge (Bq/y)	EPR Source Term Normal: Continuous Annual Discharge (Bq/y)	AP1000 Radionuclide Specific Source Term per MWth (3415 MW_{th}/Reactor Unit)	EPR Radionuclide Specific Source Term per MWth (4500 MW_{th}/Reactor Unit)	AP1000 Source Term for total energy of 33000 MW_{th}	EPR Source Term for total energy of 33000 MW_{th}	Maximum Source Term when comparing two Reactor types for equivalent energy of 33000 MW_{th}
Cr-51	2.40E+05	–	7.03E+01	–	2.32E+06	–	2.32E+06
Mn-54	1.60E+05	–	4.69E+01	–	1.55E+06	–	1.55E+06
Co-58	8.50E+06	8.67E+07	2.49E+03	1.93E+04	8.21E+07	6.36E+08	6.36E+08
Co-60	3.20E+06	1.02E+08	9.37E+02	2.27E+04	3.09E+07	7.48E+08	7.48E+08
Sr-89	1.10E+06	–	3.22E+02	–	1.06E+07	–	1.06E+07
Sr-90	4.40E+05	–	1.29E+02	–	4.25E+06	–	4.25E+06
Zr-95	3.70E+05	–	1.08E+02	–	3.58E+06	–	3.58E+06
Nb-95	9.30E+05	–	2.72E+02	–	8.99E+06	–	8.99E+06
Cs-134	8.50E+05	7.96E+07	2.49E+02	1.77E+04	8.21E+06	5.84E+08	5.84E+08
Cs-137	1.30E+06	7.14E+07	3.81E+02	1.59E+04	1.26E+07	5.24E+08	5.24E+08
Ba-140	1.60E+05	–	4.69E+01	–	1.55E+06	–	1.55E+06
Kr-85m	2.40E+10	–	7.03E+06	–	2.32E+11	–	2.32E+11
Kr-85	3.10E+12	3.13E+12	9.08E+08	6.96E+08	3.00E+13	2.30E+13	3.00E+13
Kr-87	1.90E+10	–	5.56E+06	–	1.84E+11	–	1.84E+11
Kr-88	2.70E+10	–	7.91E+06	–	2.61E+11	–	2.61E+11
Xe-131m	1.40E+12	6.75E+10	4.10E+08	1.50E+07	1.35E+13	4.95E+11	1.35E+13
Xe-133m	1.10E+11	–	3.22E+07	–	1.06E+12	–	1.06E+12
Xe-133	1.30E+12	1.42E+13	3.81E+08	3.16E+09	1.26E+13	1.04E+14	1.04E+14
Xe-135m	1.90E+11		5.56E+07	–	1.84E+12	–	1.84E+12
Xe-135	4.40E+11	4.46E+12	1.29E+08	9.91E+08	4.25E+12	3.27E+13	3.27E+13
Xe-137	4.80E+10	–	1.41E+07	–	4.64E+11	–	4.64E+11
Xe-138	8.90E+10	–	2.61E+07	–	8.60E+11	–	8.60E+11
Ar-41	1.30E+12	6.53E+11	3.81E+08	1.45E+08	1.26E+13	4.79E+12	1.26E+13
I-131	1.90E+08	1.82E+08	5.56E+04	4.04E+04	1.84E+09	1.33E+09	1.84E+09
I-133	3.10E+08	2.18E+08	9.08E+04	4.84E+04	3.00E+09	1.60E+09	3.00E+09
H-3	1.80E+12	3.00E+12	5.27E+08	6.67E+08	1.74E+13	2.20E+13	2.20E+13
C14	2.70E+11	9.00E+11	7.91E+07	2.00E+08	2.61E+12	6.60E+12	6.60E+12

Appendix 4:
Critical Groups Habit and Food Consumption Data considered in the Site Models for Dose Assessment

Table A4-1: Occupancy and exposure factors for atmospheric discharges resulting in maximum dose

Age Group	Time at location (h/y)	Fraction of time spent indoors	Cloud gamma location factor	Deposited gamma location factor	Cloud beta location factor	Deposited beta location factor	Inhalation location factor
Infant	8.76E+03	0	1	1	1	1	1
Child	8.76E+03	0	1	1	1	1	1
Adult	8.76E+03	0	1	1	1	1	1

Table A4-2: Inhalation rates

Inhalation rates (m^3/y)	Infant	Child	Adult
	1.90E+03	5.60E+03	8.10E+03

Inhalation of sea spray	Age group	Inhalation rate (m^3/y)	Distance from the sea (m)	Time spent near the sea (h/y)
	Adult	8.10E+03	1.00E+02	2.00E+03
	Child	5.60E+03	1.00E+02	2.00E+03
	Infant	1.90E+03	1.00E+02	2.00E+03

Table A4-3: Terrestrial food ingestion rates

Food Ingestion	Food Fraction Produced Locally	Infant Ingestion Rate (kg/y)	Child Ingestion Rate (kg/y)	Adult Ingestion Rate (kg/y)
Beef	1	3	15	15
Cow milk	1	130	110	95
Cow milk products	1	15	15	20
Cattle liver	1	1	2	3
Sheep meat	1	1	4	8
Sheep liver	1	1	2	3
Green vegetables	1	5	15	35
Root vegetables	1	15	50	60
Grain	1	15	45	50
Fruit	1	9	15	20

Table A4-4: Occupancy and exposure factors for liquid discharges to the sea

External Exposure Pathway	Age group	Local occupancy (h/y)
External beta from beaches	Adult	2.00E+03
External gamma from beaches		2.00E+03
External beta from fishing equipment		2.00E+03
External gamma from fishing equipment		2.00E+03
External beta from beaches	Child	2.00E+03
External gamma from beaches		2.00E+03
External beta from fishing equipment		1.00E+02
External gamma from fishing equipment		1.00E+02
External beta from beaches	Infant	2.00E+03
External gamma from beaches		2.00E+03
External beta from fishing equipment		0.00E+00
External gamma from fishing equipment		0.00E+00

Table A4-5: Critical group food consumption data used in dose assessment models

Ingestion pathway	Infant	Child	Adult
Terrestrial food ingestion rate (kg/y) per age group			
Beef	3	15	15
Cow milk	130	110	95
Cow milk products	15	15	20
Cattle liver	1	2	3

Ingestion pathway	Infant	Child	Adult
Terrestrial food ingestion rate (kg/y) per age group			
Sheep meat	1	4	8
Sheep liver	1	2	3
Green vegetables	5	15	35
Root vegetables	15	50	60
Grain	15	45	50
Fruit	9	15	20

	Age group	Food	Ingestion rate (kg/y)
Seafood	Adult	fish	100
		crustaceans	5
		molluscs	22
	Child	fish	60
		crustaceans	11
		molluscs	5
	Infant	fish	20
		crustaceans	0
		molluscs	0

Appendix 5:
An Example of the Different Exposure Pathways' Dose for Normal Continuous Discharges

Table A5-1: Thyspunt dose for all age groups from airborne exposure pathways (µSv/y)

Plume: 60 y	CG	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Re-suspension	Cattle liver	Beef	Cow milk	*Cow milk products*	Fruit	*Grain*	Green vegetables	Root vegetables	Sheep liver	Sheep meat
Adult	1	1.33E-01	3.40E-02	1.35E-03	1.13E-02	1.25E-01	1.22E-06	1.03E-02	1.12E-01	1.61E-01	*4.84E-01*	1.46E-02	*2.74E+00*	8.85E-02	6.46E-02	1.03E-02	9.35E-02
	2	1.38E-01	3.40E-02	1.39E-03	9.45E-03	1.10E-01	1.14E-06	1.06E-02	1.16E-01	1.66E-01	*4.98E-01*	1.51E-02	*2.84E+00*	9.16E-02	6.70E-02	1.07E-02	9.67E-02
	3	8.62E-02	2.17E-02	8.74E-04	8.30E-03	8.09E-02	8.42E-07	6.64E-03	7.23E-02	1.05E-01	*3.15E-01*	9.45E-03	*1.77E+00*	5.73E-02	4.18E-02	6.69E-03	6.05E-02
	4	1.18E-01	2.56E-02	1.20E-03	5.65E-03	5.01E-02	9.11E-07	9.04E-03	9.84E-02	1.41E-01	*4.23E-01*	1.29E-02	*2.42E+00*	7.80E-02	5.71E-02	9.08E-03	8.22E-02
	5	1.24E-01	2.84E-02	1.26E-03	7.24E-03	6.79E-02	1.01E-06	9.52E-03	1.04E-01	1.49E-01	*4.47E-01*	1.35E-02	*2.54E+00*	8.21E-02	6.01E-02	9.57E-03	8.66E-02
	6	1.28E-01	3.25E-02	1.29E-03	8.99E-03	1.08E-01	1.07E-06	9.84E-03	1.07E-01	1.54E-01	*4.62E-01*	1.40E-02	*2.63E+00*	8.48E-02	6.21E-02	9.90E-03	8.96E-02
	7	8.68E-02	2.26E-02	8.70E-04	6.49E-03	8.60E-02	7.24E-07	6.68E-03	7.27E-02	1.05E-01	*3.13E-01*	9.49E-03	*1.78E+00*	5.75E-02	4.21E-02	6.72E-03	6.08E-02
	8	5.05E-02	1.34E-02	5.03E-04	4.14E-03	6.17E-02	4.21E-07	3.89E-03	4.23E-02	6.08E-02	*1.82E-01*	5.52E-03	*1.04E+00*	3.35E-02	2.45E-02	3.91E-03	3.54E-02
	9	2.58E-01	7.14E-02	2.59E-03	2.00E-02	2.62E-01	2.29E-06	1.98E-02	2.16E-01	3.12E-01	*9.35E-01*	2.82E-02	*5.30E+00*	1.71E-01	1.25E-01	2.00E-02	1.81E-01
	10	3.96E-01	1.06E-01	3.99E-03	3.51E-02	4.45E-01	3.62E-06	3.05E-02	3.32E-01	4.79E-01	*1.44E+00*	4.34E-02	*8.13E+00*	2.63E-01	1.92E-01	3.07E-02	2.78E-01
15 y	1	1.49E-01	3.40E-02	1.35E-03	1.52E-02	1.25E-01	1.64E-06	7.89E-03	9.44E-02	1.40E-01	*5.37E-01*	1.23E-02	*2.29E+00*	5.97E-02	3.93E-02	8.01E-03	7.94E-02
	2	1.55E-01	3.40E-02	1.35E-03	1.27E-02	1.10E-01	1.53E-06	8.17E-03	9.77E-02	1.43E-01	*5.48E-01*	1.28E-02	*2.38E+00*	6.17E-02	4.07E-02	8.27E-03	8.20E-02
	3	9.63E-02	3.36E-02	1.34E-03	1.11E-02	8.10E-02	1.13E-06	5.12E-03	6.12E-02	9.06E-02	*3.50E-01*	8.01E-03	*1.48E+00*	3.86E-02	2.54E-02	5.20E-03	5.16E-02
	4	1.32E-01	3.37E-02	1.34E-03	7.53E-03	5.01E-02	1.23E-06	6.93E-03	8.29E-02	1.22E-01	*4.65E-01*	1.09E-02	*2.03E+00*	5.25E-02	3.47E-02	7.00E-03	6.95E-02
	5	1.38E-01	3.38E-02	1.35E-03	9.69E-03	6.79E-02	1.37E-06	7.30E-03	8.74E-02	1.28E-01	*4.92E-01*	1.14E-02	*2.13E+00*	5.53E-02	3.66E-02	7.38E-03	7.33E-02
	6	1.43E-01	3.39E-02	1.35E-03	1.21E-02	1.08E-01	1.44E-06	7.56E-03	9.04E-02	1.33E-01	*5.09E-01*	1.19E-02	*2.20E+00*	5.72E-02	3.77E-02	7.66E-03	7.60E-02
	7	9.70E-02	3.36E-02	1.34E-03	8.71E-03	8.60E-02	9.77E-07	5.13E-03	6.14E-02	9.01E-02	*3.45E-01*	8.03E-03	*1.49E+00*	3.87E-02	2.56E-02	5.20E-03	5.16E-02

Plume: 60 y	CG	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Re-suspension	Cattle liver	Beef	Cow milk	*Cow milk products*	Fruit	*Grain*	Green vegetables	Root vegetables	Sheep liver	Sheep meat
	8	5.65E-02	3.33E-02	1.34E-03	5.55E-03	6.16E-02	5.69E-07	2.99E-03	3.58E-02	5.24E-02	*2.01E-01*	4.68E-03	*8.70E-01*	2.26E-02	1.49E-02	3.03E-03	3.01E-02
	9	2.88E-01	3.51E-02	1.36E-03	2.68E-02	2.61E-01	3.09E-06	1.53E-02	1.83E-01	2.70E-01	*1.03E+00*	2.39E-02	*4.45E+00*	1.15E-01	7.61E-02	1.55E-02	1.54E-01
	10	4.43E-01	3.61E-02	1.38E-03	4.71E-02	4.45E-01	4.88E-06	2.35E-02	2.81E-01	4.14E-01	*1.59E+00*	3.67E-02	*6.82E+00*	1.77E-01	1.17E-01	2.38E-02	2.37E-01
10 y	1	1.29E-01	3.40E-02	1.35E-03	1.13E-02	1.25E-01	1.99E-06	7.74E-03	9.26E-02	1.38E-01	*5.32E-01*	1.22E-02	*2.26E+00*	5.90E-02	3.88E-02	7.79E-03	7.73E-02
	2	1.34E-01	3.40E-02	1.39E-03	9.45E-03	1.10E-01	1.87E-06	8.02E-03	9.59E-02	1.42E-01	*5.45E-01*	1.26E-02	*2.35E+00*	6.10E-02	4.02E-02	8.06E-03	8.00E-02
	3	8.33E-02	2.17E-02	8.74E-04	8.30E-03	8.09E-02	1.36E-06	5.01E-03	5.99E-02	8.96E-02	*3.47E-01*	7.88E-03	*1.46E+00*	3.82E-02	2.51E-02	5.05E-03	5.00E-02
	4	1.14E-01	2.56E-02	1.20E-03	5.65E-03	5.01E-02	1.53E-06	6.82E-03	8.16E-02	1.21E-01	*4.62E-01*	1.07E-02	*2.00E+00*	5.19E-02	3.43E-02	6.86E-03	6.81E-02
	5	1.20E-01	2.84E-02	1.26E-03	7.24E-03	6.79E-02	1.68E-06	7.18E-03	8.59E-02	1.27E-01	*4.89E-01*	1.13E-02	*2.10E+00*	5.47E-02	3.60E-02	7.22E-03	7.17E-02
	6	1.24E-01	3.25E-02	1.29E-03	8.99E-03	1.08E-01	1.76E-06	7.43E-03	8.88E-02	1.32E-01	*5.05E-01*	1.17E-02	*2.17E+00*	5.65E-02	3.72E-02	7.47E-03	7.41E-02
	7	8.39E-02	2.26E-02	8.70E-04	6.49E-03	8.60E-02	1.18E-06	5.04E-03	6.02E-02	8.92E-02	*3.42E-01*	7.91E-03	*1.47E+00*	3.83E-02	2.53E-02	5.07E-03	5.03E-02
	8	4.88E-02	1.34E-02	5.03E-04	4.14E-03	6.17E-02	6.81E-07	2.93E-03	3.51E-02	5.18E-02	*1.99E-01*	4.60E-03	*8.58E-01*	2.23E-02	1.47E-02	2.95E-03	2.93E-02
	9	2.49E-01	7.14E-02	2.59E-03	2.00E-02	2.62E-01	3.74E-06	1.50E-02	1.79E-01	2.66E-01	*1.03E+00*	2.35E-02	*4.38E+00*	1.14E-01	7.51E-02	1.51E-02	1.49E-01
	10	3.83E-01	1.06E-01	3.99E-03	3.51E-02	4.45E-01	5.86E-06	2.30E-02	2.75E-01	4.10E-01	*1.58E+00*	3.62E-02	*6.73E+00*	1.75E-01	1.15E-01	2.32E-02	2.30E-01
5 y	1	1.04E-01	3.40E-02	1.35E-03	1.52E-02	1.25E-01	2.19E-06	4.03E-03	9.58E-02	1.50E-01	*8.90E-01*	1.27E-02	*2.33E+00*	4.57E-02	3.20E-02	4.07E-03	2.41E-02
	2	1.08E-01	3.40E-02	1.35E-03	1.27E-02	1.10E-01	2.07E-06	4.17E-03	9.96E-02	1.53E-01	*9.06E-01*	1.32E-02	*2.43E+00*	4.71E-02	3.32E-02	4.21E-03	2.50E-02
	3	6.73E-02	3.36E-02	1.34E-03	1.11E-02	8.10E-02	1.50E-06	2.61E-03	6.23E-02	9.74E-02	*5.82E-01*	8.23E-03	*1.51E+00*	2.96E-02	2.07E-02	2.64E-03	1.57E-02
	4	9.20E-02	3.37E-02	1.34E-03	7.53E-03	5.01E-02	1.69E-06	3.55E-03	8.43E-02	1.30E-01	*7.67E-01*	1.12E-02	*2.06E+00*	4.01E-02	2.83E-02	3.58E-03	2.12E-02
	5	9.68E-02	3.38E-02	1.35E-03	9.69E-03	6.79E-02	1.86E-06	3.74E-03	8.92E-02	1.38E-01	*8.14E-01*	1.18E-02	*2.17E+00*	4.23E-02	2.97E-02	3.77E-03	2.23E-02
	6	1.00E-01	3.39E-02	1.35E-03	1.21E-02	1.08E-01	1.95E-06	3.87E-03	9.24E-02	1.43E-01	*8.42E-01*	1.22E-02	*2.25E+00*	4.37E-02	3.08E-02	3.90E-03	2.32E-02
	7	6.78E-02	3.36E-02	1.34E-03	8.71E-03	8.60E-02	1.31E-06	2.62E-03	6.26E-02	9.65E-02	*5.70E-01*	8.26E-03	*1.52E+00*	2.96E-02	2.09E-02	2.64E-03	1.57E-02

Plume: 60 y	CG	Inhalation of Plume	Gamma from Plume	Beta from Plume	Gamma from Ground	Beta from Ground	Re-suspension	Cattle liver	Beef	Cow milk	*Cow milk products*	Fruit	*Grain*	Green vegetables	Root vegetables	Sheep liver	Sheep meat
	8	3.94E-02	3.33E-02	1.34E-03	5.55E-03	6.16E-02	7.52E-07	1.53E-03	3.64E-02	5.59E-02	*3.30E-01*	4.81E-03	*8.84E-01*	1.72E-02	1.21E-02	1.55E-03	9.12E-03
	9	2.02E-01	3.51E-02	1.36E-03	2.68E-02	2.61E-01	4.14E-06	7.80E-03	1.86E-01	2.88E-01	*1.71E+00*	2.47E-02	*4.52E+00*	8.81E-02	6.19E-02	7.88E-03	4.66E-02
	10	3.09E-01	3.61E-02	1.38E-03	4.71E-02	4.45E-01	6.47E-06	1.20E-02	2.86E-01	4.44E-01	*2.64E+00*	3.78E-02	*6.95E+00*	1.36E-01	9.49E-02	1.21E-02	7.18E-02
1 y	1	1.03E-01	3.40E-02	1.35E-03	1.13E-02	1.25E-01	2.50E-06	5.21E-03	1.24E-01	1.96E-01	*1.17E+00*	1.65E-02	*3.02E+00*	5.94E-02	4.14E-02	5.26E-03	3.11E-02
	2	1.07E-01	3.40E-02	1.39E-03	9.45E-03	1.10E-01	2.36E-06	5.39E-03	1.29E-01	2.01E-01	*1.19E+00*	1.71E-02	*3.13E+00*	6.13E-02	4.29E-02	5.43E-03	3.22E-02
	3	6.65E-02	2.17E-02	8.74E-04	8.30E-03	8.09E-02	1.71E-06	3.37E-03	8.05E-02	1.28E-01	*7.69E-01*	1.07E-02	*1.95E+00*	3.85E-02	2.68E-02	3.41E-03	2.01E-02
	4	9.09E-02	2.56E-02	1.20E-03	5.65E-03	5.01E-02	1.94E-06	4.59E-03	1.10E-01	1.70E-01	*1.01E+00*	1.45E-02	*2.67E+00*	5.22E-02	3.66E-02	4.62E-03	2.74E-02
	5	9.56E-02	2.84E-02	1.26E-03	7.24E-03	6.79E-02	2.13E-06	4.83E-03	1.15E-01	1.80E-01	*1.07E+00*	1.53E-02	*2.81E+00*	5.50E-02	3.85E-02	4.87E-03	2.88E-02
	6	9.88E-02	3.25E-02	1.29E-03	8.99E-03	1.08E-01	2.22E-06	5.00E-03	1.19E-01	1.86E-01	*1.11E+00*	1.58E-02	*2.90E+00*	5.68E-02	3.98E-02	5.04E-03	2.98E-02
	7	6.70E-02	2.26E-02	8.70E-04	6.49E-03	8.60E-02	1.49E-06	3.39E-03	8.09E-02	1.26E-01	*7.51E-01*	1.07E-02	*1.97E+00*	3.85E-02	2.70E-02	3.41E-03	2.02E-02
	8	3.90E-02	1.34E-02	5.03E-04	4.14E-03	6.17E-02	8.55E-07	1.97E-03	4.71E-02	7.33E-02	*4.36E-01*	6.24E-03	*1.15E+00*	2.24E-02	1.57E-02	1.99E-03	1.18E-02
	9	1.99E-01	7.14E-02	2.59E-03	2.00E-02	2.62E-01	4.72E-06	1.01E-02	2.41E-01	3.78E-01	*2.26E+00*	3.19E-02	*5.84E+00*	1.15E-01	8.02E-02	1.02E-02	6.01E-02
	10	3.06E-01	1.06E-01	3.99E-03	3.51E-02	4.45E-01	7.36E-06	1.55E-02	3.70E-01	5.82E-01	*3.48E+00*	4.91E-02	*8.97E+00*	1.76E-01	1.23E-01	1.56E-02	9.24E-02

Table A5-2: Thyspunt dose for all age groups from liquid exposure pathways (µSv/y)

	Crustaceans	Fish	Molluscs	External Beta from Beaches	External Beta from Fishing Equipment	External Gamma from Beaches	External Gamma from Fishing Equipment	Sea Spray Inhalation	Total
Age: (Conservative Pathway Assumptions)									
Adult	1.65E+00	8.98E+00	3.15E+01	1.06E-02	2.22E-02	3.58E+00	3.58E-02	2.63E-05	**45.7**
15 y	1.73E+00	7.52E+00	3.31E+01	5.30E-03	1.11E-02	1.79E+00	1.79E-02	1.17E-05	**44.2**
10 y	1.70E+00	7.43E+00	3.27E+01	2.65E-03	5.54E-03	8.94E-01	8.94E-03	5.87E-06	**42.8**
5 y	7.25E-01	7.67E+00	1.37E+01	1.32E-03	0.00E+00	4.48E-01	0.00E+00	2.11E-06	**22.6**
1 y	9.39E-01	9.92E+00	1.78E+01	5.30E-04	0.00E+00	1.79E-01	0.00E+00	8.43E-07	**28.8**
Age/Pathway: (More realistic pathway assumptions)									
Adult	1.51E+00	1.53E+00	1.54E+00	1.08E-02	1.40E-02	3.72E+00	3.72E-02	2.63E-05	**8.4**
15 y	1.51E+00	8.58E-01	1.55E+00	5.42E-03	6.98E-03	1.86E+00	1.86E-02	1.17E-05	**5.8**
10 y	1.49E+00	8.48E-01	1.54E+00	2.71E-03	3.49E-03	9.29E-01	9.29E-03	5.87E-06	**4.8**
5 y	2.63E-07	7.67E-01	5.27E-06	1.35E-03	0.00E+00	4.64E-01	0.00E+00	2.11E-06	**1.2**
1 y	0.00E+00	9.92E-01	0.00E+00	5.42E-04	0.00E+00	1.86E-01	0.00E+00	8.43E-07	**1.2**

Appendix 6:
Additional Information on Radioactive Carbon-14, a Key Radionuclide in the Nuclear Installation Discharges to the Environment

Additional Information on Radioactive Carbon-14, a Principal Radionuclide in the Nuclear Installation Discharges to the Environment

Certain radionuclides that form part of the normal discharges from a NPP have specific significance because of the following attributes:

- half-life long enough to allow environmental transfer and build-up;
- magnitude of the radionuclide source term;
- dose impact as a result of a high dose coefficient; and
- the presence of the radionuclide in the discharge serves as an indicator of plant performance.

C-14 is potentially a large contributor to the source term and the largest contributor to the annual effective dose in nuclear power plants. C-14 is produced in the fuel, core structural materials, and in the reactor coolant due to the presence of the (stable) parent isotopes N-14, O-17 and C-13. These stable isotopes are present as components or impurities and are parent isotopes that are involved in the three major types of reactions to produce C-14. These reactions are listed in Table A6-1 [A6.1].

Table A6-1: C-14 production mechanisms

Target Isotope	Mechanism	Thermal Cross-Section (barns)	Isotopic Abundance of the Parent Material (%)
N-14	$^{14}N(n, p)^{14}C$	1.81	99.635
C-13	$^{13}C(n, y)^{14}C$	0.0009	1.103
O-17	$^{17}O(n, c)^{14}C$	0.235	0.038

The C-14 can remain in the:

- structural/fuel materials;
- in the coolant and the moderator;
- on ion exchange resins used in purification; or
- it can be released to the atmosphere in gaseous form.

The activation processes result in estimated C-14 production rates in pressurised water reactors as listed in Table A6-2.

Table A6-2: Annual normalised C-14 production rates for PWRs

Reactor Component	C-14 Production Rate; TBq/GWe-yr	Production Mechanism
^{17}O in UO_2 fuel	0.14	$^{17}O(n, a)^{14}C$
^{14}N impurities in UO_2 fuel	0.57	$^{14}N(n, p)^{14}C$
^{14}N impurities in zircalloy and fuel assemblies	0.38	$^{14}N(n, p)^{14}C$
Coolant ^{17}O in H_2O	0.22	$^{17}O(n, a)^{14}C$
Dissolved N_2- bounding estimates (10 to 40 ppm)	0.04–0.19	$^{14}N(n, p)^{14}C$
Total	1.3 –1.5	

The production of C-14 in the reactor coolant through the neutron-alpha reaction of the O-17 isotope, ^{17}O (n,$^{4}He)^{14}C$, is almost entirely responsible for the releases to the environment during normal operation.

Reference:

A6.1 Electric Power Research Institute (1995), Characterization of Carbon-14 Generated by the Nuclear Power Industry. Report EPRI TR-105715.

Appendix 7:
The *ERICA* Assessment Tool for Radiological Impact on Non-Human Species

The ERICA Assessment Tool for Radiological impact on Non-Human Species

ERICA is defined as an '*integrated approach to scientific, managerial, and societal issues concerned with the environmental effects of contaminants emitting ionising radiation, with emphasis on biota and ecosystems*'. The *ERICA* tool has a structure based upon the tiered *ERICA* integrated approach to assessing the radiological risk to terrestrial, freshwater, and marine biota. The tool guides the user through the assessment process, recording information and decisions, and allowing the necessary calculations to be performed to estimate risks to selected animals and plants.

An overview of the three-tier process is provided here.

Tier 1: It is a simple assessment which requires minimal input consisting basically a site description and other details to allow the problem under assessment to be described fully, for example by including:

- which radionuclides are present;
- what is the ecosystem being assessed (freshwater, marine, or terrestrial);
- how the media (water, sediment, soil, or air) concentrations will be entered (through the use of screening transport models or site-specific measurement data, etc.);
- how time dependent or spatial data may be used.

The results from this assessment are considered to be conservative and therefore can be used to screen out sites where there is a negligible radiological risk of the populations of non-human species being affected by the presence of the ionising radiation. Input media activity concentrations are compared against environmental media concentration limits which have been calculated for the most limiting organism for each radionuclide. The extent of a Tier 2 assessment will be based on the outcome of Tier 1. A decision to perform more complex Tier 3 assessments will depend on the outcome of the Tier 1 and Tier 2 assessments.

Tier 2: It is a more detailed assessment, which requires further input to better define the problem that is being assessed, particularly with regard to the exposure conditions and the transfer parameters. Typical user inputs required are the following:

- to select which radionuclides are present;
- to select which reference organisms are present in an assessment scenario;
- to add user-defined geometries needed to be able to populate the tool with all the necessary parameters for the tool to function correctly;
- to modify the default concentration ratios (CRs) and, for aquatic ecosystems, the distribution coefficient (K_d) values to add, for example, values deriving from site-specific data;
- to describe how the media (water, sediment soil, or air) concentrations will be entered (through the use of screening transport models or site-specific measurement data, etc.);

- to describe how time-dependent or spatial data may be used.

For each organism of interest, estimated absorbed dose rates are compared to the selected incremental screening dose rate. Results can be put into context by comparing to summarised tables of radiation effects and natural background exposure.

Tier 3: Those situations which give rise to a Tier 3 assessment are likely to be complex and it is therefore not possible to provide detailed or highly specific guidance on how the Tier 3 assessment should be conducted, as each situation is likely to be unique. Furthermore, a Tier 3 assessment does not provide a simple yes/no answer nor is the *ERICA* derived screening incremental dose rate of 10 µGy/h appropriate with respect to the assessment endpoint. The requirement to consider aspects such as the biological effects data contained within the *ERICA* database or to undertake ecological survey work, is not straightforward and requires an experienced, knowledgeable assessor or consultation with an appropriate expert. The following sections inform the assessor about what the *ERICA* tool can be used and how the *ERICA* database can be utilised within a Tier 3 assessment. Tier 3 is a probabilistic risk assessment in which uncertainties associated with the results may be determined using sensitivity analysis, and that allows the assessor to access a compilation of up-to-date available scientific literature (which may not be available at Tier 2) on the biological effects of exposure to ionising radiation in a number of different species. This will allow the assessor to estimate the probability (or incidence) and magnitude (or severity) of the environmental effects likely to occur and, by discussion and agreement with stakeholders, to determine the acceptability of the risk to non-human species.

The screening assessment performed for a local marine compartment used the results determined with *PC-CREAM* for the environmental concentrations (seawater and sediment concentrations for the elements listed in Table A7-1. The results for the EPR source term was used, scaled to represent 33 000 MWth for airborne and liquid radionuclides listed in Table A7-1.

Table A7-1: *ERICA* screening assessment source term radionuclides

Airborne	Liquid
Co-58	Ag-110
Co-60	C-14
Cs-134	C0-58
Cs-137	C0-60
I-131	Cs-134
I-131	Cs-137
C-14	H-3
H-3	I-131
	Mn-54
	Ni-63
	Sb-124