Eskom Holdings Limited

ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE




Assessment of the Potential Impacts on Human Health
Environmental Impact Report

January 2010

EXECUTIVE SUMMARY

The Eskom Nuclear-1 project involves the licensing of three candidate sites along the west and south coasts of South Africa for the establishment of nuclear power stations (NPSs). The sites are:

- The Thyspunt site, situated in the Eastern Cape Province in the region west of Port Elizabeth between Cape St Francis and Oyster Bay;
- The Bantamsklip site, located in the Western Cape in the area between Danger Point and Quoin Point;
- The Duynefontein site, situated on the Cape West Coast, approximately 30 km north of Cape Town, adjacent to the current Koeberg NPS.

The establishment of an NPS includes a number of activities, which require authorisation in terms of the Environmental Impact Assessment (EIA) Regulations promulgated under the National Environmental Management Act (No. 107 of 1998), as amended. The EIA process is administrated by the Department of Environmental Affairs (DEA). However, following a co-operative agreement between the DEA and the National Nuclear Regulator (NNR), it was agreed that the NNR will be the responsible authority regarding the assessment of all matters relating to impacts of ionising radiation on human health. This environmental impact report on the assessment of potential health risks associated with NPSs at the candidate sites will thus be submitted to the NNR for approval. The report has been prepared by INFOTOX (Pty) Ltd in conjunction with SRK Consulting.

Radiological protection in the low dose range is concerned primarily with protection against radiation-induced cancer and heritable disease. These effects are interpreted as stochastic, with no threshold, and they increase in frequency in proportion to the radiation dose. Radiation exposure has been demonstrated to increase the risk of other diseases, particularly cardiovascular disease, in persons exposed to high therapeutic doses and also in atomic-bomb survivors exposed to high radiation doses. However, there is no direct evidence of increased risk of noncancer diseases at doses below about 100 millisieverts (mSv). This dose level is two orders of magnitude higher than the NNR dose limit for public exposure. Protection against the development of radiogenic cancer is considered to be adequate for protection against hereditary effects and any other radiation-associated diseases.

Human beings are exposed daily to natural background radiation from environmental soil, building materials, air, food, cosmic rays, and even from radioactive elements within the human body. There is no general property that makes the effects of man-made radiation different from those of naturally-occurring radiation.

The NNR specifies an annual effective dose limit of 1 mSv for members of the public from all authorised actions. This limit applies to the average member of the critical group within the exposed population, which represents a homogeneous group of the highest exposed individuals. In addition, the NNR stipulates a dose constraint of 0.25 mSv specific to an authorised action, to ensure that the sum of the doses received by the average member of the critical group from all controlled sources

would be smaller than the dose limit. A dose constraint is a prospective and source related restriction on the individual dose from a source in planned operations, which serves as an upper bound on the predicted dose in the optimisation of exposure from that source.

The NNR requires that any exposure above the natural background radiation should be kept as low as reasonably achievable (the ALARA principle). Dose limits and dose constraints must always be interpreted as upper bound limits in conjunction with the ALARA principle, inferring that exposures from authorised activities in practice would be lower than the dose limits and dose constraints.

Reactor technologies have not been selected for the Nuclear-1 project at this time and the current assessment is based on the concept of a technology envelope (TE), which sets an upper limit on radiological discharges, requiring that radiological doses to the average member of the critical group at any of the sites under consideration would not exceed the NNR regulatory requirements. For a selected power generation capacity at a site, combinations of reactors may be considered, as long as radiological discharges would not exceed the TE. The health impact assessment presented in this report has been based on the premise that the NNR will issue a license for a site only if full compliance with regulatory requirements is demonstrated. This would take into account not only the radiological dose assessment for normal operation of the NPS, which will be submitted to the NNR in the form of a site safety report (SSR), but all the other studies that are required for the assessment of the overall safety case.

This environmental impact report outlines the methodologies for quantification of radiological exposure and places the NNR regulatory requirements in context with potential risks to human health. The approach considers site-specific scenarios for multiple pathways of exposure. The quantified radiological doses determined for the SSR will be assessed in terms of regulatory requirements of the NNR. The assessments for the candidate sites must not only demonstrate compliance with the NNR dose limits and dose constraints, but must also take into consideration the principles of ALARA. Should a calculated dose be within the acceptable NNR requirements, it can be concluded that the cancer risk would be within the *de minimis* lifetime risk range, which represents a level of health risk that is regarded as insignificant or trivial. Protection against the development of radiogenic cancer is considered to be adequate for protection against hereditary effects and other radiation-associated diseases.

The impact assessment has highlighted that there is extensive mitigation built into reactor design for safety and that there are multiple precautionary defenses against the consequences of failures in materials and equipment and human error.

For purposes of the EIA, it is acknowledged that the NNR will issue a license for the establishment of an NNR at any particular site only if full compliance with the radiological dose limits and dose constraints is demonstrated, taking into account the principles of ALARA and all other matters relating to the overall safety case. Considering the methodologies for dose assessment that are presented in this report, it is recommended that the approach be accepted as adequately protective against

adverse health effects to members of the community. This applies to the construction phase, operational phase and decommissioning.

CONTENTS

TABLES

FIGURES

ABBREVIATIONS

ALARA	As low as reasonably achievable
AOOs	Anticipated operational occurrences
Bq	Becquerel
CFR	Code of Federal Regulations (USA)
DBA	Design basis accidents
DCF	Dose conversion factor
DEA	Department of Environmental Affairs
EIA	Environmental impact assessment
ESP	Early site permit (USA)
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiatiological Protection
IE	Initiating event
mSv	Millisievert
NNR	National Nuclear Regulator (South Africa)
NORM	Naturally occurring radioactive material
NPS	Nuclear power station
NRC	National Research Council (USA)
SSR	Site safety report
Sv	Sievert
TE	Technology envelope
USEPA	US Environmental Protection Agency

GLOSSARY

Annual effective dose	The summation of the annual tissue equivalent doses, each multiplied by a tissue weighting factor.
Anticipated operational occurrences	An operational process deviating from normal operation which is expected to occur at least once during the lifetime of the facility but which, because of appropriate design provisions, would not cause any significant damage to items important to safety or lead to accident conditions.
Carcinogen	A substance that causes cancer (or is believed to cause cancer).
Chronic health effects	Adverse effects resulting from repeated doses of or exposures to a substance over a relatively prolonged period of time (months to years).
Critical group	A group of members of the public 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 effective dose or equivalent dose (as applicable) by the given exposure pathway from the given source.
de minimis risk	A level of health risk that is regarded as insignificant or trivial.
de manifestis risk	A level of risk at which regulatory action is taken to reduce risk.
Defence in depth	The application of more than a single protective measure for a given radiation or nuclear safety objective, so that the objective is achieved even if one of the protective measures fails.
Design basis accident	Accident conditions against which a facility is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within authorised limits.
Deterministic assessment	The deterministic assessment calculates public dose with a specific set of parameters that characterise the sources of the radioactive discharges, the population that may be exposed to these radioactive discharges and the pathways and processes by which these exposures may occur, without taking the probabilities of different event sequences into account.. Uncertainties in these parameters are accounted for by selecting conservative values that will ensure that public dose is not underestimated.
Discharge	A planned and controlled release of radioactive nuclides to the environment.
Dose constraint	A prospective and source-related restriction on the individual dose arising from the predicted operation of the authorised *action* which serves exclusively as a bound on the optimisation of radiation protection and nuclear safety.
Hazard	The potential of a substance to cause harm.
ICRP	International Commission on Radiological Protection.
Intitiating event	All event initiators and combination of independent even initiators (occurring at the same time) that might lead to exposure.
Noncarcinogen	A substance with adverse health effects on humans other than cancer.
Normal operation	Operation within specified operational limits and conditions. This includes starting, power operation, shutting down, shutdown, maintenance, testing and refuelling.
Normal operational exposure	An exposure which is expected to be received under normal operating conditions, including possible minor mishaps that can be kept under control.

Pathway	The pathway is the route the source takes to reach the receptor. Pathways include, for example, air, water, soil, animals, vegetables and eco-systems.
Prior safety assessment	A safety assessment undertaken prior to commencement of operations.
Probabilistic risk limits	An expression of the chance of harmful consequences associated with radiation exposure. It may refer to morbidity or mortality.
Public exposure	Exposure incurred by members of the public from radiation sources, excluding any occupational or medical exposure and the normal local background radiation.
Radioactivity	The spontaneous transformation of an unstable atom resulting in the emission of radiation. This process is referred to as a transformation, a decay or a disintegration of an atom.
Radioisotopes	Radioactive isotopes of an element.
Radionuclide	A nuclide is a specific atom defined by the number of neutrons and protons it contains. A radionuclide is a nuclide that is radioactive.
Receptor	A receptor is a person, animal, plant, eco-system, property or any environmental unit affected by contamination.
Representative person	An individual receiving a dose that is representative of the more highly exposed individuals in the population. It is equivalent to the average member of the critical group referred to in NNR regulations.
Route of exposure	The way in which humans may come into contact with a hazardous substance. Three routes of exposure are breathing (inhalation), eating or drinking (ingestion), or contact with the skin (dermal contact).
Safety case	A collection of arguments and evidence in support of the safety of a facility or activity. Normally this will include the findings of a safety assessment and a statement of confidence in the findings.
Sievert (Sv)	The standard international unit of equivalent dose, effective dose and operational dose quantities. The unit is joule per kilogram (J/kg).
Source-pathway-receptor methodology	A model used in risk assessment to identify the source of any contamination, the receptors that may be affected by the contamination, and how the contamination may reach the receptors (pathway).
Stochastic effects	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 a threshold.
Tissue weighting factor	Factor accounting for the different sensitivities of different organs and tissues to the induction of stochastic effects of radiation.

1 INTRODUCTION

1.1 Background

The Eskom Nuclear-1 project involves the licensing of three candidate sites along the west and south coasts of South Africa for the establishment of nuclear power stations (NPSs). The sites are:

- The Thyspunt site, situated in the Eastern Cape Province in the region west of Port Elizabeth between Cape St Francis and Oyster Bay.
- The Bantamsklip site, located in the Western Cape in the area between Danger Point and Quoin Point.
- The Duynefontein site, situated on the Cape West Coast, approximately 30 km north of Cape Town, adjacent to the current Koeberg NPS.

The establishment of an NPS includes a number of activities, which require authorisation in terms of the Environmental Impact Assessment (EIA) Regulations promulgated under the National Environmental Management Act (No. 107 of 1998), as amended. The EIA process is administrated by the Department of Environmental Affairs (DEA). In July 2008, the original Plan of Study, together with the Final Scoping Report for the Nuclear-1 EIA, was submitted to the DEA (then the Department of Environmental Affairs and Tourism) for review and approval. In a letter dated 19 November 2008, the Department approved the Final Scoping Report in accordance with EIA Regulations.

Subsequently, a co-operative agreement was reached between the DEA and the National Nuclear Regulator (NNR), in which it was agreed that the NNR will be the responsible authority regarding the assessment of all matters relating to impacts of ionising radiation on human health. Reference is made to a document titled *'Notification of statement issued by the Department of Environmental Affairs and Tourism regarding the consideration of matters pertaining to nuclear safety in environmental impact assessment processes on nuclear installations'*, dated 10 February 2009. The document serves to communicate consensus reached between the DEA and the National Nuclear Regulator (NNR) in terms of management of issues relating to radiological matters. One of the main purposes of the engagement between DEA and the NNR was to *'prevent unnecessary and unavoidable duplication of effort'*. According to Section 20 (1) of the National Nuclear Regulator Act, 1999 (Act No. 47 of 1999), no person may site, construct, operate, decontaminate or decommission a nuclear installation without a nuclear installation license. The NNR process applies specifically to issues of nuclear and radiation safety related to the siting, design, construction, operation and decommissioning of nuclear installations. The document refers to a meeting held on the 15 June 2006, whereby it was agreed that nuclear safety, radiation and radiology *'are better placed within the regulatory process of the National Nuclear Regulator Act and that consideration of the same issues in an EIA process will result in unnecessary and avoidable duplication.'*

This Environmental Impact Report has been prepared by INFOTOX (Pty) Ltd in conjunction with SRK Consulting and will be submitted to the NNR for approval.

Draft Regulations in terms of section 36 (read with Section 47), of the National Nuclear Regulator Act on the siting of new nuclear installations specify that the applicant for a nuclear installation license must submit, in support of its application, a Site Safety Report (SSR) to the NNR comprising the following:

1. Motivation for the choice of the site to ensure a low risk of public exposure from the operation of the nuclear installation(s).

2. Statement as to the proposed use of the site in terms of scope of technologies being considered for proposed nuclear installation(s) and use on the site, including as appropriate the maximum thermal power, general design characteristics such as the engineered safety features of the nuclear installations included as safety measures against the hazardous consequences of postulated events and layout of the site.

3. Source terms analysis representative of the overall potential hazards posed to the public (and environment) due to the range of technologies under consideration for nuclear installation(s) at the site, taking into consideration a representative scope of internal and external events enveloping all potential technologies of nuclear installation(s) considered for construction and operation on the site.

4. A probabilistic risk assessment using the source terms referred to above as well as the site-specific environmental data, including meteorology, land use, population demographics and regional development, based on projections to account for the design life of the nuclear installation(s), to demonstrate compliance with the probabilistic risk limits. The cumulative impact of all nuclear installation(s) planned or existing must be taken into account in this analysis.

5. Analysis of the impact on the public due to normal operations, anticipated operational occurrences and design-basis accidents of the nuclear installation(s) to demonstrate compliance with regulatory dose limits.

6. Analysis to demonstrate the viability of an emergency plan taking into account the above factors, including transport and disaster management infrastructure.

7. An assessment from the relevant national security authorities on the suitability of the site for establishing nuclear installation(s) from a security perspective.

8. A programme to monitor all the site-specific characteristics and environmental data necessary for the SSR, including a programme of reporting to the NNR.

Eskom is in the process of preparing SSRs for each of the three candidate sites and will submit the SSRs to the NNR in accordance with agreed timescales. The SSRs will contain all information as specified above, as well as any additional information that may be required by the NNR for the nuclear license application. In taking its decision about a proposed NPS, the NNR will consider not only the SSR, but also other regulatory requirements for the assessment of the overall safety case.

1.2 Purpose of the study

It is compulsory, as part of the NNR licensing requirements, that an assessment be conducted of potential impacts on human health at off-site locations as a result of radioactive substances (radionuclides) that may be discharged from the proposed NPS. It is the purpose of this study to assess potential radiological impacts to members of the public from the proposed NPSs at the three candidate sites.

1.3 Study Approach

Quantitative assessment of the potential radiological impact on the public will be presented to the NNR by Eskom in support of the overall safety case for each of the candidate sites. Public dose assessments will consist of the following primary components:

- Description of the radioactivity source
- Site-specific exposure assessment
- Public dose quantification.

In accordance with the terms of reference for the assessment of potential impact on human health in the EIA, this study is based on the premise that the NNR will issue a license for a site only if full compliance with regulatory requirements is demonstrated. This study thus outlines the assessment methodologies and places the NNR regulatory requirements in context with potential risks to human health.

1.4 Structure of the report

The report is structured as follows:

Section 2 provides a general overview of the effects of ionising radiation exposure on human health.

Section 3 provides a description of the study areas and a discussion of the methodology followed for quantification of human exposure to radionuclides from an NPS.

Section 4 provides a description of the methodology applied in the regulatory dose compliance assessment.

Section 5 provides the identification and assessment of potential impacts associated with an NPS.

2 RADIATION EXPOSURE AND ITS EFFECTS ON HUMAN HEALTH

2.1 General

Radiation is a general term used for energy that travels through space in the form of particles or electromagnetic waves. Sunshine is one of the most familiar forms of radiation that delivers light and heat to the earth. There are many types of radiation, for example including visible light, heat, radio and television signals, infrared radiation and microwave radiation.

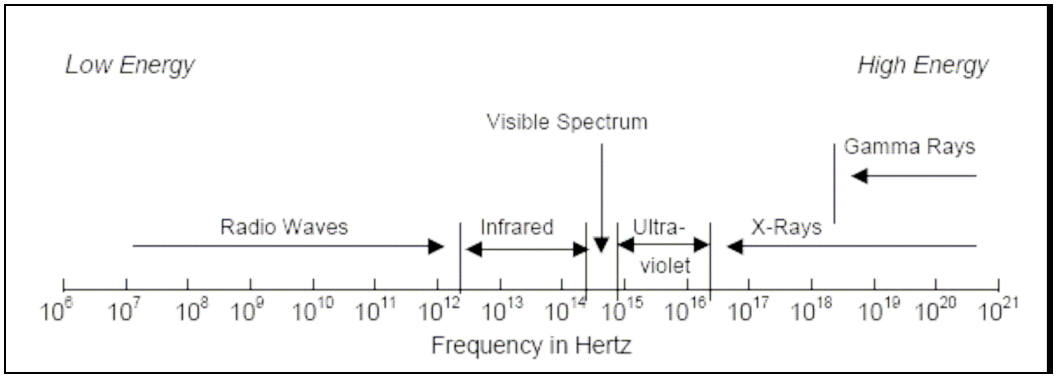

Figure 2.1: The electromagnetic spectrum.

The different types of radiation differ from each other in their frequencies (number of vibrations per second). As shown in Figure 2.1, the different types of radiation can be depicted as a spectrum of frequencies, known as the electromagnetic spectrum. The radiation associated with radioactive materials has very high frequencies and accordingly can transfer high quantities of energy. Ionising radiation has sufficient energy to displace electrons from molecules. Free electrons, in turn, can damage human cells. Ionising radiation can consist of electromagnetic radiation, such as X-rays or gamma rays (γ-rays), or of subatomic particles such as protons, neutrons, and α-particles. Radiation exposures are measured in terms of the quantity of absorbed dose, which equals the ratio of energy imparted to the mass of the exposed body or organ.

Ionisation of atoms can significantly alter the chemical structure of a material by causing chemical bonds between atoms to break and other chemical bonds to form. Ionisation of atoms in the human body by radiation can lead to harmful biological effects.

Human beings are exposed daily to natural background radiation from environmental soil, building materials, air, food, cosmic rays, and even from radioactive elements within the human body. There is no general property that makes the effects of man-made radiation different from those of naturally-occurring radiation. In many cases the primary exposure associated with background ionising radiation results from exposure to radon gas and its decay products. Radon is a colorless, odourless gas

that emanates from natural materials in the earth and, along with its decay products, emits a mixture of high- and low linear energy transfer radiation. Data published for the United Kingdom (Harrison and Phipps, 2000) and elsewhere (NRC 2006; World Nuclear Association 2002) indicate that doses to members of the public from radionuclides introduced into the environment by human activity are generally small in comparison with doses from naturally-occurring radiation.

2.2 Biological effects of radiation

Radiological protection in the low dose range is concerned primarily with protection against radiation-induced cancer and heritable disease. These effects are interpreted as stochastic, with no threshold, and they increase in frequency in proportion to the radiation dose (ICRP 2007).

Ionising radiation has sufficient energy to change the structure of molecules, including DNA, within the cells of the human body. Although there are repair mechanisms, it is possible to damage the genetic code permanently by means of ionising radiation, resulting in faulty genetic information. Faulty genetic information may result in cell death, or the cell may survive and divide, transferring the faulty genetic information to the next cell lineage. Faulty genetic information may result in abnormal cell function, manifesting as harmful effects in the organism. However, the evidence is that only a very small fraction of such changes would be expected to result in cancer or other health effects.

There are two types of cells in the human body – somatic cells and germ cells (spermatozoa and ova) in the reproductive system. Tissues with particular specialised functions are referred to as organs. Cells, tissues and organs are maintained through regulated processes of cell division. The division, structure and functioning of cells are controlled by DNA in the nucleus of the cell. The DNA in cells carry the blueprint of the cell structure and function, and this information is commonly referred to as the genetic code. During cell division, the genetic code is transferred from one lineage of cells to the next with remarkable fidelity.

Abnormal somatic cell function, arising from damaged DNA, may lead to cancer in the tissue or organ of the exposed individual. Cancer results from uncontrolled cell division and proliferation. When this occurs, it often happens that the daughter cells (the result of cell division) divide before reaching their mature state. The result then is an ever increasing number of cells that have no beneficial function to the body, yet are absorbing body nutrition. Whether cancer is fatal or not depends on the tissue in which it is located, how rapidly it grows, and how soon it is detected.

The most thoroughly documented cases of radiation-induced cancer in humans are the survivors of the Hiroshima and Nagasaki atomic bombs. Cancer cases above the general population cancer rates were observed at doses of about 40 to 1 600 times the average annual background exposures (NRC 2006). The types of cancer caused by radiation are not different from those that occur due to other causes. Therefore, there is not any specific cancer that can be unequivocally attributed to ionising

[1] Deoxyribonucleic acid - a nucleic acid that is the main constituent of the chromosomes of all organisms (except some viruses).

radiation.

Hereditary effects occur when DNA in human germ cells is damaged. The male germ cells are sperm and the female germ cells are oocytes (egg cells). If the damaged germ cell participates in conception, the defect is reproduced in the cells of the new organism that results from this conception, including those cells that will later become germ cells. The defect that resulted from the original mutation can thus be passed on for many generations. The mutation may manifest as a gross anatomical abnormality, or as a subtle physiological or biochemical abnormality, nonetheless with detrimental effects on the health of the affected individual. This risk is small and has not been detected in humans, even in thoroughly studied irradiated populations such as those of Hiroshima and Nagasaki (NRC 2006).

In addition to cancer and hereditary effects, radiation exposure has been demonstrated to increase the risk of other diseases, particularly cardiovascular disease, in persons exposed to high therapeutic doses and also in atomic-bomb survivors exposed to high radiation doses. However, there is no direct evidence of increased risk of noncancer diseases at doses below about 100 mSv (ICRP 2007). Protection against the development of radiogenic cancer is considered to be adequate for protection against hereditary effects and other radiation-associated diseases.

3 DESCRIPTION OF AFFECTED ENVIRONMENT

3.1 Study areas

At each of the three candidate sites a study area had to be identified in terms of which the potential impacts from a proposed NPS would be assessed. From a health risk perspective, determination of the study area is an iterative process considering geographic boundaries, air dispersion modelling of radionuclide discharges and public dose quantification. At each of the three sites the dispersion characteristics of airborne substances that may be discharged from the proposed NPS were used as the basis for determination of the study area. To illustrate this approach, a graphical representation of the air dispersion modelling results of tritium for the Thyspunt site is presented in Figure 3.1 (Airshed 2009).

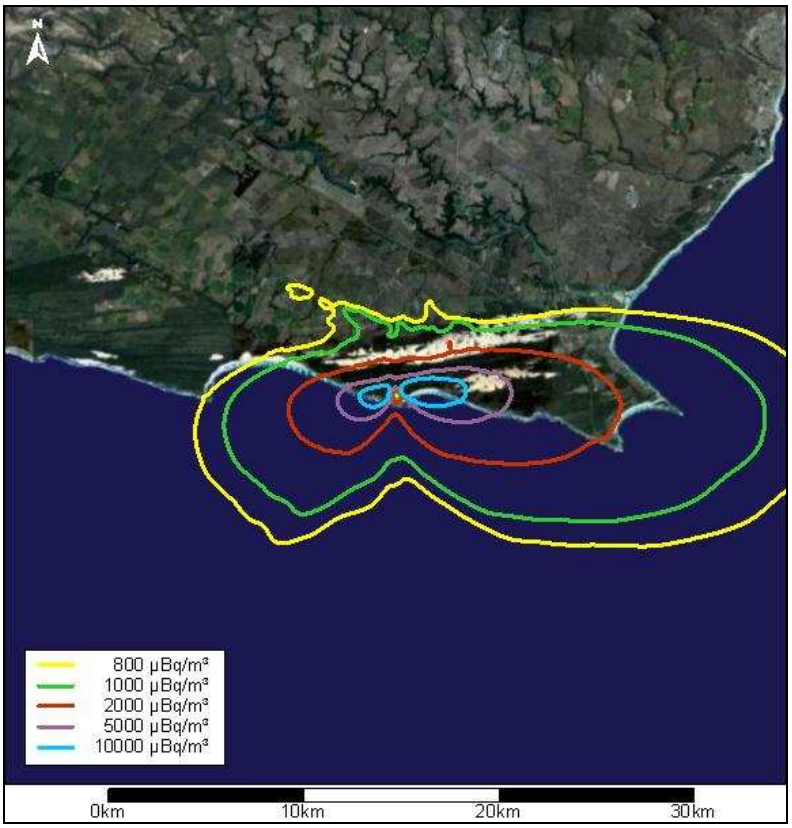

Figure 3.1: Air dispersion of tritium at the Thyspunt site.

Mathematical dispersion modelling uses emissions information of substances together with meteorological data of the area to estimate ambient air concentrations at various distances from the source. Concentrations in ambient air at ground level are graphically presented as regions with similar concentration by coloured lines known as concentration isopleths. A concentration isopleth is used to indicate the outside boundary of a concentration zone, providing a picture of the most likely air concentrations in certain areas, but as a continuum with some overlap between the indicated concentrations.

As an example, the dispersion pattern in Figure 3.1 indicates that airborne radionuclide concentrations at the Thyspunt site would be the highest close to the source (i.e., the NPS) and would decrease with distance from the source. Similar trends in dispersion patterns were demonstrated for the Bantamsklip and Duynefontein sites.

The methodology for exposure quantification provides for consideration of potential contamination of groundwater, surface water (freshwater) and the ocean in the study area. Potential pathways of exposure are discussed in Section 4.4.

At each of the three candidate sites there are residential communities relatively close to the source. At Thyspunt, the Oyster Bay community is situated at a distance of between 4 km and 5 km from the site. Port Elizabeth is more than 80 km from Thyspunt and potential impacts associated with the NPS would be much lower than at Oyster Bay. At Bantamsklip, the community of Pearly Beach is situated at between 5.5 km and 6 km from the proposed site. At Duynefontein, the residential area known as *'Duynefontein'* has its closest point situated approximately 2.5 km from the site. These communities that are closest to the respective sites can be expected to receive a higher dose of radioactivity from the NPS than communities further away and, therefore, would potentially have a higher risk of experiencing the impacts assessed in this report.

Potential impacts associated with exposure to radioactive substances have been evaluated in the identified communities, irrespective of the size of such a community. The study area for this assessment has been defined as the area in a 10 km radius around each candidate site, which adequately covers potentially exposed members of the neighbouring populations for the purpose of quantifying the highest potential exposures. The exposure assessment is refined by considering a *'critical group'*, in accordance with NNR requirements, as discussed in Section 3.2 below.

3.2 Critical groups

The selection and characterisation of the exposed population is a fundamental element in the assessment of potential risk to members of the community. It is to be expected that all members of an exposed population would not be exposed to radiation in exactly the same way. The concept of a critical group was therefore introduced by the International Commission for Radiological Protection (ICRP) in 1965 (ICRP 2006). The aim of radiological exposure assessment is to identify one or more groups of people whose habits, location, age or other characteristics would cause them to receive a higher dose than the rest of the exposed population. More recently, the notion of basing dose assessments, in particular prospective dose assessments, on the characterisation of an individual rather than a group, was introduced by the ICRP (ICRP 2006 and ICRP 2007). This individual is defined as the *'representative person'* and the term is described as the equivalent of the '*average member of the critical group'*, representing the more highly exposed individuals. The NNR still refers to the *'average member of the critical group'* in its documents (see Section 4.1.1).

In accordance with the ICRP guidelines, the approach of identifying and characterising a critical group or representative person on which the exposure assessment is based, is followed in the quantification of dose in this study. The average member of the critical group is identified for the candidate sites by using human activity patterns and land use data in conjunction with estimated radionuclide concentrations in the environment.

3.3 Site-specific aspects

Climatology, local meteorological parameters and current air quality at the three potential sites are described in the air quality specialist study (Airshed 2009). This information was used to determine the ambient air concentrations and deposition rates of radionuclides. Industrial activities other than the NPS may add sources of pollution that would be relevant in the assessment of potential impacts on human health and should be considered with regard to potential impacts on the proposed NPS. Any industries that may currently be in the vicinity of the sites have to operate within air quality standards and as such should have minimal impacts on the proposed NPS. Any future industries that will be established in the vicinity of the proposed NPS will have to undergo an environmental impact assessment to ensure that they would not pose risks to the environment and the health of surrounding communities and, furthermore, that the safety measures relating to the NPS would not be affected.

4 METHODOLOGY

4.1 Regulatory framework

4.1.1 Acts, regulations and requirements applied in the study

The regulatory framework within which the SSR dose assessment must demonstrate compliance is constituted by the following Act and Regulations:

- National Nuclear Regulator Act, 1999 (Act No. 47 of 1999)
- Regulations in terms of Section 36, read with Section 47, of the National Nuclear Regulator Act, 1999 (Act No. 47 of 1999), on the Siting of New Nuclear Installations
- 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
- Government Notice R.385, promulgated in terms of Section 24 of the National Environmental Management Act, 1998 (Act No 107 of 1998)

The above Act and Regulations are supported by the following documents that have relevance to the assessment of potential impacts on human health:

RD-0014 - Emergency planning and response requirements for nuclear installations

RD-0018 - Basic licensing requirements for the pebble bed modular reactor

RD-0022 - Radiation dose limitation at Koeberg Nuclear Power Station

RD-0024 - Requirements on risk assessment and compliance with principal safety criteria for nuclear installations

RD-0026 - Decommissioning of nuclear facilities

RD-0034 - Quality and safety management requirements for nuclear installations

LG-1032 - Licensing Guide LG-1032: Guidelines on the Assessment of Radiation Hazards to Members of the Public from Mining and Mineral Processing Facilities, National Nuclear Regulator. 2007

4.1.2 Initiating events

The NNR, in RD-0018, defines three categories of initiating events (IE) or combinations of IE, which lead or could potentially lead to exposure of members of the public to ionising radiation. These categories are:

Category A: Comprising potential exposures from normal operation as well as from anticipated operational occurrences (AOO) which are IE, estimated to occur with a frequency of more than one in one hundred years ($\geq 10^{-2}$ y^{-1}).

Category B: Events that potentially lead to exposure and which could occur with a frequency of less than one in one hundred years ($<10^{-2}$ y^{-1}) and more than one in one million years ($\geq 10^{-6}$ y^{-1}). Category B events lead to consequences and conditions that are considered for the design basis but are beyond the range of Category A. Category B events are not expected to occur during the life cycle of the plant.

Category C: All possible events that potentially could lead to exposure, including those which are demonstrated to be beyond the range of category B events. As such, Category C events are those that are expected to occur with an annual frequency of less than 10^{-6}. As such, category C events include category A and B events as well as those events that occur with a frequency of less than 10^{-6} per year (*beyond category B events*).

This study considers discharges from Category A (normal operation and AOO) and Category B (design-basis accidents) events only. Design-basis accidents (DBAs) usually have a low probability of occurrence during the operational lifetime of an NPS, *viz*, less than one in one hundred years, but more than one in one million years.

Releases associated with beyond-design-basis-accidents (Category C) do not form part of this assessment but are considered as part of the emergency response environmental impact assessment in the EIA (Khoathane 2009).

RD-0018 applies to the pebble bed modular reactor (PBMR), but the categories of events represent a generic classification of probability of occurrence for the purpose of risk assessment and can be applied to the safety case of pressure water reactors.

4.1.3 Dose limits

Regulation R. 388 (listed in Section 4.1.1) specifies for members of the public an annual effective dose limit from all authorised actions of 1 mSv. This limit applies to the average member of the critical group within the exposed population. In addition, the NNR stipulates a dose constraint of 0.25 mSv specific to an authorised action, to ensure that the sum of the doses received by the average member of the critical group from all controlled sources would be smaller than the dose limit. A dose constraint is a prospective and source related restriction on the individual dose from a source in planned operations, which serves as an upper bound on the predicted dose in the optimisation of exposure from that source (ICRP 2007).

The NNR requires that any exposure above the natural background radiation should be kept as low as reasonably achievable (the ALARA principle). Dose limits and dose constraints must always be interpreted as upper bound limits in conjunction with the ALARA principle, inferring that exposures in practice would be lower than the dose limits and dose constraints.

The assessment for a proposed site for an NPS will consider the desired generation capacity that may consist of several nuclear reactors on a particular site. The generation capacity is evaluated as one radionuclide discharge envelope for a candidate site and the annual effective dose limit for members of the public must not exceed 1 mSv. Irrespective of the reactor technology and the number of units required for the generation capacity, the dose limit of 1 mSv shall not be exceeded and, in any event, must be demonstrated to be ALARA. This must also be viewed against specifications in the NNR Requirements Document RD-0018, which apply to the PBMR. The specifications refer to public exposure and potential health risks and can be applied similarly in the assessment of pressure water reactors. In consideration of both design and all stages of operation of a facility, as stated in RD-0018, compliance must be demonstrated to an annual design dose limit of 250 µSv for non-occupationally exposed plant personnel as well as for an average member of the critical group, considering normal operation and a representative set of AOOs. In addition, all radiation doses must be optimised by the application of the ALARA principle, with the ALARA target for normal operation set at a trivial level of about 10 µSv per year.

A dose limit for events such as DBAs is not specified in Regulation R. 388. Reference to a dose limit associated with events that have a frequency of occurrence between one in one hundred years ($<10^{-2}$ y^{-1}) and one in one million years ($\geq 10^{-6}$ y^{-1}) is made in RD-0018, which specifies an accumulated total individual design dose limit of 50 mSv per event. This applies to non-occupationally exposed plant personnel, site visitors and an average member of the critical group. Document RD-0018 is applicable to the PBMR, but the dose limit has as purpose the protection of human exposure and can be applied also in the assessment of DBAs for pressure water reactors. This dose limit can be compared with the dose of 50 mSv suggested for *'one-off'* exposures in ICRP 103 (2007). Furthermore, RD-0018 specifies that all radiation doses must be optimised by the application of the ALARA principle. If the dose to any member of the public resulting from a category B event could potentially exceed an annual individual effective dose of 1 mSv, emergency measures have to be implemented to keep the resulting dose ALARA.

The dose criteria prescribed by the NNR are summarised in Table 4.1 below:

Table 4.1: NNR dose criteria.

Events	Public dose criteria	Frequency	Source
Normal operation and anticipated operational occurrences	1 mSv/y (all sources)	$>10^{-2}$/y	Regulation R. 388 and Requirements document RD-0018
	0.25 mSv/y (a single source)		
Design basis accidents	50 mSv for a single event	$<10^{-2}$/y to $>10^{-6}$/y	Requirements document RD-0018

The dose limits for members of the public are deemed by the NNR to be protective against all adverse health effects in members of the exposed population, including cancer and hereditary effects.

4.2 The dose compliance assessment methodology

The objective of the dose compliance assessment is to assess the radioactive discharges for compliance with the NNR recommended dose limit and dose constraint for the protection of the public. These radioactive discharges are associated with the Category A and B events indicated above. The radiological doses used for the assessment of public radiation protection may be estimated either deterministically or probabilistically.

A deterministic approach calculates public dose with specific parameters that characterise the sources of the radioactive discharges, the population that may be exposed to these radioactive discharges and the pathways and processes by which these exposures may occur. Uncertainties in these parameters are accounted for by selecting conservative values that will ensure that public dose is not underestimated.

A probabilistic assessment deals with uncertainty by including a range of possible parameter values and developing a distribution of doses. Dose assessments may also be described as either prospective or retrospective assessments. A prospective assessment calculates doses that may be received in future, and a retrospective assessment considers exposures that have occurred in the past. The difference between these assessments resides in the level of certainty in the assessment. Whereas a retrospective assessment can be based on actual measured radioactivity discharges and public exposure data, a prospective assessment often has to rely on estimated values. The dose compliance assessment in this document is a prospective assessment because it considers the suitability of candidate sites for the establishment of an NPS of which the specific technology configuration and design has not yet been determined. Uncertainties are addressed by using conservative assumptions in exposure quantification to ensure that public dose is not underestimated.

Dose assessment follows a number of discrete steps. Firstly, the types and quantities of radionuclides discharged from an NPS have to be determined. The approach is based on the evaluation of radionuclide discharge data that are determined within the design parameters of the NPS. This is referred to as the *'source term'* and is discussed in more detail in Section 4.3 below.

Secondly, concentrations of radionuclides in the environment have to be estimated. This requires mathematical dispersion modelling from the discharge source to various environmental media. This step includes modelling of uptake into the food chain. Environmental concentrations of radionuclides are then considered in conjunction with land use and human behavioral data that are defined by site-specific exposure scenarios, and human exposure is quantified through inhalation, ingestion and external exposure. The pathways of exposure are discussed in more detail in Section 4.4.

Finally, dose coefficients are applied that relate radionuclide concentrations in the environment and food chain to internal and external dose rates in individuals in the exposed population. Contributions from internal and external dose are summed to derive a total effective radiological dose, as described in Section 4.5. The total effective dose is compared with a public dose limit to demonstrate regulatory compliance (see Table 4.1), taking into account the principles of ALARA.

4.3 Source term

Radioactive materials occur naturally throughout the environment – in air, water, soil and food; even the bodies of humans and animals contain radioactive substances. Discharges from an NPS represent a source of radiation in the environment and may lead to radiological exposure of humans over and above that from natural sources.

The term *'discharge'* refers to *'a planned and controlled release of radioactive nuclides to the environment'*, as described in Regulation R. 388 (listed in Section 4.1.1). Discharges during normal operation and AOOs, as well as during DBAs, are considered.

The magnitude of a discharge is defined in a source term, an expression that is commonly used to describe contaminant release data (in this case for radionuclides). The source term gives quantities of radioactivity expressed in units of becquerel (Bq) for each identified radionuclide. The source term is determined within the design parameters of the NPS as part of the overall safety case of the NPS. More than one type of nuclear power generating technology and design may be considered within the design parameters. The associated radionuclides and the discharge quantities may differ between various technologies; therefore, different source terms are possible.

The approach of developing a technology envelope (TE) for a specific site that encompasses all relevant and foreseeable discharges, without being limited to a particular reactor design, is followed in the site assessment for Nuclear-1. This approach circumvents the generation of multiple sets of dose assessment results, of which all but one will be redundant once the choice of design and technology is finalised. In stead, one set of results is developed, which encompasses all reactor designs and technologies under consideration as an upper limit of radiological discharges for the required generation capacity. Any reactor technologies can be selected to achieve the desired power generation capacity at a site, as long as it can be demonstrated that radionuclide discharges will be within the TE, thus complying with NNR dose limits and dose constraints, with due consideration to the principles of ALARA.

The technology envelope (also referred to as the plant parameter envelope) approach is in line with standard international practice and follows, in general, the approach for early site permit (ESP) applications to the US Nuclear Regulatory Commission for nuclear power plants in the USA in accordance with 10 CFR[2] Part 52 .

[2] US Code of Federal Regulations.

To demonstrate application of the TE approach in siting assessments, reference is made to the Exelon Generation Company Application for the Clinton Site[3], the ESP for Dominion's North Anna Nuclear Plant Site[4], the ESP application of Southern Nuclear Operating Company for the Vogtle Site[5] and the application of System Energy Resources Inc (SERI) for the Grand Gulf Site[6].

4.4 Potential Pathways of Exposure

Human exposure to radionuclides is a function of the environmental pathway followed from the source to the point of exposure, as well as the route through which a person would be exposed to the substance. In quantification of exposure, all potential pathways of exposure must be considered. A particular pathway can be disregarded only if it can be shown that it is not present at the site (also described as an incomplete pathway), or that its contribution to total exposure would be negligible.

The following exposure scenarios are considered and evaluated to determine the annual effective dose to the public:

- Inhalation of airborne radionuclides
- External exposure to contaminated air (cloud immersion)
- External exposure to contaminated soil (ground shine)
- External exposure to contaminated water
- Ingestion of contaminated water
- Ingestion of contaminated soil
- Ingestion of contaminated crops
- Ingestion of contaminated animal products and seafood

The conceptual source-pathway-receptor model used for the assessment is based on a description of the relevant features, events and processes associated with gaseous and liquid discharges of radioactivity to the environment that may pose a health impact, as reflected in the total effective dose to human beings.

Radioactive substances discharged into air may be dispersed from the NPS into the study area and human receptors in the critical group may be exposed to these substances. Air is thus a potential pathway of both internal and external exposures that have to be assessed. The following pathway evaluation scheme (Figure 4.1) is a diagrammatic representation of the holistic source-pathway-receptor approach followed for the assessment of radionuclide discharges into air. The transport of contaminants from source, the media transfer, and possible routes of exposure are considered in the quantification of dose.

[3] http://www.nrc.gov/reactors/new-reactors/esp/clinton.html.
[4] http://www.nrc.gov/reactors/new-licensing/esp/north-anna.html.
[5] http://www.nrc.gov/reactors/new-licensing/esp/vogtle.html.
[6] http://www.nrc.gov/reactors/new-licensing/esp/grand-gulf.html.

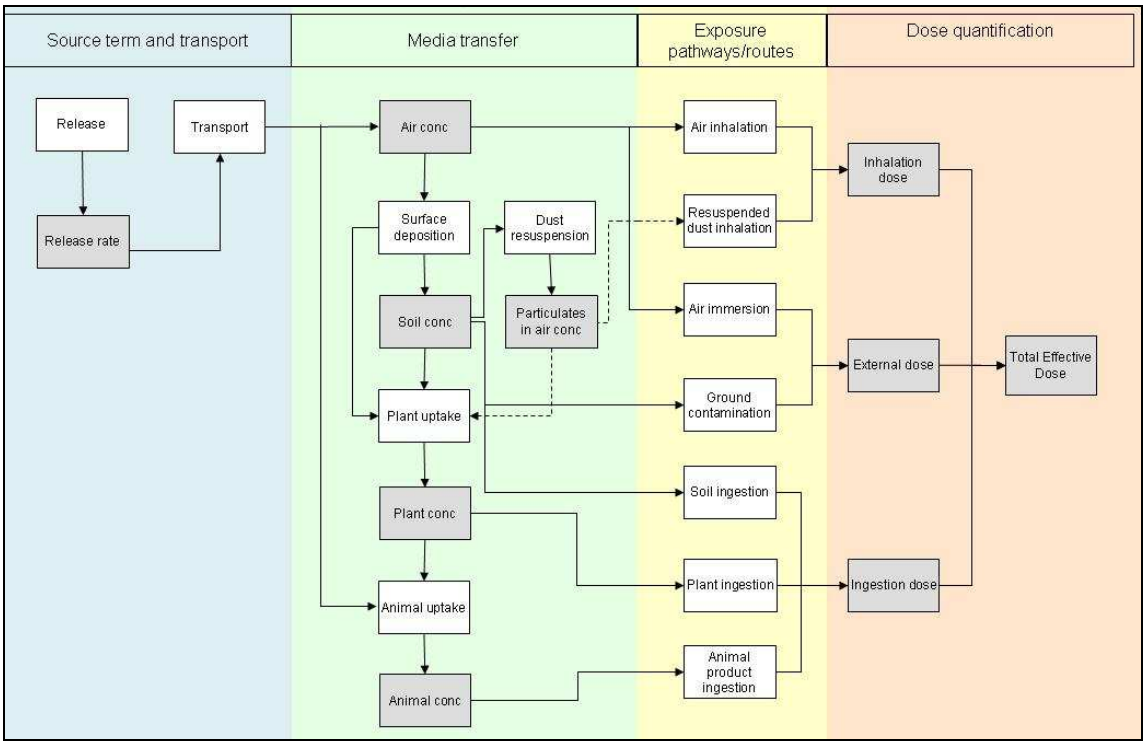

Figure 4.1: Pathway evaluation scheme for radionuclides discharged into air.

The evaluation scheme is divided into assessment compartments. The first of these compartments (source term and transport) deals with the discharge of radioactive substances into the environment. Radioactivity discharged from an NPS is dispersed through the atmosphere, followed by the deposition of the radionuclides onto the surface environment.

The media transfer compartment in Figure 4.1 evaluates how contaminants discharged into primary media such as air may move into other environmental media or the food chain. These secondary pathways would contribute to a total effective radiological dose. As shown in Figure 4.1, airborne radionuclides may be deposited onto soil, resulting in radioactivity in the soil. Similarly, radionuclides may be intercepted and deposited onto crops, and subsequently may be washed off during rain events, adding to radioactivity in the soil. Root uptake processes may contribute to crop radioactivity levels, e.g., in fruits, cereals or vegetables, and biological decay of crops containing radionuclides may in turn transfer radionuclides to soil contamination. Furthermore, some of the activity in the soil may migrate to deeper inaccessible levels of soil. Depending on the prevailing atmospheric conditions, the radionuclides deposited onto the soil may be re-suspended into air. Through the process of deposition and re-suspension, airborne radionuclides can thus be redistributed.

The activity incorporated into the crops is estimated by using a concentration factor that represents the transfer of activity from the soil to the crop. The soil-to-crop concentration factors used in this assessment are obtained from IAEA TECDOC Series 1616 (IAEA 2009).

Similarly, animal products such as meat, milk and eggs may become contaminated as a result of animals ingesting contaminated soil, feed and fodder. The activity concentration of animal products is a function of several parameters including the animal ingestion rate of contaminated soil, feed and fodder, a concentration factor to account for the transfer of activity from the soil to the animal feed and a transfer factor that represents the transfer of activity from the animal feed to the animal product. The concentration and transfer factors used in this assessment are obtained from IAEA TECDOC Series 1616 (IAEA 2009). Animal ingestion rates of soil, feed and fodder are obtained from a licensing guide published by the NNR (LG-1032, see Section 4.1.1).

Following the assessment of media transfer, the different routes of exposure relevant to each of the contaminated media, plants or animal products are considered, as illustrated in Figure 4.1. Human ingestion of contaminated crops, soil or animal products or the inhalation of airborne radionuclides would result in an internal human dose. Furthermore, exposure to a radionuclide cloud or to deposited radionuclides onto soil would contribute to an external radiation dose. The total effective dose through the atmospheric pathway is the sum of the ingestion, inhalation and external radiation doses.

Similar assessment diagrams have been developed for discharges to groundwater, surface water and the sea, as shown in Figures 4.2, 4.3 and 4.4, respectively.

Groundwater and surface water resources in the study area may be impacted through deposition of airborne radionuclides. Direct contamination of surface water and groundwater as a result of contaminated surface water run-off from an NPS is extremely unlikely due to rigorous management and is not considered to be a significant pathway for off-site radioactivity contamination.

Several environmental factors would play a role in determining the potential for human exposure. Amongst these are distribution of radionuclides in soils and sediments, dilution and transport in surface water bodies and aquifers, and uptake into the aquatic and terrestrial food chains. Considering these factors, the following pathway assessment diagrams for groundwater and surface water indicate the possible pathways and routes of exposure that are considered in dose quantification.

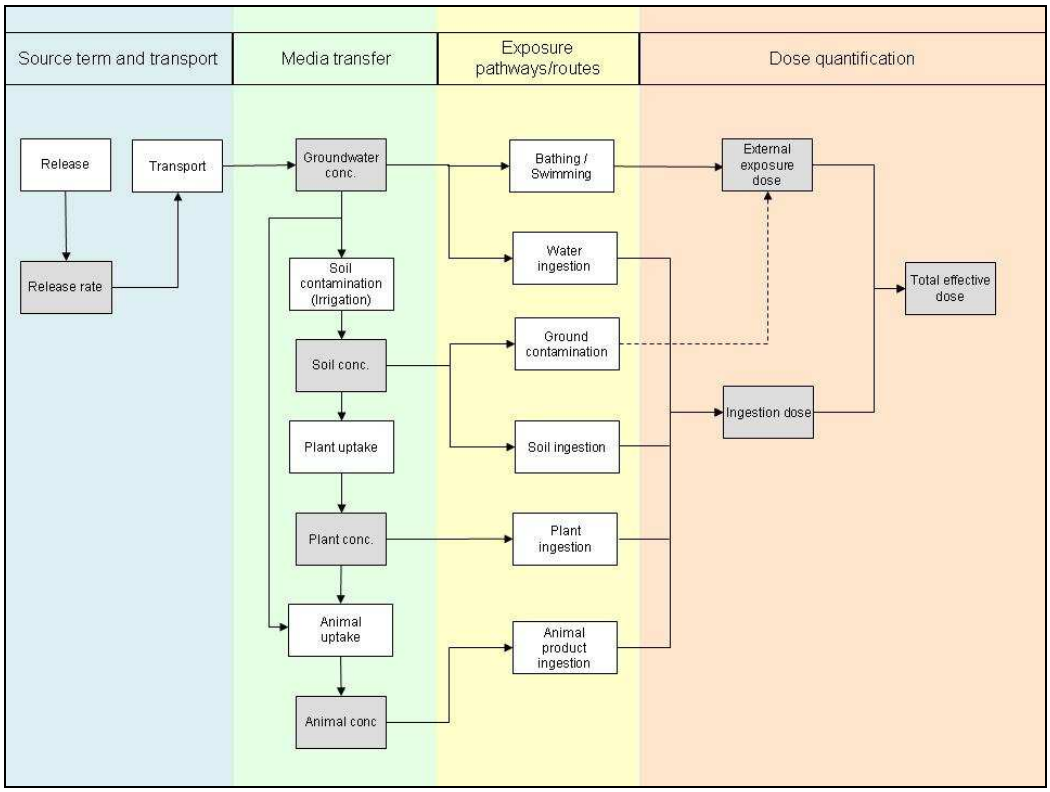

Figure 4.2: Pathway evaluation scheme for radionuclides discharged into groundwater.

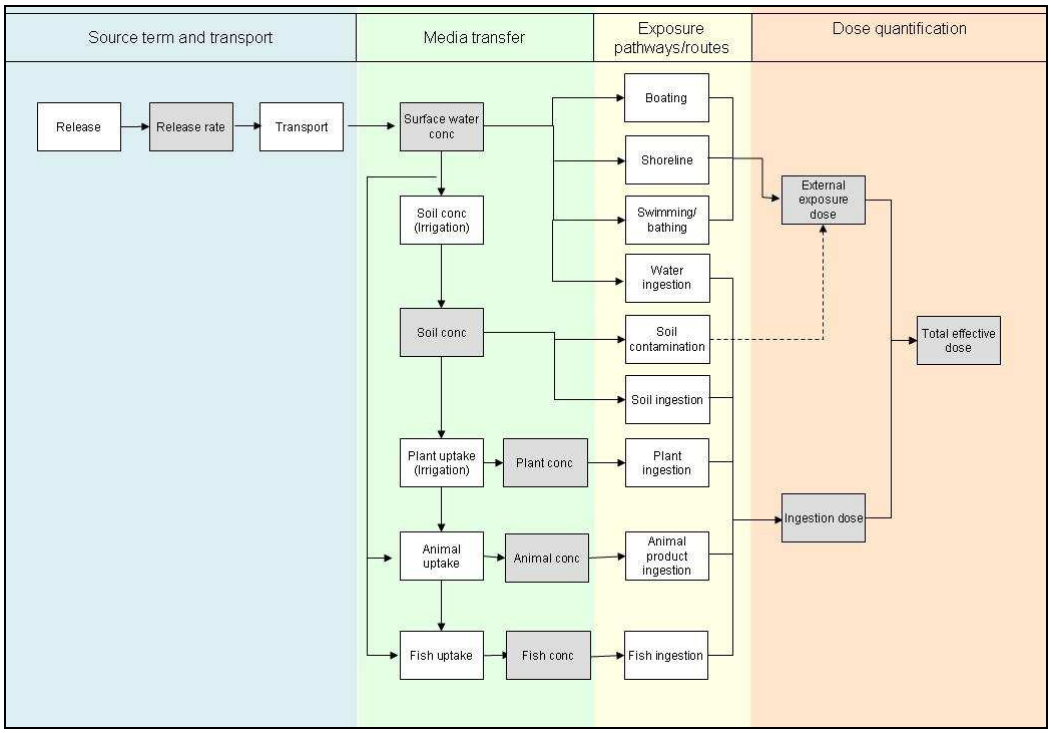

Figure 4.3: Pathway evaluation scheme for radionuclides discharged into surface water.

Liquid effluent radioactivity concentrations of an NPS as determined in the cooling water outflow to the sea is used directly, without dilution in the sea, as a conservative estimate to calculate the exposure of members of the critical group through direct and indirect exposure pathways. The exposure pathways and routes are indicated in the assessment diagram depicted in Figure 4.4.

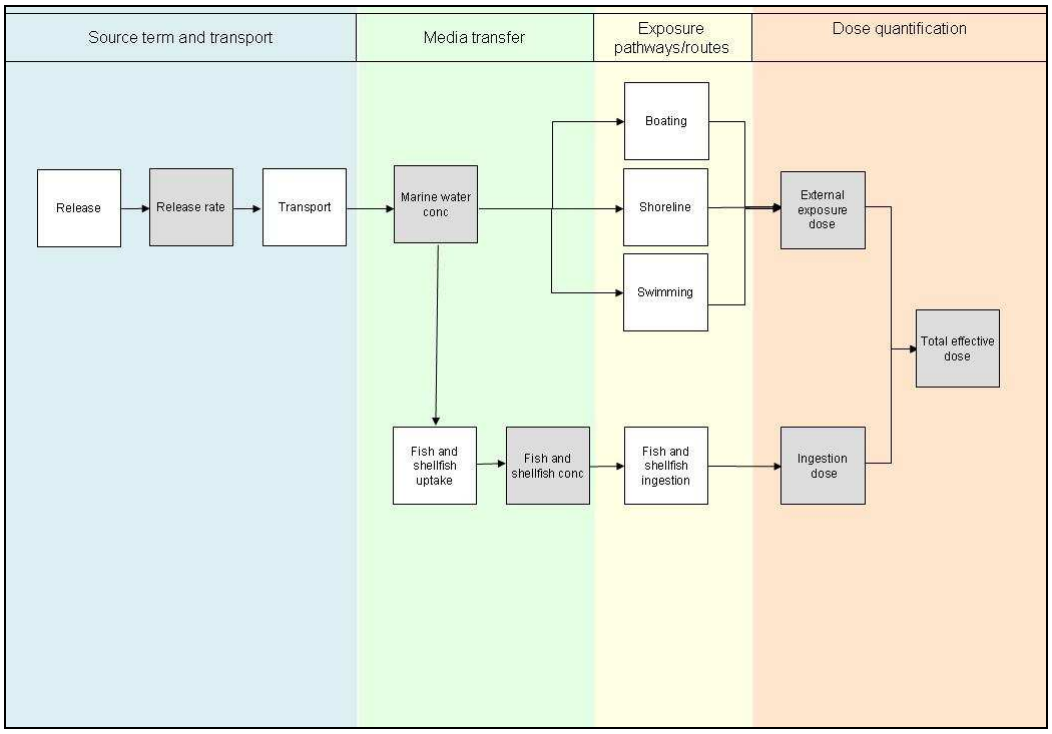

Figure 4.4: Pathway evaluation scheme for radionuclides discharged into the sea.

4.5 Dose assessment

Dose coefficients are applied to relate radionuclide concentrations in the environment and food chain to internal and external dose rates in individuals in the exposed population. The contributions from internal and external dose are summed to derive a total effective dose. Dose due to inhalation and ingestion is calculated using dose conversion factors (DCF) specified in ICRP-72 (ICRP 1996) applicable to the following age groups: 0-2 years, 2-7 years, 7-12 years, 12-17 years and adults.

The dose from external exposure to a cloud of radionuclides in the air (cloud immersion) and exposure to contaminated soil (ground shine) are calculated from the radionuclide concentrations in air and soil, multiplied by appropriate DCFs and the period of exposure. The nuclide-specific external DCFs used in the calculation of dose for the different age groups are as published by Eckerman and Ryman (1993).

The radiological dose received through the ingestion of different commodities is a direct function of the radionuclide concentration of the commodity and the rate at which the commodity is consumed by members of the public.

Once radioactivity concentrations in commodities have been determined, the internal dose from human ingestion of the commodities and contaminated water is calculated from the ingestion rate and the nuclide-specific, age-dependent DCFs for ingestion, as obtained from ICRP-72 (ICRP 1996). The age-dependent ingestion rates of the different commodities used in the assessment are obtained from the NNR LG-1032 licensing guide (See Section 4.1.1).

All effective doses received by the public through all potential exposure pathways are summed and the resulting total effective dose is compared with a public dose limit or dose constraint to demonstrate regulatory compliance.

For purposes of the EIA, it is assumed that quantified radiological doses through all pathways and routes of exposure at any of the sites with a proposed new NPS will be within the NNR dose limits and dose constraints for public exposure. Furthermore, application of the ALARA objective should assure that doses will in fact be lower than the dose limit and dose constraints.

5 IMPACT IDENTIFICATION AND ASSESSMENT

5.1 Impact identification

5.1.1 Construction phase

The construction phase is expected to have a short time span relative to the operational phase and would therefore exclude chronic health effects such as cancer. The impact of non-radioactive substances (welding fumes, paint etc.) is expected to be localised to the construction site and it is assumed that members of the public will not be allowed in this area. These exposures should be assessed and managed in accordance with occupational exposure limits. Environmental dust generation from the site will be controlled in accordance with a health risk management plan, based on ambient air quality guidelines and standards.

There will be no nuclear fuel on site during the construction phase and the only radiological impact would be due to natural background levels. These levels may increase slightly due to natural radioactivity in construction materials, but impacts associated with naturally occurring radioactive material (NORM) during construction of a nuclear power station would not be significantly different from other construction projects that use natural materials. Impacts associated with radiation exposure during the construction phase are thus not regarded as significant.

5.1.2 Operational phase

There is no direct evidence of increased risk of noncancer diseases at doses below about 100 mSv (ICRP 2007) and such health outcomes are not regarded as significant in the impact identification. The NNR dose limits are much lower than 100 mSv, as presented in Section 4.1.3. The primary concern about exposure to ionising radiation in the low dose region is the potential for development of radiogenic cancers and heritable disease. These effects are interpreted as stochastic in nature, with no threshold, and they increase in frequency in proportion to the radiation dose (ICRP 2007). Potential impacts must therefore be assessed in terms of the interpretation of the non-threshold nature of stochastic effects. All exposures must be assessed, even cases where exposures may be very low.

The dose assessment methodology described in Section 4 will be applied for quantification of radiological dose to the critical group for each candidate site. The quantified doses for the site-specific exposure scenarios are compared with the NNR dose limits and dose constraints (Table 4.1), considering also the rigorous application of the ALARA principle.

5.1.3 Decommissioning

In accordance with Regulation No. R. 388 (see Section 4.1.1), a decommissioning strategy must be submitted to the NNR as part of the prior safety assessment that is

to be conducted prior to commencement of operations. This decommissioning strategy has to be updated throughout the operation of the NPS as a basis for detailed decommissioning planning and for authorisation of specific actions or phases of decommissioning, with due regard to dose limits and probabilistic risk limits as stipulated in Regulation No. R. 388 and its Annexures 2 and 3. Decommissioning will thus be under rigorous regulatory control, ensuring health risks ALARA. Assessment of radiological impacts during decommissioning should thus be within the same framework as the assessment of the operational phase, as presented in Section 5.2 below.

5.1.4 The no-go scenario

Because of the insignificant impacts of an NPS on public health due to regulatory control through dose limits and dose constraints, as well as through the rigorous application of the ALARA principle, there would be no measureable difference at any of the proposed sites in the frequency of cancer, hereditary effects and other diseases that may be associated with exposure to ionising radiation whether an NPS is constructed or not. These considerations are discussed in Section 5.2 below.

5.2 Impact Assessment

The NNR will issue a license for a site for construction of an NPS only if full compliance with the dose limits and dose constraints is demonstrated. The dose limits and dose constraints apply to the concept of a TE, within which any reactor technologies can be accommodated for the required generation capacity at a particular site.

Submissions to the NNR will demonstrate that the combined impact of gaseous and liquid discharges of radioactive substances will be below regulatory public dose limits, dose constraints and in accordance with the ALARA objective. The primary concern is the risk of developing radiogenic cancer.

The cancer risk range that is deemed acceptable in various parts of the world is from 1 case in a million to 1 case in ten thousand. This risk range reflects a *de minimis* lifetime risk that is so trivial that any action to reduce risk is not warranted (Kocher and Hoffman, 1994).

The NNR regulatory dose limit of 1 mSv/year is an upper limit of exposure, representing a level of *de manifestis* risk, above which regulatory action would be taken to reduce risks (Kocher and Hoffman, 1994).

The importance of the ALARA objective in controlling exposures of the public is demonstrated by the fact that for nuclear facilities in the USA, the average annual individual dose is only 0.05 per cent of the annual dose limit of 1 mSv for all controlled sources combined. Individuals who receive the highest dose (the critical group) normally do not receive more than about 10 per cent of the dose limit and often substantially less (Till and Grogan, 2008). This is achieved through rigorous application of the ALARA objective. The NNR follows similar rigorous application of

the ALARA objective and doses to members of the public will be controlled with similar effectiveness.

ICRP (2007) has proposed a nominal cancer risk coefficient of 0.055 per Sv for the whole population, for the purpose of estimating conservative upper-limit cancer risks when radiological exposures are known. Application of this nominal cancer risk coefficient produces cancer risk estimates that in practice would not be higher than the calculated value, but most likely would be lower. For exposures below the annual dose limit of 1 mSv, as required by the ALARA principle, the upper limit of cancer risk would be in the *de minimis* lifetime risk range. This conservative approach confirms that cancer risks to members of the community would be trivial under the application of the rigorous regulatory control of the NNR. Protection against the development of radiogenic cancer is considered to be adequate for protection against hereditary effects and other radiation-associated diseases. The potential impact on human health due to exposure to ionising radiation from an NPS during normal operation and AOOs under these conditions is therefore assessed as of low significance.

The assessment of DBAs has indicated that the probability of occurrence of such events is very small during the operational lifetime of an NPS. However, it will be demonstrated in the submission to the NNR that the dose to the critical group during such an event would be within the dose limit of 50 mSv and ALARA. The potential impact due to DBAs is therefore assessed as of low significance over the lifetime of an NPS.

Dose compliance assessments are conducted on the side of caution, because the dose limits apply to members of the so-called *critical group*, which represents the highest exposed individuals. Other members of the community would receive even lower doses.

6 MITIGATION

The likelihood of adverse health impacts associated with radiological exposure due to an NPS is regarded as remote. A key focus of accident prevention has long been the use of multiple precautionary defences against the consequences of failures. This approach of *'defence in depth'* is aimed at preventing equipment failures and human errors and mitigating their consequences, should any of these happen. Comprehensive assessment methodologies are applied in the design phase of nuclear installations by applying such methods as failure-mode and effects analysis, cause-consequence analysis and fault tree analysis, to select components and materials that have an extremely low probability of failing during operation. Furthermore, should components or materials fail, or should human errors lead to consequences that may have adverse effects on human health and the environment, several layers of backup systems and other controls are automatically introduced to stop the propagation of the IE or to mitigate its consequences.

In addition to regulatory dose constraints and dose limits set to protect human health, the NNR also applies the ALARA principle, thereby assuring by a large margin of safety that radiological doses to members of the community would be in the *de minimis* lifetime risk range.
Furthermore, should radiological doses approach the *de manifestis* level of risk, the NNR would intervene by taking regulatory action to reduce the risk. There are thus several layers of mitigation to protect human health against the consequences of radiological exposure.

7 CONCLUSIONS AND RECOMMENDATIONS

This report has outlined the methodologies that will be followed to quantify exposure of members of the community to ionising radiation. The approach considers site-specific scenarios for multiple pathways of exposure. The quantified radiological doses will be assessed in terms of regulatory requirements of the NNR. The assessments for the candidate sites must demonstrate compliance with the NNR dose limits and dose constraints, and must also take into consideration the principles of ALARA. Should a calculated dose be within the acceptable NNR requirements and ALARA, it can be concluded that the cancer risk would be within the *de minimis* lifetime risk range. Protection against the development of radiogenic cancer is considered to be adequate for protection against hereditary effects and other radiation-associated diseases.

The calculation based on applying the ICRP (2007) nominal cancer risk coefficient to estimated radiological doses should be regarded as a rough estimate of cancer risk, considered to be on the side of caution, thus designed to overestimate rather than underestimate risk. In the absence of detail of the reactor technologies for an NPS, as is the case in this assessment, this approach provides the best available information for the purposes of the EIA. The risk assessment can however be refined considerably where reactor technologies and radionuclide source data are available. Based on what is known about radiological doses at NPSs elsewhere in the world (Till and Grogan, 2008), it is expected that risk quantification based on technology-specific source terms within a TE as outlined in Section 4.1.3 would demonstrate cancer risks well below the conservative estimate presented in this document.

For purposes of the EIA, it is acknowledged that the NNR will issue a license for the establishment of an NNR at any particular site only if full compliance with the radiological dose limits and dose constraints is demonstrated, taking into account the principles of ALARA and all other matters relating to the overall safety case. Considering the methodologies for dose assessment that have been presented in this report, it is recommended that the approach be accepted as adequately protective against adverse health effects to members of the community.

8 REFERENCES

Airshed. *Air Quality Impact and Climatology Assessment Study*. Airshed Planning Professionals (Pty) Ltd. 2009.

Eckerman, K.F. and Ryman, J.C. Federal Guidance Report No. 12, External Exposure to Radionuclides in Air, Water, and Soil, *Report EPA-402-R-93-081*, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831. 1993.

Harrison, J.D. and Phipps, A.W. *Comparing man-made and natural sources of radionuclide exposure. National Radiological Protection Board, Chilton, Didcot, Oxon. OX11 0RQ. Consultative Exercise on Radiation Risks of Internal Emitters (CERRIE).* Paper presented at the BNES Conference (Health Effects of Low-level Radiation) in Oxford, 22-24 September 2000.

IAEA. Quantification of Radionuclide Transfer in terrestrial and Freshwater Environments for Radiological Assessments. *IAEA TECDOC Series 1616*, 3 August 2009.

ICRP. Age Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients. *International Commission on Radiological Protection Publication 72 Volume 26 No. 1*. Published for the ICRP by Pergamon Press, Oxford. 1996.

ICRP. Assessing Dose of the Representative Person for the Purpose of Radiation Protection to the Public. *International Commission on Radiological Protection Publication 101*, Edited by J Valentin. Published for the ICRP by Elsevier Ltd., Oxford. 2006.

ICRP. Recommendations of the ICRP - Annals of the ICRP Volume 37/2-4. *International Commission on Radiological Protection Publication 103*, Published for the ICRP by Elsevier Ltd., Oxford. 2007.

Khoathane M. Emergency Response Environmental Impact Assessment Report. 2009.

Kocher, D.C. and Hoffman F.O. A Proposed Framework for Consistent Regulation of Public Exposures to Radionuclides and Other Carcinogens. *Oak Ridge National Laboratory Review Vol. 26, No. 1*. 1994.

NRC. *Health risks from exposure to low levels of ionizing radiation: BEIR VII, Phase 2 / Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, Board on Radiation Effects, Research Division on Earth and Life Studies*, National Research Council of the National Academies. 2006.

SRK. Geohydrology Environmental Impact Report. SRK Consulting. 2009.

Till, J.E. and Grogan, H.A. (Ed). *Radiological Risk Assessment and Environmental Analysis.* Oxford University Press. 2008.

World Nuclear Association. *Radiation and Life*. 2002. http//www.world-nuclear.org/education/ral.htm.