Appendix D17

Kareerand TSF Expansion Project: Radiological Public Impact Assessment

- AquiSim Consulting, 2020

GCS
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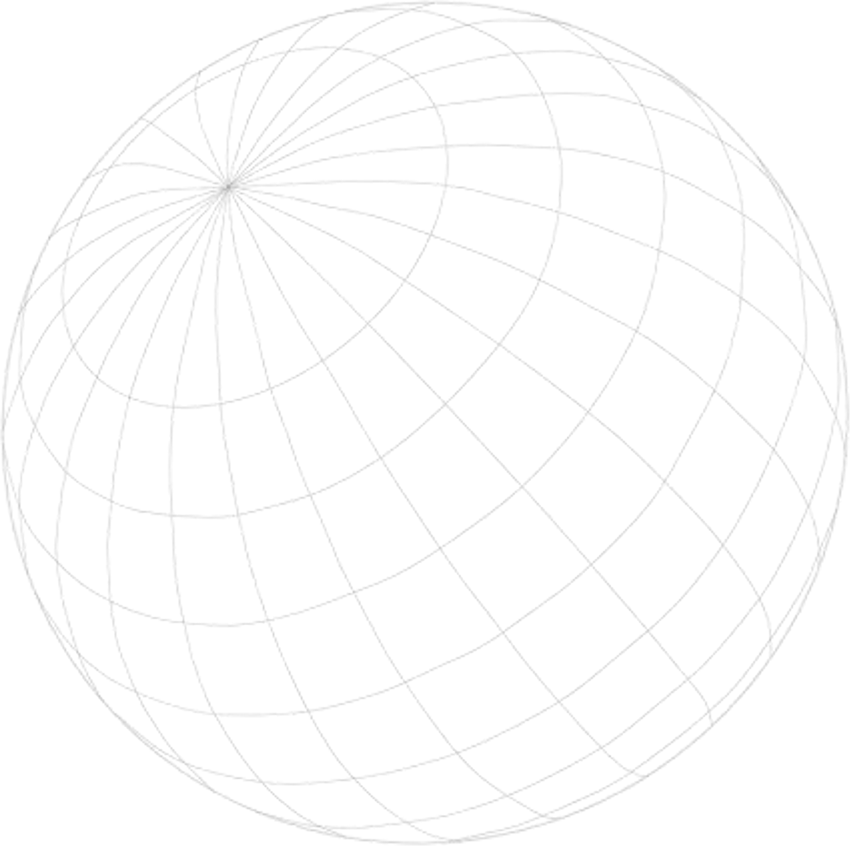
Consultants

Kareerand TSF Expansion Project: Radiological Public Impact Assessment



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Technical Report

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EXECUTIVE SUMMARY

Mine Waste Solutions (MWS) is in the process of applying for the expansion of the Kareerand Tailings Storage Facility (TSF), with due considering of revised tailings production forecast rates and land ownership constraints.

The Kareerand TSF was designed with an operating life of 14 years, taking the operation of the facility to the year 2025, and having a total design capacity of 352 million tonnes. After commissioning of the TSF, MWS was acquired by AngloGold Ashanti (AGA) and the tailings production target has increased by an additional 485 million tonnes, which will require operations to continue until the year 2042. The additional tailings, therefore, require an extension of the design life of the Kareerand TSF.

The proposed extension will be to the west of the current TSF and will cover an additional area of approximately 380 ha.

AquiSim Consulting (Pty) Ltd (AquiSim) was commissioned by Mine Waste Solutions as Radiation Protection Specialist (RPS) to perform the Radiological Public Safety Assessment of the Kareerand Project. The purpose of this report is to present the Radiological Public Safety Assessment of the Kareerand Project in a comprehensive, systematic, and transparent manner that is consistent with the NNRA and NEA, as well as with NNR requirements and regulations in general (NNR process). The public safety assessment was then used as a basis to present the radiological public impact assessment in a manner that is consistent with the NEMA and EIA regulations (EIA process).

To evaluate the potential radiological impact on members of the public, radiation exposure conditions were defined to evaluate the contribution through the surface water, groundwater, and atmospheric pathways. To evaluate the potential contribution of the groundwater pathway, hypothetical conditions supplemented with site-specific conditions were considered to illustrate the radiological impact.

- It was illustrated that the dissolution of radionuclides, the leaching and subsequent migration of radionuclides through an aquifer is a slow process and it would take hundreds to thousands of years to migrate to an abstraction borehole a few hundred meters from the TSF. A source duration of both 1,000 and 2,000 years was considered.
- It was illustrated that for the assumed conditions, the potential contribution from the groundwater pathway at a point 300 m from the current Kareerand TSF is only visible in hundreds of thousands of years, and potentially at doses that are below 100 μSv.year^{-1}.

The contribution from radon inhalation to the radiological impact to members of the public was evaluated separately.

- With the Kareerand TSF as the only contributing source, it was illustrated that the contribution from the radon inhalation dose is less than 100 μSv.year^{-1} 200 m outside the southern TSF boundary.

The Commercial Agricultural Exposure Condition was defined to evaluate the radiological consequences to members of the public practising commercial farming near the Kareerand Project. The assumed conditions are very conservative, which means that the exposure condition is equally relevant to any agricultural activities practices anywhere near the Kareerand Project.

- It was illustrated that the south and south-east of the Kareerand TSF, the impact is the most significant and the total effective dose is less than 250 µSv.year^{-1} within 200 m from the edge of the TSF. Within 1,000 m, the total effective doses for the'0 to 2 years' age group is less than 100 µSv.year^{-1}.
- It was illustrated that at actual receptor locations along the Vaal River and around the Kareerand Project, the total effective doses are all less than 30 µSv.year^{-1} with the radon inhalation and food and soil ingestion the dominant pathways.

The radiological impact assessment rating makes a distinction between the different phases of the project (i.e., construction, operation, and post-closure) as well as the contribution of the atmospheric, surface water and groundwater pathways, as appropriate. The reason for the latter is because the timescales over which the pathways contribute to a potential radiological impact to members of the public differs. Where required, mitigation or management options are proposed for activities during the different phases, followed by an impact rating for the revised (mitigated) conditions.

Activities that will be performed during the construction phase of the Kareerand Project will not involve the handling, processing, or releasing radioactive material to the environment *per se*. This means that the potential radiological impact on members of the public through the relevant pathway during the construction phase is negligible.

The tables below present the significant rating for the activities associated with the operational and post-closure phases of the Kareerand Project. The management objective is first to ensure that the radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint), and secondly to optimise the radiation protection by applying the ALARA principle. From the mitigation and management of the impact perspective, the following was noted:

- The total effective dose as a contribution from radon gas released from the Kareerand TSF is well below the regulatory compliance criteria, which means that from a compliance perspective no additional management or mitigation measures are required.
- The radon exhalation rate from the surface of tailings material is determined by several factors, of which moisture content is one. This means that at the wet beach and pool areas of the TSF, the radon exhalation rate will be reduced marginally. However, it is not effective to wet the whole TSF deep enough (2 to 4 m) to reduce the radon exhalation rate marginally. The most effective way to reduce the radon exhalation rate is to provide a covering layer. This will increase the diffusion length to allow for the decay of the radon progeny before being released from the tailings surface.

Dimension	**Rating**	**Motivation**	**Significance**
Impact Description: Exhalation and dispersion of radon gas to the atmosphere during the operational phase of Kareerand Project			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 135
Severity	Insignificant (1)	The potential impact of the radon exhalation and subsequent dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of airborne radon gas exhaled from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near the TSF to be affected by radon inhalation above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Exhalation and dispersion of radon and the subsequent contribution to a radon inhalation dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Exhalation and dispersion of radon gas is not visible and require environmental measurements to detect an increase in the airborne radon concentration	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the radon exhalation and subsequent dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of airborne radon gas exhaled from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by radon inhalation above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Exhalation and dispersion of radon and the subsequent contribution to a radon inhalation dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Exhalation and dispersion of radon gas is not visible and require environmental measurements to detect an increase in the airborne radon concentration	

Dimension	**Rating**	**Motivation**	**Significance**
Impact Description: Emission and dispersion of particulate matter that contains radionuclides to the atmosphere during the operational phase of Kareerand Project.			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the dispersion of dust that contains radionuclides beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of dust emitted from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near the TSF to be affected by dust dispersed into the environment above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of dust that contains radionuclides and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	Dispersion of dust is visible and can be observed without much effort. Note that the annual averages are used.	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 117
Severity	Insignificant (1)	The potential impact of the dispersion of dust that contains radionuclides beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of dust emitted from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by dust dispersed into the environment above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of dust that contains radionuclides and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	Dispersion of dust is visible and can be observed without much effort. Note that the annual averages are used.	

Dimension	**Rating**	**Motivation**	**Significance**
Impact Description: Release of contaminated water that contains radionuclides into the environment during the operational phase of Kareerand Project.			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 70
Severity	Significant (3)	The unauthorised release of contaminated water that contains radionuclides to the environment can be significant and slightly harmful	
Spatial Scale	Local (3)	The unauthorised of contaminated water that contains radionuclides to the environment can be beyond the mining rights area into the immediate surroundings	
Duration	Immediate (1)	The unauthorised of contaminated water that contains radionuclides to the environment has to be reported as an Incident with the NNR. It t is unlikely that the duration will be beyond 1 month	
Frequency of activity	Improbable (1)	The unauthorised of contaminated water that contains radionuclides to the environment is unlikely to occur more than once a year	
Frequency of impact	Very Seldom (2)	Even if the activity occurs, it is very seldom that it will lead to a public radiation exposure condition	
Legal Issues	Fully covered by legislation (5)	The release of contaminated water that contains radionuclides to the environment covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	The unauthorised of contaminated water that contains radionuclides can be observed without much effort.	
Post-Mitigation / Management			
Nature	Negative		Low Risk (negative) – 48
Severity	Small (2)	With the implementation of a management programme, the impact of the activity can be small	
Spatial Scale	Local (3)	The unauthorised of contaminated water that contains radionuclides to the environment can be beyond the mining rights area into the immediate surroundings	
Duration	Immediate (1)	The unauthorised of contaminated water that contains radionuclides to the environment has to be reported as an Incident with the NNR. It t is unlikely that the duration will be beyond 1 month	
Frequency of activity	Improbable (1)	The unauthorised of contaminated water that contains radionuclides to the environment is unlikely to occur more than once a year	
Frequency of impact	Almost never (1)	With the implementation of a management programme, the impact will occur almost never	
Legal Issues	Fully covered by legislation (5)	The release of contaminated water that contains radionuclides to the environment covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Immediately (1)	With the implementation of a management programme, the activity will be detected almost immediately.	

- The total effective dose as a contribution from the windblown dust released from the Kareerand TSF (PM_{10} and TSP) is well below the regulatory compliance criteria, which means that from a compliance perspective no additional management or mitigation measures are required.
- From a dose optimisation perspective, mitigation measures that are in line with the measures proposed in the air quality impact assessment will contribute to a reduction in the total effective dose if applied for the duration of the operational period.

The scope of the assessment was limited to the Kareerand Project and did not make provision for a regional assessment to evaluate cumulative effects. Also, the application of the dose constraint as regulatory compliance criteria opposed to the dose limit of 1 mSv.year^{-1} (or 1,000 µSv.year^{-1}), is to allow for the cumulative impact from more than one operation in an area. In other words, by constraining Kareerand Project in terms Regulation 388 to 250 µSv.year^{-1}, provision is made for a cumulative impact while still in compliance with the public dose limit of 1,000 µSv.year^{-1}.

The radiological monitoring plan defined for the Project made a distinction between baseline characterisation and the routine monitoring programme to implement. The objective of the baseline characterisation is to establish the radiological condition of the site and associated infrastructure to develop an appropriate radiation management plan, and to establish the radiological characteristics of radioactive material associated with the TSFs. The following activities were proposed:

The table below summarises the proposed monitoring programme for Kareerand Project aimed at public radiation protection. Most of the monitoring points proposed to be part of the monitoring programme coincide with the monitoring programme for the environmental pathways.

Monitoring Element	Comment	Frequency
Surface water	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Biannually
	Total Uranium and Thorium, and Ra-226	Quarterly
Sediments	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Annually
	Total Uranium and Thorium, and Ra-226	Biannually
Groundwater	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Once every two years
	Total Uranium and Thorium, and Ra-226	Biannually
Radon gas	Environmental radon using Radon Gas Monitors (RGMs)	Quarterly for a period of 2 to 3 month
Dust fallout	Total Uranium and Thorium, and Ra-226	Quarterly

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1 Introduction

1.1 General

Mine Waste Solutions (MWS) is in the process of applying for the expansion of the Kareerand Tailings Storage Facility (TSF), with due considering of revised tailings production forecast rates and land ownership constraints.

The Kareerand TSF was designed with an operating life of 14 years, taking the operation of the facility to the year 2025, and having a total design capacity of 352 million tonnes. After commissioning of the TSF, MWS was acquired by AngloGold Ashanti (AGA) and the tailings production target has increased by an additional 485 million tonnes, which will require operations to continue until the year 2042. The additional tailings, therefore, require an extension of the design life of the Kareerand TSF.

The proposed extension will be to the west of the current TSF and will cover an additional area of approximately 380 ha.

Naturally occurring radionuclides associated with the uranium, thorium and actinium decay series are associated with the gold-bearing reefs of the Witwatersrand Basin that are present in the area. These naturally occurring radionuclides are, therefore, present in ore brought to the surface for processing and consequently are also carried through to the mining and mineral processing residues generated through these processes, such as tailings. Materials and residues that contain naturally occurring radionuclides are generally referred to as Naturally Occurring Radioactive Materials (NORM) (IAEA, 2007a).

Due to the presence of naturally occurring radionuclides, NORM has the potential to impact negatively on the health of humans that are exposed to these materials (Marsh *et al.*, 2010). Given the nature of tailings storage facilities as NORM, the possibility exists that the Kareerand Project will change how members of the public are currently exposed to radiation-induced by the naturally occurring radionuclides present in the tailings material.

1.2 Regulatory Context

In South Africa, the protection of human health and the environment from adverse effects associated with exposure to ionizing radiation is regulated in terms of the National Nuclear Regulator Act (NNRA) (Act 47 of 1999) and the Nuclear Energy Act (NEA) (Act No. 46 of 1999). The NNRA established the National Nuclear Regulator (NNR) as the statutory body responsible for regulating the nuclear industry, as well as regulating NORM associated with the mining and mineral processing industry. The legal limit for material to be classified as *radioactive* in terms of national standards (published in terms of the NNRA) is 0.5 $Bq.g^{-1}$ or 500 $Bq.kg^{-1}$ (radionuclide specific).

Section 22 (1) of the NNRA states:

> "*Any person wishing to engage in any action which is capable of causing nuclear damage (Section 2(1)(c)) may apply in the prescribed format to the chief executive officer for a Certificate of Registration (CoR) and must furnish such information as the board requires*".

AngloGold Ashanti holds a Certificate of Registration (CoR-02) issued by the NNR for the Vaal River Operations and CoR-30 for the MWS Operations located near the Vaal River Operations. The Kareerand Project means a change in the current scope of CoR-30. According to the NNR regulatory process, Mine Waste Solutions, therefore, must obtain nuclear authorisation from the NNR for the Kareerand Project by submitting an Authorisation Change Request (ACR). One of the key documents submitted to the NNR as part of the ACR application is a radiological public safety assessment.

Also, the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA) and the Environmental Impact Assessment (EIA) Regulations, dated 2014 (as amended in 2017) require that the impact of specific activities be assessed and an EIA and an Environmental Management Programme report (EMPr) be submitted to the Department of Environmental Affairs (DEA).

Mine Waste Solutions commissioned AquiSim Consulting (Pty) Ltd (AquiSim) as Radiation Protection Specialist (RPS) to perform the Radiological Public Safety Assessment of the Kareerand Project according to the provision, requirements, and guidelines of the NNR (NNR process) and to perform the radiological public impact assessment according to the NEMA and EIA regulations (EIA process).

1.3 Naturally Occurring Radionuclides and Background Radiation

Many radioactive isotopes (or radionuclides) occur naturally throughout the Earth's crust and are present in rocks, soils, river water, as well as in seawater. Most of these naturally occurring radionuclides are members of four radioactive series identified as the uranium (U-238), actinium (U-235), thorium (Th-232), and neptunium (Np-237)[1] series, named according to the radionuclides that serve as progenitor (or parent) to the series products. Naturally occurring radionuclides that are of particular interest to radiation protection that is not members of the four decay series include isotopes of potassium (K-40) and rubidium (Rb-87) (Martin, 2006b).

In undisturbed environmental conditions, these naturally occurring radionuclides form part of the natural background radiation, to which all humans are exposed daily through the air they breathe, the water they drink, the soil they live and work on, as well as the food they eat (Kathren, 1998). The annual average total dose, over the population of the world, is about 2.8 mSv. As indicated in Figure 1.1, over 85% of this total is from natural sources (2.4 mSv), with about half (1.2 mSv) coming from radon decay products in the home.

Medical exposure of patients accounts for 14% of the total (0.4 mSv), whereas all other artificial sources — fallout, consumer products, occupational exposure, and discharges from the nuclear

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[1] Primordial sources of Np-237 no longer exist because its half-life is only 2.1 million years (Martin, 2006), which means that natural sources of Np-237 decayed to insignificant levels since their creation some 4.5 billion years ago.

industry — account for less than 1% of the total value. Other natural background radiation sources include cosmic radiation, gamma radiation, and internal radiation in the body (IAEA, 2004a).

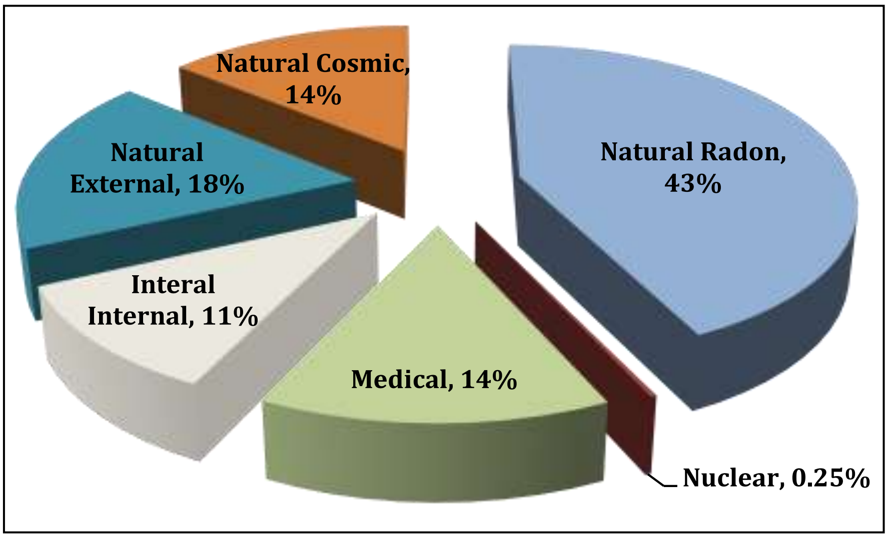

Figure 1.1 Distribution of the background radiation contribution as a percentage of the annual dose, average over the population of the world [Reproduced from IAEA (2004a)].

In addition to the natural background radiation, practices that exploit the earth's resources may enhance the potential for human exposure to naturally occurring radionuclides by way of their products, by-products, residues and wastes. Industries such as mining and mineral processing operations and associated facilities and activities have the potential to alter the natural background radiation and potentially increase radiation exposure by:

- Moving naturally occurring radionuclides from inaccessible locations to locations where humans can be exposed;
- Increasing the concentration of radionuclides in the accessible environment; or
- Changing the chemical or physical environment, so that immobile radionuclides become more mobile in the natural environment (e.g. more soluble in water, or more transportable by wind).

1.4 Purpose of This Report

GCS Water and Environment (Pty) Ltd (GCS) have been appointed as the independent Environmental Assessment Practitioners (EAP) to align Kareerand Project with the NEMA and associated EIA Regulations (see Section 1.1). Due to the presence of naturally occurring radionuclides and thus NORM, the potential radiological impact to nearby members of the public was identified as one of the key issues of concern during the scoping phase of the EIA process (GCS, 2018a).

It follows from Section 1.2 that Mine Waste Solutions must obtain nuclear authorisation by submitting an ACR to the NNR for the Kareerand Project to address the change in the current scope of CoR-30.

The purpose of this report is consequently to present the radiological public safety assessment of the Kareerand Project in a comprehensive, systematic and transparent manner that is consistent with the NNRA and NEA, as well as with NNR requirements and regulations in general (NNR process). The public safety assessment will then be used as a basis to present the radiological public impact assessment in a manner that is consistent with the NEMA and EIA regulations (EIA process).

1.5 Scope and Structure of the Report

The report assumes a basic understanding of ionizing radiation and the effects of exposure to ionizing radiation on human health and the environment. If more information is needed on these subjects, the interested reader is referred to readily available literature resources, an example of which is a document entitled '*Radiation, People and the Environment*' published by the International Atomic Energy Agency (IAEA, 2004a) or the IAEA online Safety Glossary (IAEA, 2018).

The scope of the report is limited to documenting the potential radiological impact to members of the public that reside near Kareerand Project as it pertains to exposure to naturally occurring radionuclides potentially released and dispersed into the environment from Kareerand Project. As such the occupational exposure of workers to ionising radiation or exposure to non-radiological elements are excluded from the scope of the report, as well as general matters related to mine health and safety.

Different approaches can be followed to perform an assessment of this nature, none of which is considered as the singular or correct approach. What is important is that the approach selected is fit for purpose and ensures confidence in the assessment results with due consideration of the graded approach to safety assessment (IAEA, 2009a). The conceptual framework used to perform the radiological impact assessment for Kareerand Project is schematically illustrated in Figure 1.2. It resembles the International Atomic Energy Agency (IAEA) ISAM (Improvement of Safety Assessment Methodologies) methodology developed for the safety assessment of near-surface radioactive waste disposal facilities (IAEA, 2004b). It is inherently systematic and structured and allows for the continual improvement of the assessment or components of the assessment through successive iterations.

It follows from Figure 1.2 that the assessment framework consists of several interrelated elements. Each of the elements is addressed as a different section in the report, with an overall structure as follows:

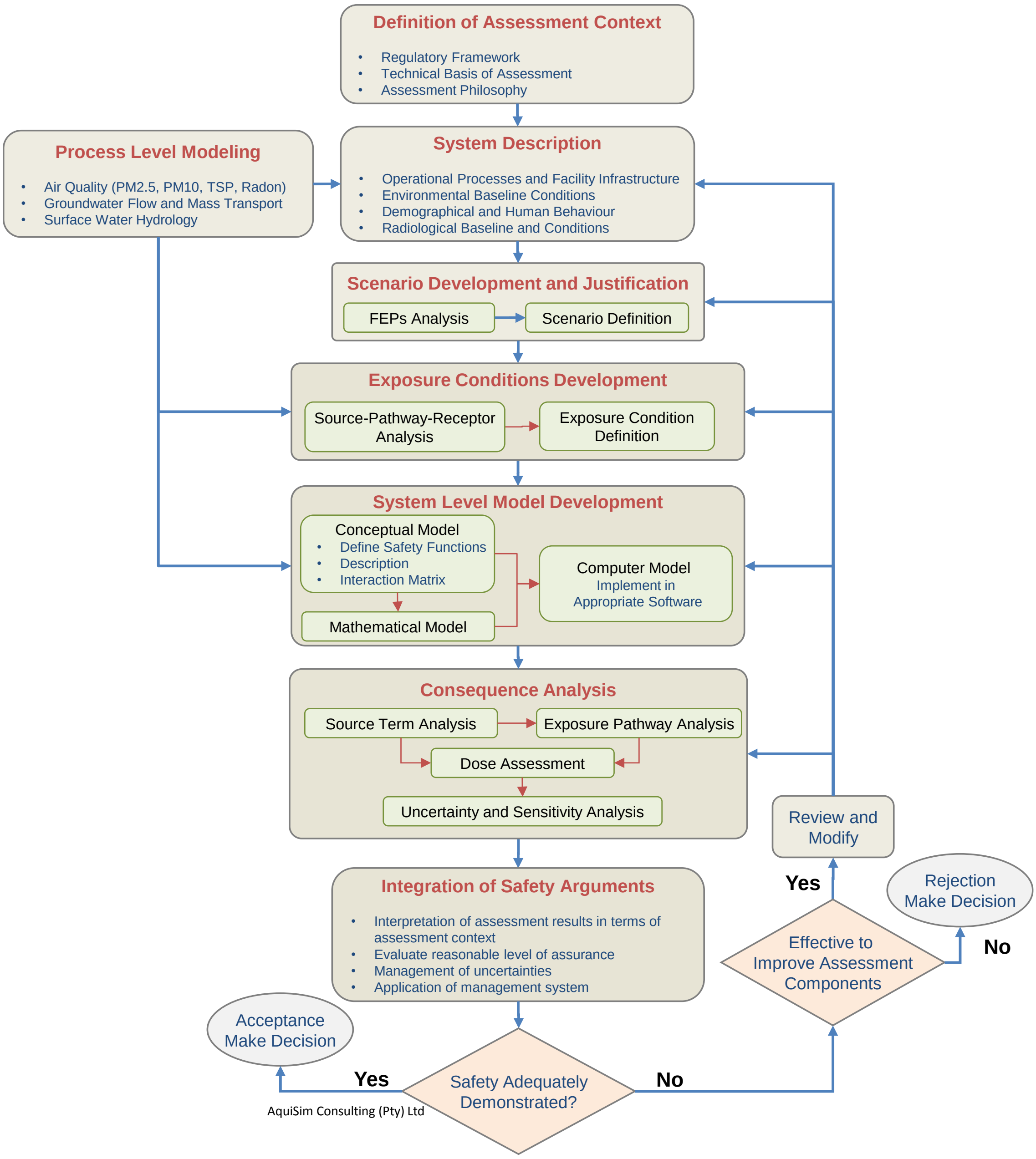

Figure 1.2 Conceptual framework used for the radiological public safety and impact assessment of Kareerand Project.

- Section 2 presents the overview of the assessment context that defines the high-level assumptions and constraints imposed on the assessment, with the focus on the nuclear regulatory framework.
- Section 3 describes the areas and activities associated with the Kareerand Project and includes the regional and local setting and the associated operational components. An overview of the physical environment and the human receptors potentially affected is also presented as appropriate.
- Section 4 presents a discussion of the conditions of public exposure considered for the assessment. The section starts with a source-pathway-receptor analysis as derived from the

project and environmental system descriptions, followed by a definition of discrete sets of public exposure conditions.

- Section 5 is a discussion of the calculation approach used to estimate the total effective doses, calculate the doses for the public exposure conditions and discuss the results in terms of regulatory compliance criteria.
- Section 6 is devoted to the impact assessment rating for the construction, operational and post-closure phases of Kareerand Project.
- Section 7 defines the radiological monitoring plan for Kareerand Project that include the monitoring programme and the proposed monitoring locations.
- Section 8 presents some overall conclusions and recommendations for the improvement of public radiation safety, with Kareerand Project impact assessment as a basis.

2 Assessment Context

2.1 General

The purpose of the assessment context is to define in simple terms the *basis* or *context,* within which the radiological public safety assessment of the Kareerand Project was conducted. Generally, it consists of a set of high-level assumptions and constraints that defines the boundary conditions within which the assessment was performed. This includes the regulatory framework that applies to the assessment as presented in Section2.2 and the technical basis of the assessment as presented in Section 2.3.

2.2 Nuclear Regulatory Framework

2.2.1 General

The regulatory framework is defined by a combination of national legislation (see Section 1.1), and regulations, as well as guidance and requirements defined in terms of this legislation. The national framework is supplemented with principles, requirements, and guidance from international organisations concerned with radiation protection and the management of radioactive waste, including NORM.

Regulations regarding safety standards and regulatory practices in South Africa were Gazetted in 2006 (Regulation No. 388 dated 28 April 2006). Regulation No. 388 deals with Safety Standards and Regulatory Practices and defines the standards and principles that must be met to ensure safety at any nuclear installation (e.g. nuclear power plants, medical facilities, research centres and any other industrial applications of radiation sources), including mining and mineral processing facilities.

In 2013, the NNR published Regulatory Guide RG-002 entitled: "*Safety Assessment of Radiation Hazards to Members of the Public from NORM Activities*". RG-002 is intended to provide guidelines to holders and prospective holders of NNR authorisations on how to conduct prior and operational public safety assessments for activities and operations involving NORM.

The international framework for radiation protection in the nuclear, medical, and mining industries is well established and recognised. According to IAEA (2004a), organisations that play a key role in this regard include the *United Nations Scientific Committee on the Effects of Atomic Radiation* (UNSCEAR), the *International Commission on Radiological Protection* (ICRP), and the *International Atomic Energy Agency* (IAEA).

The Basic Safety Standards (BSS) published in 1996 was a cornerstone of the IAEA safety standards for many years (IAEA, 1996). GSR Part 3 in the General Safety Requirement series "*Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*" (IAEA, 2014) is now available and supersedes the BSS. The overall objective of the publication is to establish requirements (i.e. *shall* statements) for the protection of people and the environment from harmful effects of ionizing radiation and the safety of radiation sources.

2.2.2 The ICRP System of Radiological Protection

The ICRP recommended a System of Radiological Protection having the primary aim of providing an appropriate standard of protection for human beings without unduly limiting beneficial practices derived from radiological materials (ICRP, 1991).

To achieve this, the system is intended to prevent the occurrence of deterministic effects by keeping doses below the relevant threshold. It also ensures that all reasonable steps are taken to reduce the induction of stochastic effects by keeping doses as low as reasonably achievable (ALARA) with economic and social factors being taken into account (ICRP, 2000).

The ICRP System of Radiological Protection is based on three key principles. The first two principles are source-related and apply in all exposure situations, while the third principle is related to exposure of an individual and applies in planned exposure situations (ICRP, 1991):

- *The Principle of Justification*: Any decision that alters the radiation exposure situation should do more good than harm. This means that by introducing a new radiation source, coupled with reducing existing exposure and reducing the risk of potential exposure, one should achieve sufficient individual or societal benefit to offset the detriment it causes.
- *The Principle of Optimisation of Protection*: The likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable (ALARA), considering economic and societal factors.
- *The Principle of Application of Dose Limits*: The total dose to any individual from regulated sources in planned exposure situations (other than medical exposure of patients) should not exceed appropriate limits.

In its revised System of Protection (ICRP, 2007), three types of exposure situations are recognised. The exposure situations are intended to cover the entire range of possible exposures, and are described as follows:

- *Planned Exposure Situations*: Planned exposure situations involve the deliberate introduction and operation of sources. It may give rise to exposures that are anticipated to occur (normal exposures) and to exposures that are not anticipated to occur (potential exposures);
- *Emergency Exposure Situations*: Emergency exposure situations refer to unexpected situations that may occur during the operation of a planned situation, or from a malicious act, or from any other unexpected situation that requires urgent action to avoid or reduce undesirable consequences.
- *Existing Exposure Situations*: Existing exposure situations refer to exposure situations that already exist when a decision on control must be taken, including prolonged exposure situations after emergencies or those caused by natural background radiation.

2.2.3 Safety Standards for Protection of the Public

To avoid severely inequitable outcomes of the optimisation procedure, there should be restrictions on the doses or risks to individuals from a source of radiation exposure. The regulatory tools that can be used to achieve this are dose or risk constraints and reference levels.

In planned exposure situations, the ICRP recommends that public exposure is controlled by the procedures of optimisation below the source-related constraint and using dose limits. In an emergency or existing exposure situations, the ICRP uses the term ‘reference level’ for the restriction on dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur, and below which optimisation of protection should be implemented.

The ICRP recommends that any exposure caused by human activity above natural background radiation should be kept as low as reasonable achievable (ALARA), economic and social factors being taken into account, but below the following individual dose limits (ICRP, 1991):

- The individual dose limit for public exposure in planned exposure situations is 1 mSv.year^{-1}.
- In special circumstances, an effective dose up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year, can be applied.
- Also, the ICRP recommends equivalent dose limits of 15 mSv in a year to the lens of the eye and 50 mSv in a year to the skin.

The ICRP further recommends that consideration must be given to the presence of other sources that may cause simultaneous radiation exposure to the same group of the public. Allowance for future sources must be kept in mind so that the total dose received by an individual member of the public does not exceed the dose limit.

For this reason, dose constraints that are lower than the dose limit and typically around 0.1 to 0.3 mSv per year are proposed to ensure that 1 mSv per year is not exceeded. Dose constraints are thus set separately for each source under control and they serve as boundary conditions in defining the range of options for optimization. *Note that* the *dose constraint is not a dose limit* (IAEA, 2014); *exceeding a dose constraint does not represent non-compliance with regulatory requirements*, but could result in follow-up actions (IAEA, 2014).

The dose limits for public exposure presented in Schedule III of GSR Part 3 (IAEA, 2014) are consistent with the limits defined in ICRP (1991):

- An effective dose of 1 mSv in a year;
- In special circumstances (e.g., in authorized, justified, and planned operational circumstances that lead to transitory increases in exposures), a higher value of effective dose in a single year could apply, provided that the average effective dose over five consecutive years does not exceed 1 mSv per year;
- An equivalent dose to the lens of the eye of 15 mSv in a year; and
- An equivalent dose to the skin of 50 mSv in a year.

This means that the criteria of 1 mSv in a year adopted for the protection of the public in South Africa in Regulation No. 388 are consistent with the ICRP and IAEA recommendations for public exposure. Regulation No. 388 dose constraint of 0.25 mSv in a year for public exposure per CoR holder is also within the range of 0.1 to 0.3 mSv per year proposed by the ICRP and IAEA.

2.2.4 National Radioactive Waste Management Policy and Strategy

The purpose of the National Radioactive Waste Management Policy and Strategy (NRWMP) published in 2005 (DME, 2005) is:

> *To ensure the establishment of a comprehensive radioactive waste governance framework by formulating, additional to nuclear and other applicable legislation, a policy, and implementation strategy in consultation with all stakeholders.*

Within the national framework, the NRWMP is viewed as the starting point for the definition and selection of an appropriate solution for the management of radioactive waste. One of the issues addressed in the NRWMP is options for managing radioactive waste generated through the nuclear industry, as well as waste containing unconcentrated natural occurring radioactive materials from the mining and minerals processing industries.

In guiding the national strategy for radioactive waste management, several strategic points of references in dealing with radioactive waste are defined. Two of the guiding principles that are of importance in terms of managing NORM is Principle No. 4 and Principle No. 13 (DME, 2005):

> *The aim (of a radioactive waste management strategy) shall be to achieve a maximum degree of passive safety in storage and disposal (Principle No. 4)*.
>
> *The deliberate dilution of radioactive waste is not acceptable, however, in the case of NORM waste, the dilution of higher concentration material with lower concentration material will be considered if all relevant regulatory concerns are addressed (Principle No. 13)*.

In implementing the NRWMP, South Africa followed the IAEA guidelines regarding the definition and classification of radioactive waste as presented in IAEA (1994b) (unless deviations therefrom can be justified). Note that when the NRWMP was drafted in 2005, the waste classification scheme was in line with the IAEA waste classification scheme applicable at the time and presented in IAEA (1994b). The IAEA classification scheme has subsequently been revised and is presented in IAEA (2009b).

The NRWMP further provides several options for NORM management. The options available depend on the classification of the NORM as either low activity (long-lived radionuclide concentration < 100 Bq.g^{-1}) or enhanced activity (long-lived radionuclide concentration > 100 Bq.g^{-1}). Table 2.1 summarises the management options available to each of these classes of NORM waste.

Table 2.1 Management options for Low Activity NORM and Enhanced Activity NORM as defined in DME (2005).

Low Activity NORM (less than 100 Bq.g^{-1})	Enhanced Activity NORM (more than 100 Bq.g^{-1})
Reuse NORM as underground backfill material in an underground area	
Extraction of any economically recoverable minerals from the NORM, followed by disposal in any mine tailings dam or another sufficiently confined surface impoundment	
Authorised disposal	Regulated deep or medium depth disposal
Clearance	

2.3 Technical Basis of the Assessment

2.3.1 General

A radiological public safety assessment can be performed for different purposes as part of the overall management of an operation, facility or activity. As the operation, facility or activity moves from a pre-operational to the post-closure phase, the purpose, scope and focus of these assessments may vary. Before operations commence, a pre-operational safety assessment is performed on a *prospective* basis to assess whether the proposed operations do not pose a radiological risk to workers and members of the public above the regulatory compliance criteria. Once operational, the prospective assessment is updated with a facility and site-specific safety assessment, as appropriate. The purpose of this section is to define the technical basis of the assessment, which is largely defined by the purpose, scope and focus of the assessment, but *inter alia* the spatial and temporal boundary conditions and associated assessment endpoints.

2.3.2 Stakeholders to the Assessment

A radiological safety assessment is generally undertaken to provide confidence to stakeholders that an operation, facility or activity does not pose a radiological risk to exposure groups, notably workers and members of the public.

As used here, stakeholders are groups or individuals with an interest in the radiological safety of an existing or proposed operation, facility or activity. In some cases, these groups may have specific interests that may affect the purpose, scope and focus of the assessment. This may result in additional assessment endpoints to be considered, or consideration as to how the assessment results are to be presented. For this reason, including the list of stakeholders as part of the technical basis in the assessment context report is justified.

Generally, the stakeholders include management and technical staff responsible for the design, implementation and operation of facilities or activities, as well as regulatory authorities, workers, members of the public and environmental interest groups. Viewed from this perspective the main stakeholders or target audience include the following:

- Regulatory authorities that include the NNR as a statutory body responsible for regulating NORM and that is responsible for monitoring the process to ensure that the operational activities are performed according to relevant regulatory guidance and requirements;
- GCS as the Independent Environmental Practitioner responsible for the alignment of Kareerand Project with the NEMA and associated EIA Regulations;
- Management of MWS as the owners and operators of Kareerand Project;
- Workers at the Kareerand Project;
- Members of the public living near the Kareerand Project,
- Mining and industry, in particular the interested mining and mineral processing operations near the Kareerand Project; and
- Technical, scientific and environmental groups that might have an interest in the approach followed for the assessment and the subsequent results.

2.3.3 Purpose of the Assessment

Any company endeavouring to develop a mining or mineral processing operation must undergo a rigorous permitting effort to convince regulators and public stakeholders that the mining, milling, and associated processing facilities can be developed, operated, decommissioned, and closed without threatening worker and public health, nearby communities, and the environment (Chambers *et al.*, 2012).

A key element in this process is the radiological public safety assessment, which can be defined as analysis to evaluate the performance of the overall system (e.g. mining and mineral processing operation, facility or activity) and its impact, where the performance measure is radiological safety to members of the public and workers (IAEA, 2007b). This definition is consistent with Regulation No. 388.

The regulatory framework (see Section 2.2) is clear on the overall safety objective (IAEA, 2006) and associated need to protect human health and the environment over the timescales of concern for all facilities and activities, including mining and mineral processing operations (IAEA, 2009a; ICRP, 2000). These assessments are required for all facilities and activities, including new or existing mining and mineral processing operations. Viewed from this perspective and complemented with the EIA regulations in terms of the NEMA, the purpose of the radiological public safety assessment is twofold:

- To demonstrate that members of the public residing near the Kareerand Project will not be exposed to levels of ionizing radiation released to the environment above the regulatory compliance criteria set for public exposure as defined in Section 2.2.3; and
- To assess the radiological impact on members of the public living near the Kareerand Project as input into the EIA process. The basis for the impact assessment is the outcome of the radiological safety assessment and is performed according to the criteria specified in Section 2.3.7.3.

2.3.4 Scope and Focus of the Assessment

2.3.4.1 Natural Background Radiation

The contribution of naturally occurring radionuclides to background radiation was introduced in Section 1.2. Nationally and internationally, the contribution of natural background radiation is not amenable to regulatory control. The focus of this assessment is thus on the radiation exposure contribution induced by the Kareerand Project, *above natural background radiation*. This means the background radiation is not included in the comparison of the total effective dose with the regulatory compliance criteria.

The approach that is followed for this purpose is to determine a source term (release rate) of radioactivity to the environment, estimate the dispersion of released radioactivity into the environment, and evaluate the subsequent interaction of members of the public with the affected environmental media. Where necessary and justified, this assessment approach is complemented by actual environmental measurements and observation to quantify the dose contribution to members of the public.

2.3.4.2 Site-Specific Assessment

The assessment is based on site-specific data as far as practically possible and justified. Where appropriate and justified, the site-specific data and information were supplemented with values from the literature. However, all the assumptions and conditions used in the assessment were documented accordingly.

2.3.4.1 Assessment of Exposure to Radiation

NORM may pose hazards to humans or the environment not only from the presence of naturally occurring radionuclides, but also from toxic elements and compounds present in their products, by-products, residues, and wastes. The focus of the assessment was radiation exposure induced by naturally occurring radionuclides and excludes any health risk considerations that may arise due to non-radioactive substances or any other health and safety aspect.

2.3.4.2 Contaminants of Concern

The contaminants of concern were those naturally occurring radionuclides associated with the uranium and thorium decay series. These series and their radiological properties are listed in Table A 1 to Table A 3 and are illustrated schematically in Figure A 1 (see Appendix A).

Uranium is a high-density metallic element that occurs naturally in the earth's crust at an average abundance of approximately 3 ppm. Naturally occurring uranium consists of three isotopes, all of which are radioactive, namely U-238, U-235, and U-234. U-238 and U-235 are the parent nuclides of two independent decay series, while U-234 is a decay product of the U-238 series. A third decay series, which is usually included as part of an assessment considering naturally occurring radionuclides, is that of the thorium (Th-232) isotope. Pure thorium is a soft and very ductile substance that readily combines with oxygen at ambient temperatures. It, therefore, occurs naturally as black Thorium oxide and is almost three times as abundant as uranium.

Exposure to the isotopes of uranium, thorium and their progeny (i.e. daughter products), has been linked to detrimental health impacts in humans based on their property of emitting ionizing radiation and the extensive weight of evidence provided by epidemiological studies of radiogenic health effects in humans (Klaassen, 2001). However, not all the radionuclides in these decay series contribute equally to a total effective dose.

Radionuclides that pose a significant risk to human health are identified from their dose conversion factors and reported half-lives. Only those radionuclides that can be shown to make a significant contribution to a total effective dose are considered. These radionuclides are:

- Alpha (α) emitters: U-234, U-235, U-238, Th-230, Ra-226, Po-210, Pa-231, Th-232 and Th-228.
- Beta (β) emitters: Ac-227, Pb-210 and Ra-228.

Where applicable, radioactive decay and in-growth were taken into consideration in the assessment, not only to avoid overly conservative results in the case of the slower transport processes but also to account for the impact of the relevant decay products.

Secular equilibrium[2] was assumed between parent and daughter products in cases where analyses results of the daughters are not available. This implies that in the absence of analytical results, the following assumptions are applied:

- Po-210 = Pb-210 = Ra-226 = Th-230 = U-234 = U-238.
- Ra-224 = Th-228 = Ra-228 = Th-232.
- Ra-223 = Ac-227 = Pa-231 = U-235.

2.3.4.3 Cumulative Effect

The ICRP principles and consistent national safety standards set limits for the protection of human health and the environment from all radiation exposure situations or practices. This implies that limits set for the protection of members of the public are from all potential contributing operations near the Kareerand Project.

The focus of the assessment is on the contribution of the Kareerand Project to the annual effective dose to members of the public. Other potential sources of radionuclides in the area include operational and historic gold mining activities associated with the AngloGold Ashanti Vaal River Operations as well as other operations in the area. The scope of the assessment does not cater for a regional radiological safety assessment to include *all* potential operational activities and sources in the area. However, recognition is given to the potential contribution from these and other operations to a total effective dose through the application of the regulatory dose constraint.

2.3.4.4 Assessment of Non-Human Biota

The concept of developing dose limits for non-human biota has been raised by the ICRP in Publication 103 (ICRP, 2008) and Publication 108 (ICRP, 2009), but no specific guidance about dose limits or an assessment framework for practical application has been developed. However, neither the NNR (NNR, 2013) nor Regulation No. 388 requires at present that the impact to non-human biota be addressed.

A major problem is the complexity and variability of the natural environment. As an example, most of the research to protect the environment and its application is being done in northern European countries, which has a different natural environment than in South Africa. Radiological impact on non-human biota is thus excluded from the scope of the safety assessment, since it is assumed that if individual humans are shown to be adequately protected, then non-human biota is also being protected, at least at the species level (ICRP, 1991).

2.3.5 Spatial Domain of Concern

The spatial domain considered in the assessment is largely dictated by an understanding of the processes governing the movement of radionuclides and potential exposure pathways for the

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[2] Secular equilibrium is a steady state condition of equal activities between a long-lived parent radionuclide and its short-lived daughter. The criterion upon which secular equilibrium depends is given in L'Annunziata (1998).

potentially exposed groups. While physical boundaries cannot be applied rigorously to some of these processes, a 3 to 5 km radius around the environmental release points defines the area environmental pathways need to be considered. If justified, a wider study area may be defined to accommodate processes governing the movement of radionuclides beyond these boundaries. Since the intent of the analysis is to evaluate critical groups, the exposure locations to be evaluated are likely to be near the sources, which mean that the spatial scale is likely to be limited by the selected exposure conditions.

2.3.6 Assessment Timescales

The life cycle of operations, facilities and activities can be considered as three distinct periods, namely a pre-operational period (i.e. design, construction, and commissioning period), an operational period, and a post-operational or post-closure period. A period of active or passive institutional control may apply to the post-closure period. The national regulations concerned with nuclear authorization does not provide specific guidance on the period or conditions to assume for institutional control.

The NNR Regulatory Guide RG-002 (NNR, 2013) requires an assessment of the operational period. However, it also states that consideration should be given to the effect of long-lived radionuclides. Consequently, the assessment primarily addressed the radiological impact associated with the operational period. However, an attempt was made to address the radiological impact that may occur in the distant future to the extent possible and justified.

Note that an assessment of the potential radiological impact during the operational phase can be performed with a greater level of certainty since the conditions at present or in the near future are known or can be more reliably predicted than conditions after the start of the operational period. Conditions during the post-closure period are even more uncertain.

2.3.7 Assessment Endpoint

2.3.7.1 General

Assessment (or calculation) endpoints for a safety assessment is determined by the regulatory framework, as well as the purpose, scope, and focus of the assessment. In some cases, the target audience or stakeholders may determine additional assessment endpoints to consider. While quantitative endpoints are most common for a safety assessment, in some cases qualitative endpoints may also be required.

2.3.7.2 Radiological Public Safety Assessment Endpoints

The focus of the assessment was the radiological impact on members of the public near the Kareerand Project (see Section 2.3.2). More specifically, the objective was to quantify the release and subsequent distribution of radioactivity into and through the environment, and the subsequent interaction of members of the public with the environmental media.

Consistent with the ICRP System of Protection (see Section 2.2.2), the primary assessment endpoint was the annual total effective dose rate (unless otherwise stated, the term dose refers to the annual individual effective radiation dose, calculated using the method described in ICRP

(1991) to workers and members of the public). This is consistent with the NNR requirements for the radiological protection of members of the public and adopted in the Safety Standards and Regulatory Practices presented in Regulation No. 388.

2.3.7.3 EIA Criteria

GCS prescribed a methodology whereby the significance of each impact was evaluated. Clearly defined rating and rankings scales presented in Table 2.2 to Table 2.7 were used to assess the impacts associated with the proposed activities. Each identified impact was then rated according to the expected magnitude, duration, scale and probability of the impact, as presented in Table 2.9.

To ensure uniformity, the assessment of potential impacts was addressed in a standard manner so that a wide range of impacts is comparable. For this reason, a clearly defined rating scale was used to assess the impacts associated with their investigation. Each identified impact was assessed in terms of scale (spatial scale), magnitude (severity) and duration (temporal scale). The risk is then based on the consequence and likelihood using the following relationship:

Risk = Consequence x Likelihood

where consequence was determined as follows:

Consequence = Severity + Spatial Scale + Duration

and the likelihood of the activity was calculated based on the frequency of the activity and impact, how easily it can be detected, and whether the activity is governed by legislation, through the following relationship:

Likelihood = Frequency of activity + Frequency of impact + Legal issues + Detection

To assess each of these factors for each identified impact, the ranking scales presented in Table 2.2 to Table 2.7 were used.

Table 2.2 Severity of the impact.

Insignificant / non-harmful	1
Small / potentially harmful	2
Significant / slightly harmful	3
Great / harmful	4
Disastrous / extremely harmful / within a regulated sensitive area	5

Table 2.3 Spatial Scale - How big is the area that the aspect is impacting on?

Area-specific (at impact site)	1
The whole site (entire surface right)	2
Local (within 5km)	3
Regional / neighboring areas (5km to 50km)	4
National	5

Table 2.4 Duration.

One day to one month (immediate)	1
One month to one year (Short term)	2
One year to 10 years (medium-term)	3
Life of the activity (long term)	4
Beyond the life of the activity (permanent)	5

Table 2.5 Frequency of the activity - How often do you do the specific activity?

Improbable / almost never / Annually or less	1
Low probability / Very seldom / 6 monthly	2
Medium probability / Infrequent / Temporary / Monthly	3
Highly probable / Often / semi-permanent / Weekly	4
Definite / Always / permanent / Daily	5

Table 2.6 Frequency of the incident/impact - How often does the activity impact on the environment?

Almost never / almost impossible / >20%	1
Very seldom / highly unlikely / >40%	2
Infrequent / unlikely / seldom / >60%	3
Often / regularly / likely / possible / >80%	4
Daily / highly likely / definitely / >100%	5

Table 2.7 Legal Issues - How is the activity governed by legislation?

No legislation	1
Fully covered by legislation	5

Table 2.8 Detection - How quickly/easily can the impacts/risks of the activity be detected on the environment, people and property?

Immediately	1
Without much effort	2
Need some effort	3
Remote and difficult to observe	4
Covered	5

Environmental effects were rated as either of high, moderate or low significance on the basis provided in Table 2.9.

Table 2.9 Impact Ratings.

RATING	CLASS
1 – 55	(L) Low Risk
56 – 169	M) Moderate Risk
170 – 600	(H) High Risk

Table 2.10 Impact assessment calculation.

Consequence = Severity + Spatial Scale + Duration
Likelihood = Frequency of Activity + Frequency of Incident + Legal Issues + Detection
Significance\Risk = Consequence X Likelihood

3 System Description

3.1 Introduction

The purpose of the system description is to provide a summary overview of the Kareerand Project, with specific reference to the facilities, activities, and associated infrastructure that constitute the Kareerand Project. This information is normally complemented with a description of the prevailing site characteristics and potentially affected human populations located near Kareerand Project.

The section is structured as follows. Section 3.2 presents the regional and local setting of Kareerand Project, followed by a description of the local land cover and use conditions in Section 3.3. Section 3.4 describes Kareerand Project, processes and associated infrastructure as well as the waste or by-products generated as part of these processes, highlighting the areas and activities that may contribute to the release and dispersion of naturally occurring radionuclides into the environment. With the various specialist studies prepared as part of the EIA for Kareerand Project as the primary source of information, Section 3.5 is limited to a summary of these studies and reports that describes the baseline environmental conditions and the population characteristics observed near Kareerand Project. Section 3.7 summarises the radiological data presently available for Kareerand Project.

3.2 Site Location

Figure 3.1 shows that regionally the Kareerand Project is located in the western portion of the Witwatersrand Basin, some 160 kilometres (km) from Johannesburg in the Republic of South Africa. The Kareerand Project falls within the City of Matlosana and JB Marks Local Municipalities, both of which are in the Dr Kenneth Kaunda District Municipality within the North-West Province.

The Kareerand Project is located approximately 15km south-east of the MWS Plant in Stilfontein, approximately 8km East of Klerksdorp, 15km north-east of Orkney and 2.7km south-east of Khuma Township. It is situated in a loop of the Vaal River, with the river being approximately 2km to the east and 3km to the south of the Kareerand TSF. The proposed expansion will abut the western side of the existing facility as shown in Figure 3.1.

3.3 Land Capability and Land Use

The land capabilities in the area range from moderate to very poor quality arable soils with areas of moderate to low economic potential, and wilderness and wetlands. The strong correlation between soil depth and structure and the capability of the land is evident across the area, with the shallow and sensitive soils being confined to low-intensity grazing and wilderness activities such as game farming, and deeper and less sensitive soils being utilized for better quality (higher density) grazing and some cultivation of annual crops (GCS, 2018a).

The land capability of the areas was consequently classified into four classes namely wetland, arable land, grazing land and wilderness (GCS, 2018a).

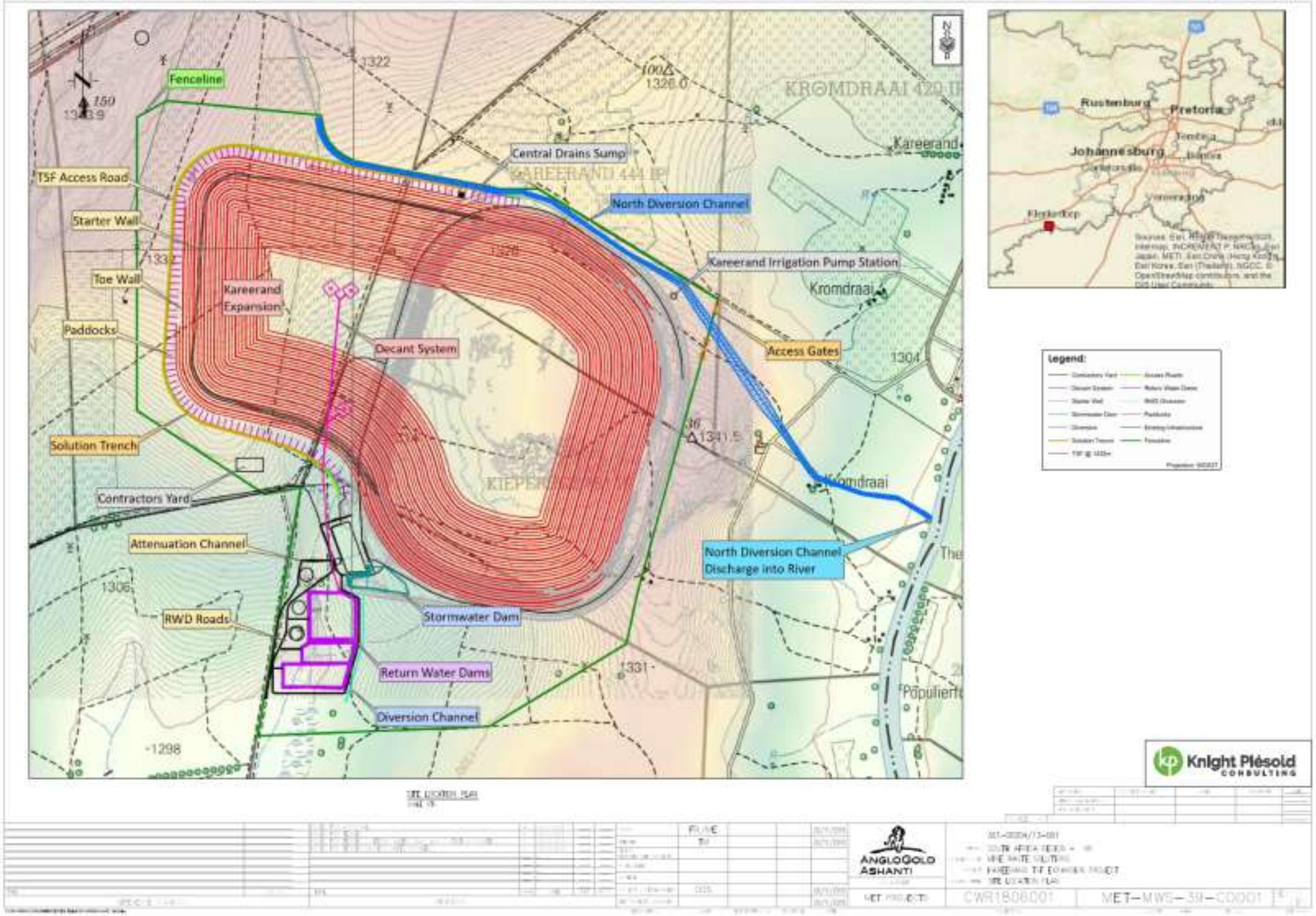


Figure 3.1 Locality map showing the Kareerand Project relative to nearby features (Knight Piésold, 2018).

The area is traditionally known for its cattle farming and several old cattle drinking sites were identified in the area (old boreholes, which are mostly abandoned). Informal cattle farming still exists north and west of the Kareerand TSF. The eastern portion along the Vaal River has irrigation fields and game camps. The western portion has old mining operations. North of the R502 provincial road is the Kumha Township.

3.4 Process Description

3.4.1 General

This section summarises the Kareerand Project and associated infrastructure as presented in the final scoping and the pre-feasibility reports (GCS, 2018a; Knight Piésold, 2018). The information served as a basis for the source characterisation process (and associated source term analysis) for the development of public exposure conditions in Section 4. Figure 3.1 is a locality map that shows the site layout and infrastructure that constitutes the Kareerand Project.

3.4.2 TSF Site Selection

A detailed site selection process was initiated in 2016 to determine the optimal site for the Kareerand Project. A total of 7 alternative sites were identified that were evaluated on a risk basis to determine the preferred alternative. Of the alternative options shown in Figure 3.2, it was concluded that two options (Option 4 and Option 5) were identified as least disruptive to the environment and social aspects. Option 4 was selected as the better alternative for the following reasons (GCS, 2018a):

- Land owned by the applicant;
- An extension to the current facility, keeping the source of pollution at 1 central point;
- Tailings facility on Option 4 is not situated on dolomite reducing the risk substantially;
- Infrastructure on the current facility can be used by the new facility;
- Infrastructure is relatively far from communities and reduces the risk of a facility failure; and
- One source of pollution to manage and mitigate.

3.4.3 Technical Design Specifications

The pre-feasibility report provides a detailed table of the design criteria of the Kareerand Project (Knight Piésold, 2018). The life of the TSF, which is expected to become operational in 2021, is estimated at 21 years, with a maximum heed feed of 2.471 Mtpm. The final tonnages on the existing TSF (including tonnage already deposited) and on the extension to the TSF would be 498Mt for the existing footprint and 354Mt for the extension.

The extension is expected to cover an area of 380 ha, which means that the total Kareerand TSF will cover an area of 868ha. The vertical spacing of each beach is 12m, with an intermediate drainage bench at the mid-point. The bench width is 23m for the main bench and 5m for the drainage benches. The final elevation of the existing section is 1,430mamsl, while the elevation of the combined TSF would be 1,414mamsl. This means that the final height will be in the order of 120m. The expected rate of rising is 6m per annum.

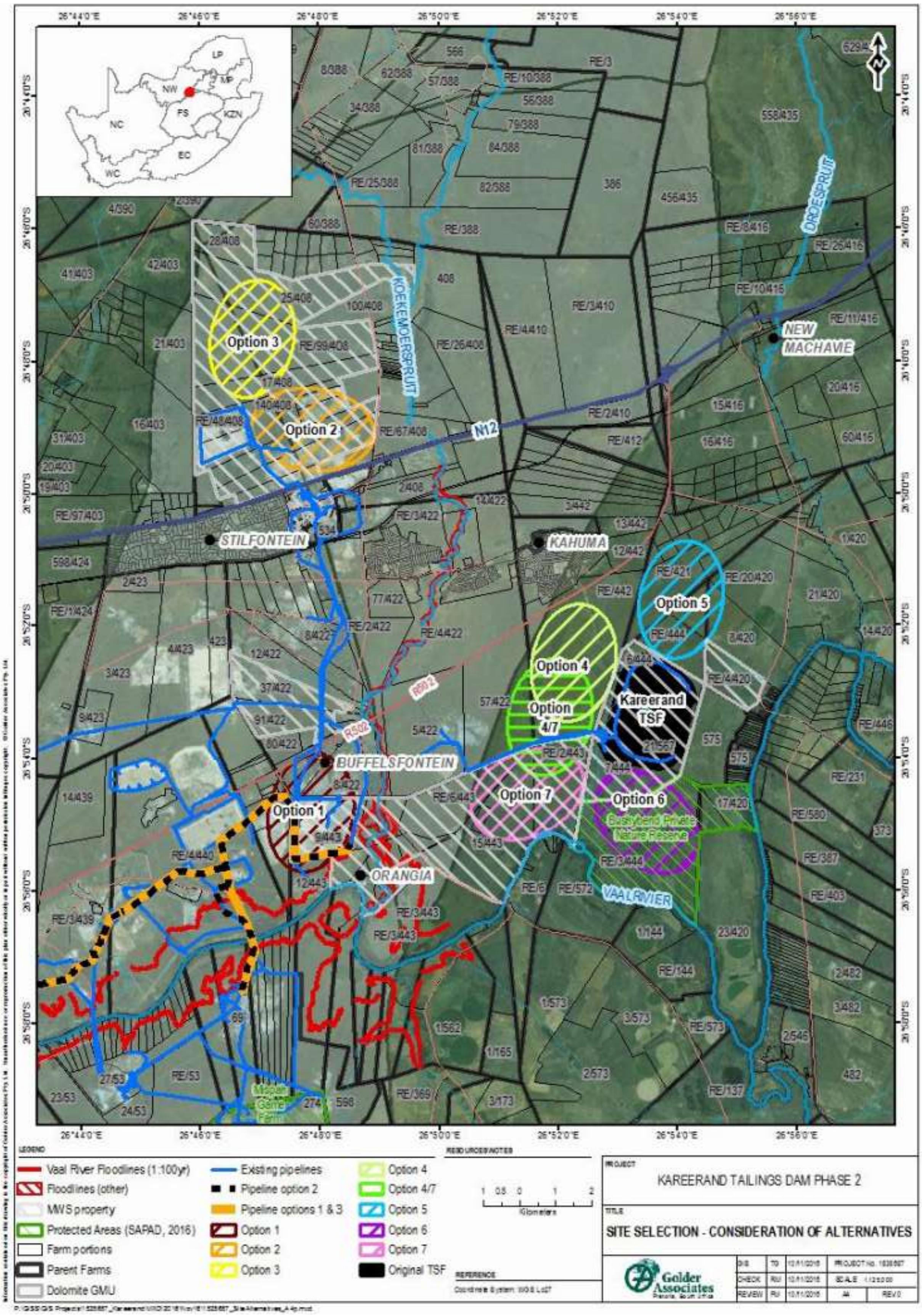


Figure 3.2 Locality map showing the alternative site options considered for the Kareerand Project (GCS, 2018a).

3.4.4 TSF Construction (Knight Piésold, 2018)

The Kareerand Project broadly consists of the following elements as presented in Knight Piésold (2018), which gives a good indication of the construction methods that will be used and the supporting infrastructure:

- An earth fill starter wall to provide containment during early deposition into the facility, when the Rate of Rise exceeds the maximum permissible rate of 6 m per annum for a cyclone TSF.
- An earth fill toe wall to contain downstream deposited cyclone underflow and provide a defined perimeter toe for the facility.
- A main filter drain constructed on the downstream side of the starter wall, a central filter drain constructed mid-way between the starter wall and the toe wall, and a toe filter drain constructed immediately upstream of the toe wall.
- A large central filter drain located along with the interface between the existing TSF and the Extension, which is an identified drainage path for surface and groundwater.
- A temporary gravity decants with three intermediate penstock inlets to decant water off the facility during initial deposition. The gravity decants will be sealed and abandoned once the pool has reached its permanent position and will be replaced either by pumps situated on a floating barge or by a siphon system.
- Toe paddocks to contain runoff and silt eroded from the outer slopes of the facility.
- A concrete-lined solution trench to convey filter discharge and runoff from the outer slopes to the return water dam.
- A pump sump at the low point at the north side of the TSF to contain the filter discharge and a pump system and pipeline to pump the water into the solution trench on the northwest side of the TSF, from where it will flow towards the RWD south of the TSF.
- A new main access road and a perimeter access road.
- New return water dam (RWD) and silt traps.
- Booster Pump Station and Emergency Spills Pond Upgrades.

3.4.5 Supporting Infrastructure (Knight Piésold, 2018)

3.4.5.1 Filter Drains

Three perimeter filter drains will be incorporated in the TSF extension. Each of the filters consists of a 160 mm diameter perforated HDPE pipe surrounded by 19 mm crushed aggregate, which is wrapped in a needle punched geofabric. The drain is then covered by an 8 m wide layer of clean river sand 200 mm thick. Filter drain outlets are located at 200 m spacing around the perimeter of the TSF. The outlets will discharge into the concrete-lined solution trench.

On the northern side of the TSF, the filters will drain to a low point near the position where the extension abuts onto the existing TSF. A sump with pumps and pipelines will be provided, to pump the water to the solution trench on the northwest side of the new TSF. A large central filter drain, 10 m wide with up to 5 No 160 mm diameter slotted pipes will be located along the interface between the existing TSF and the Extension. This filter drain will be underlain by an HDPE liner to minimise ingress of water into the comparatively permeable in-situ soil along this drainage path. It is recommended that the existing filter drain outlets discharging into the solution trench along the western side of the existing TSF should be extended to connect with this new central filter drain.

3.4.5.2 Solution Trench

The solution trench will be lined with 150 mm thick mesh reinforced concrete. The flow direction from the north-western corner of the TSF will be southward along the western side of the TSF to the new RWDs, and eastward along the northern side of the TSF to the low point close to where the extension abuts the existing TSF. A pump sump will be located at this low point, equipped with a vertical spindle pump to convey accumulated drain discharge through a 200 NB HDPE pipe to the north-western corner of the TSF, where it will be discharged into the solution trench.

3.4.5.3 Toe Paddocks

Toe paddocks will be constructed between the toe wall and the solution trench to contain and attenuate runoff from the outer slopes of the TSF. These toe paddocks have sufficient capacity to contain runoff from the outer slopes of the TSF arising from the 1:50 year 24-hour duration storm. The paddocks on the northern side of the extension will be made larger than those on the west and southern sides (approximately 70 m wide), as runoff from this section of the perimeter cannot be drained via the solution trench to the Return Water Dams.

3.4.6 Storm Water Management (Knight Piésold, 2018)

A significant consideration in the design, operation and management of a TSF is the stormwater management system. The following philosophies were applied in terms of the control of stormwater:

- The operating system for the TSF is focused on the safe storage of the tailings, maintenance of the stability of the containment structures and control of the quality and quantity of the supernatant water stored on the TSF.
- A decant system is required to regulate the volume of water that can be safely retained in the TSF under all conditions and to control the quantity of the return water back to the process water circuit. Also, the supernatant pond must be sized to ensure satisfactory settlement of the finest tailings particles to achieve a clear decant effluent and to minimise recycling of particulate material.
- The design philosophy is to maximise the volume of water returned to the plant. The size of the pool on the TSF should be kept to a minimum to minimise the losses resulting from evaporation, void entrapment and seepage.
- The size and position of the pool on the TSF must be carefully managed throughout the service life of the facility to ensure that adequate freeboard and beach lengths are maintained, as the stability analysis demonstrated that the factor of safety against the development of a slip circle failure is sensitive to the location of the phreatic surface in the outer wall.

- The water balance takes into account runoff from the outer slopes of the TSF and will, therefore, be affected by concurrent rehabilitation of the facility. Once rehabilitation has commenced, runoff from the slopes will be reduced, with a commensurate reduction in return water availability.

The following strategy was applied in terms of managing process and stormwater from the TSF:

- The existing TSF has a RWD, which is referred to as the Buffer Dam (BD). This dam currently handles all the process and run-off water and is under capacity during a large storm event. It has a design capacity of 169,830 m^3. The BD will be kept in operation and used for dust suppression.
- A new stormwater dam (SWD) with a capacity of 155,000 m^3 is planned to be constructed as part of the water management strategy for the existing footprint, next to the existing BD. This will alleviate the pressure on the BD and will cater for the run-off and drainage from the existing TSF. This item is not covered in the Capital Estimate as it is considered to be a requirement for the operation of the existing facility.
- A new RWD with a capacity of 452,510 m^3 will be constructed as part of the Extension to cater for the decant, drainage and run-off from the Extension. The solution trench around the west and south of the TSF extension will deliver filter drain discharge, side slope runoff and decant water through two concrete silt traps into the RWD.
- Two subsequent modules of 258,000 m^3 and 258 000 m^3 each will be required during the life of the dam. A diversion trench from the eastern silt trap will enable return water from the TSF Extension to bypass the Phase 1 RWD directly into the Phase 2 RWD to facilitate the cleaning of the Phase 1 RWD.
- An additional storage dam with a capacity of approximately 220,000 m^3 will eventually be required to cater for the end of life run-off. This dam was allowed for the in the cost estimate but is not currently shown on the drawings. It can be placed to the south of the new SWD or added to the south of modular RWDs.

The total storage capacity of the RWDs and SWDs at the end of the operation will, therefore, be approximately 1,512,500 m^3 including the current return water dam (buffer dam).

3.4.7 Surface Water Management (Knight Piésold, 2018)

3.4.7.1 General

Stormwater management on the TSF is required to ensure compliance with GN704 of the South African National Water Act (Act 36 of 1998). This means that:

- Clean (unpolluted) and dirty (polluted) water must be kept separate and no spillage between clean and dirty water systems should occur more frequently than once in every 50 years.
- All water arising within any dirty area, including seepage water from mining operations (including TSF's), must be contained within into a dirty water system.
- Any dam or TSF that forms part of a dirty water system must have a minimum freeboard of 0.8 metres above full supply level.

- All water systems or conveyances must be capable of handling flows derived from floods with an average period of recurrence of once in 50 years.

The following infrastructure will be provided to ensure compliance with these requirements:

- Two diversion channels will be provided to divert stormwater away from the TSF. One diversion channel located north of the TSF will divert surface flow from the catchment north of it in an easterly direction to the Vaal River. The second channel west of the TSF will divert flow from Khuma Township southwards to the Vaal River.
- A cut-off trench will be provided on the north-west corner of the new RWD to divert stormwater past the RWD.
- Surface runoff from the outer slopes of the TSF in the west, south and east of the TSF, will be collected in toe drains and be directed to the BD or RWD.
- Toe paddocks will be constructed around the toe of the TSF Extension, between the toe wall and the solution trench. The toe paddocks intend to attenuate runoff and act as silt traps for tailings eroded from the outer slopes of the TSF.
- The toe paddocks along the northern side of the TSF have been designed to have sufficient capacity to contain all runoff from the outer slopes of the facility arising from the 1:50 year rainfall event of 24-hour duration.
- Drainage water on the northern side will be collected in a sump from where it will be pumped to the north-western corner of the TSF into the toe drain from where it will flow to the new RWD.

3.4.7.2 Water Course Diversion

The existing TSF lies immediately to the east of a non-perennial watercourse running north to south past the western side of the facility. The proposed extension to the TSF will straddle this watercourse so that a diversion channel is required upstream (north) of the facility to redirect flow to the Vaal River east of the TSF.

The diversion channel has been designed according to with GN704 of the South African National Water Act (NWA) (Act 36 of 1998) (South Africa, 1998). This diversion channel is referred to as the eastern diversion channel. The channel depth is 2m with an invert width of 10 m. The maximum depth of flow is 1.75 m, with a flow capacity of 200 $m.s^{-1}$. The channel sides are at a flat slope of 1:2.5 to enable people or animals to climb out of the channel if they inadvertently fall into or gain access to the channel.

A second diversion channel will divert runoff from Khuma Township southwards past the west side of the TSF Extension. This channel (to be referred to as the western diversion channel) will take the form of an extension of the existing outflow channel from Khuma and will have the same cross-section as the existing Khuma Stormwater Channel and will have similar flat side slopes as the eastern channel to enable persons and livestock to climb out.

3.4.7.3 Stormwater Management on the Outer Slopes of the TSF

The stormwater management system for the outer slopes of the TSF has been designed to cope with the 200-year recurrence interval, 24-hour duration storm event of 202 mm. This necessitated the design of a stormwater drainage system on the benches to attenuate runoff from higher slopes and drain it in a controlled manner to the solution trench in the case of the original TSF or to toe paddocks in the case of the extension to the TSF.

3.4.8 Return Water Dam (Knight Piésold, 2018)

A new modular RWD will be constructed as part of the Extension, with subsequent RWD's added in the future as the volume requirement increases over time. The volume requirements are driven by the run-off of the side slopes of the TSF.

The actual capacity available in the current BD is not available, due to silt accumulation. The dam(s) need to be dredged to restore the full design capacity of 169,830 m^3. The new RWD will assist in providing operating capacity to allow cleaning of the BD. Compartment sizes for the RWD will be optimised during detail design to assist in cleaning operations in the future.

The RWDs will be lined with a double HDPE liner with seepage interception system. The cost estimate includes for a double 1.5 mm liner with a geonet in between for leak detection. An underdrainage system below the liner will alleviate groundwater uplift pressure on the liners.

3.4.9 Rehabilitation and Closure

According to Knight Piésold (2018), the principle of abutting the new section of the facility against the existing Kareerand TSF has been adopted as it will enable the outer slopes of the existing TSF to be flattened, and it also improves the ratio of slope area to storage volume for the combined facility. Once the first step-in at 1,328 mamsl has been constructed, all deposition will be upstream. This will enable concurrent rehabilitation to commence at a comparatively early stage in the life of the facility. The downstream wedge below 1,328 mamsl is required for stability.

The following features have been incorporated into the design (Knight Piésold, 2018):

- Intermediate slopes have been flattened to 1V:4H and the overall outer slope has been flattened to 1v:6.33H.
- Step-ins at 12 m vertical intervals are 23 m wide to facilitate two-way traffic on the TSF. This will reduce haul distances for trucks conveying soil cover for rehabilitation.
- An intermediate 5m wide step-in has been introduced midway between full step-ins for stormwater management and to reduce the slope lengths, which in turn reduces the thickness of soil cover required for rehabilitation.
- Topsoil stripping of the basin will be managed to ensure that material that is suitable as topsoil for rehabilitation is stockpiled separately from material that is unsuitable for this purpose.

3.5 Baseline Conditions

3.5.1 General

Within the conceptual framework presented in Figure 1.2, a description of the baseline conditions provides input into understanding the potential release, subsequent distribution and accumulation of radioactivity from Kareerand Project into the environment and associated environmental media. It is thus used as a basis for the Source-Pathway-Receptor analysis presented in Section 4. The baseline conditions observed near the Kareerand Project are comprehensively described in a series of specialist studies that serve as input into the EIA process. In addition to the Scoping Report (GCS, 2018a) that serves as a source of information, the specialist studies that were consulted include the following:

- A description of the local geology, the hydrogeology and the associated hydrogeological impact of the Kareerand Project as provided in GCS (2018b);
- A description of the local meteorological conditions and the air quality impact of the Kareerand Project as provided in Airshed (2018); and
- A description of the population characteristics and social conditions observed near Kareerand Project as provided in Equispectives (2015).

3.5.2 Topography

Figure 3.3 shows that there is no significant variation in the topography of the area. The regional elevation ranges between 1,350mamsl in the northwestern part of the area and 1,290mamsl to the south and east where the Vaal River flows from east to west. The study area is located within the Koekemoer Spruit catchment (C24A). The receiving water body for the Kareerand Project is the Vaal River.

3.5.3 Geology and Structural Geology

Figure 3.4 shows that the geology consists largely of the clastic sediments and volcanic formations of the Witwatersrand, Transvaal, and Ventersdorp Supergroups, which stretches from the south of Johannesburg, beyond Carletonville to Orkney in the west. The three gold-bearing reef formations exploited at the area include the Vaal Reef (VR), Ventersdorp Contact Reef (VCR) and the secondary Crystalkop Reef (C Reef).

The VR is part of the Witwatersrand Supergroup and is stratigraphically located near the middle of the Central Rand Group in the Johannesburg Subgroup on an unconformity below the Krugersdorp Formation. The VR unit can reach a thickness of more than two metres and consists of a thin basal conglomerate and a thicker sequence of upper conglomerates, separated by internal quartzite. The high gold values in the VR are often associated with high uranium values. The VCR has a lower gold grade than the VR and is encountered up to one kilometre above the VR. The VCR located at the contact between the overlying Kliprivierberg Lavas of the Ventersdorp Super Group and the underlying sediments of the Witwatersrand Supergroup, which creates a distinctive seismic reflector. The C Reef is a thin, small-pebble conglomerate with the carbon-rich basal contact, located approximately 270 metres above the VR.

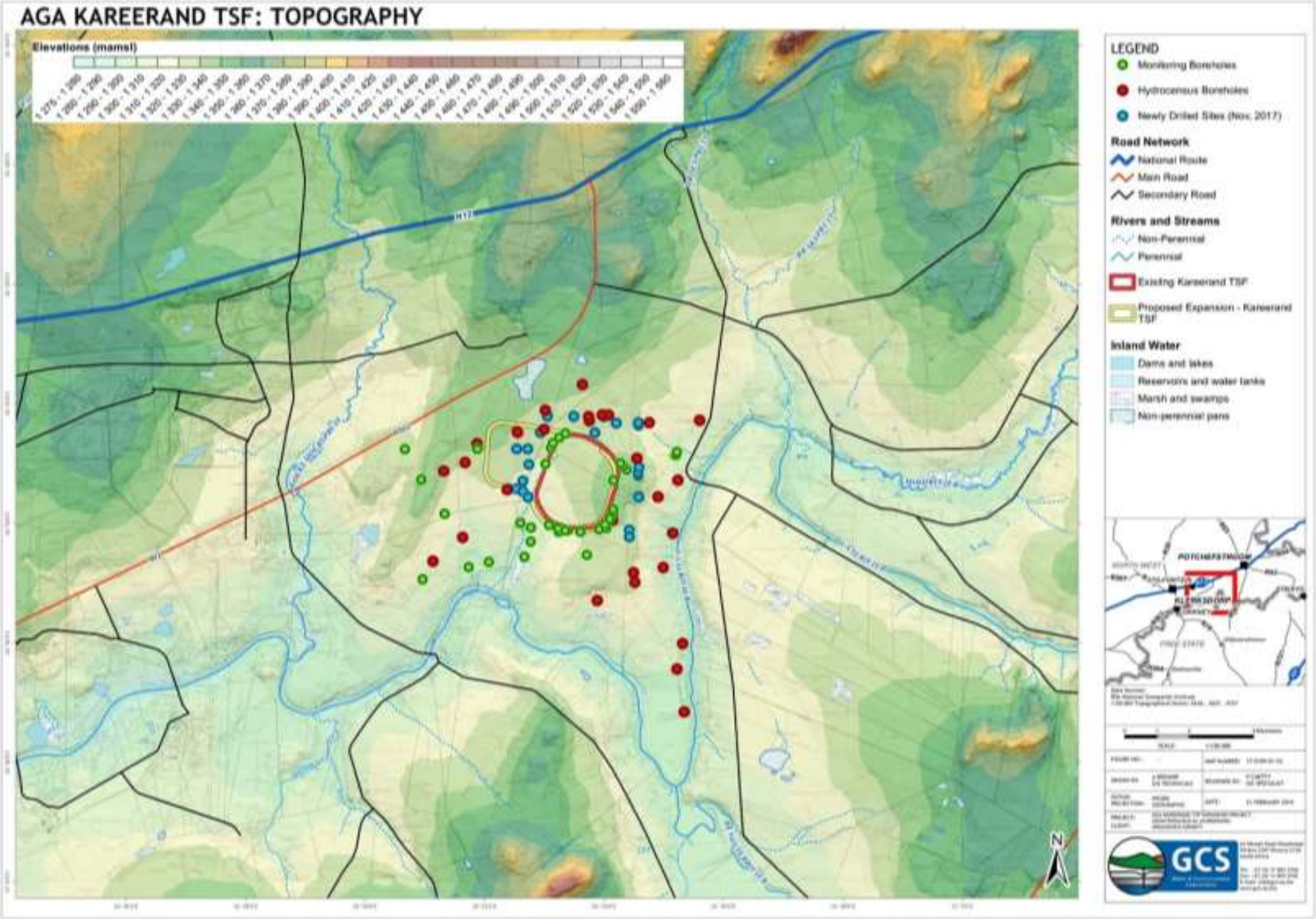


Figure 3.3 Locality map showing borehole location superimposed on the local and regional topography of the area (GCS, 2018b).

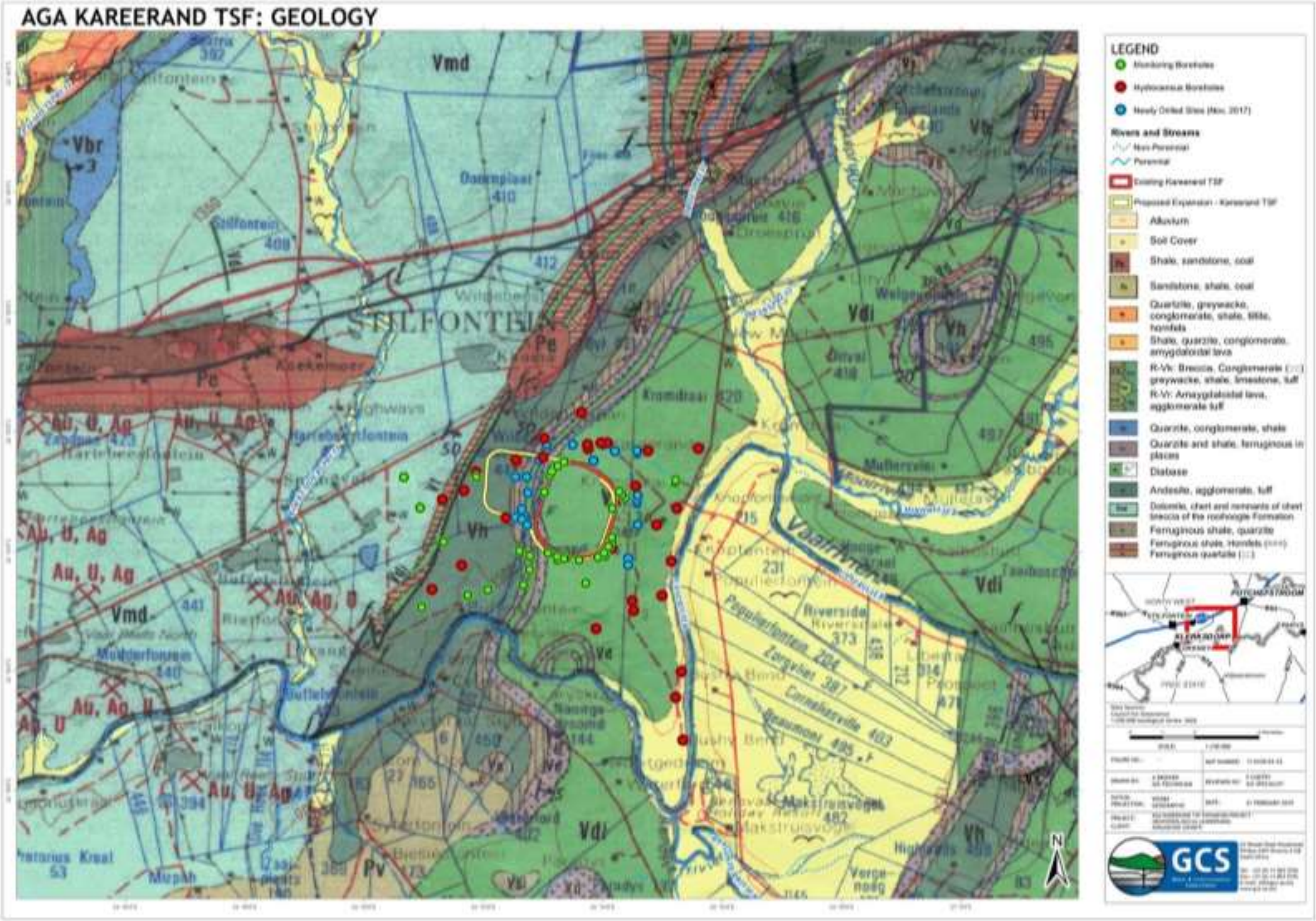


Figure 3.4 Locality map showing borehole location superimposed on the local and regional geology of the area (GCS, 2018b).

The surface geology of the area consists largely of three geological units, i.e., the Ventersdorp Supergroup, the Black Reef Formation and the Malmani Subgroup of the Transvaal Sequence. Along the banks of the Vaal River and Schoon Spruit, alluvium overlies bedrock, forming a separate geological unit. The strata in the area have been affected by extensive folding and faulting and two dykes strike north-south across the area.

Most of the faulting (a fault is a natural fracture that cuts through the rock) in the area trends in a SW-NE direction and is normal, with displacement both to the north and south of between 10m to 250m. The geological map indicates a major fault zone that runs from SW-NE in the western part of the investigation area, approximately 1.5km west of the proposed TSF site.

3.5.4 Hydrogeology

3.5.4.1 General

The local aquifer characteristics were extensively characterised the past 10 years through hydrocensus, geophysical surveys, drilling and testing of boreholes, and sampling of groundwater and surface water in the area (GCS, 2018b). Figure 3.3 and Figure 3.4 show the location of existing monitoring and hydrocensus boreholes, as well as the location of newly drilled boreholes.

Regionally the area is underlain by a variety of complex fractured and intergranular aquifer systems. The Malmani dolomite underlies the entire area and a Karoo inlier rests on top of the dolomite. Alluvium occurs in the river valleys of the surface water bodies (i.e., the Koekemoer Spruit and Vaal River). Transmissivities in the dolomites are both stratigraphically and structurally controlled.

3.5.4.2 The Dolomite Aquifer System

The dolomite aquifer system is a major aquifer that is highly vulnerable to groundwater contamination. It consists of solid chert-poor formations, largely located in the west, and chert-rich dolomites located in the east. The chert-rich dolomites have a higher permeability than the chert-poor dolomites and are associated with water-bearing geological structures, such as folds and fractures. Highly permeable zones within the dolomite aquifer system have important influences on contaminant transport rates and directions, as it forms preferred pathways for contaminant migration.

Very little (if any) surface runoff occurs in dolomitic terrain and most rainwater percolates *via* enlarged fractures to the upper saturated portion of the weathered zone, where down gradient horizontal flow predominates (GCS, 2007).

3.5.4.3 Weathered Dolomitic Aquifer

The weathered aquifer consists of both alluvium and weathered dolomitic material. The depth of weathering ranges from 5 to 20 m below surface and the groundwater level is relatively shallow and generally lies within the weathering profile itself. Water strikes are mostly associated with the contact between alluvial clays and the dolomitic bedrock, at the base of the cherty weathering profile or within solution cavities and joints in dolomite. The weathered aquifer is the most vulnerable and susceptible to contamination from pollution sources. A high potential for aquifer contamination exists where thick accumulations of cherty gravel occur (GCS, 2007).

3.5.4.4 Solid/Fractured Dolomitic Aquifer

The top of the fractured dolomitic aquifer is generally located at the base of the weathering profile approximately 5 to 20 m below surface. The primary porosity of dolomite is negligible. Percolating water, forming carbonic acids, dissolves the dolomite to form dissolution cavities. Although dissolution cavities and fractures have been intersected during drilling, the study area is not characterized by large dissolution cavities. Previous investigations have suggested that the hydraulic interconnection between the dolomitic aquifer and the Vaal River is poor. However, such could be misleading as active groundwater abstraction is currently in progress (GCS, 2007).

3.5.4.5 Alluvium Aquifer System

The northern bank of the Vaal River is underlain by solid to fractured dolomite. Alluvial sands and clay beds directly overlie the dolomite and contain perched groundwater levels, which could result in shallow seepage, migrating towards the Vaal River (GCS, 2007).

3.5.4.6 Groundwater Levels

In addition to the hydrocensus boreholes, a total number of 58 test and observation boreholes have been drilled over the past 10 years. The following can be derived from the available data (GCS, 2018b):

- Groundwater levels were in the order of 15 to 20 m below the ground level before deposition. Groundwater levels have increased by an average of 10 to 15m below the TSF over time, which has reduced the thickness of the unsaturated zone.
- The areas further to the west, where andesite and dolomite were intersected, indicated much deeper groundwater levels (>30m), which have not changed significantly over time.
- Figure 3.5 shows the correlation between the groundwater elevation and the topographical elevation. The data shows a variation in depth between shallow or artesian boreholes situated close to the Kareerand TSF and deeper groundwater levels further to the west, away from the TSF.
- The zone of unsaturation has dramatically changed because of increasing water levels over 3 to 5 years and decreased from almost 15m thick to between 0 and 5m below and around the TSF.

Figure 3.6 is a graphical representation of the groundwater level elevations and flow directions as derived from the available groundwater level data. The shallow levels around the Kareerand TSF are visible that results in flow away from the TSF, with the most dominant flow towards the low-lying areas associated with the Vaal River.

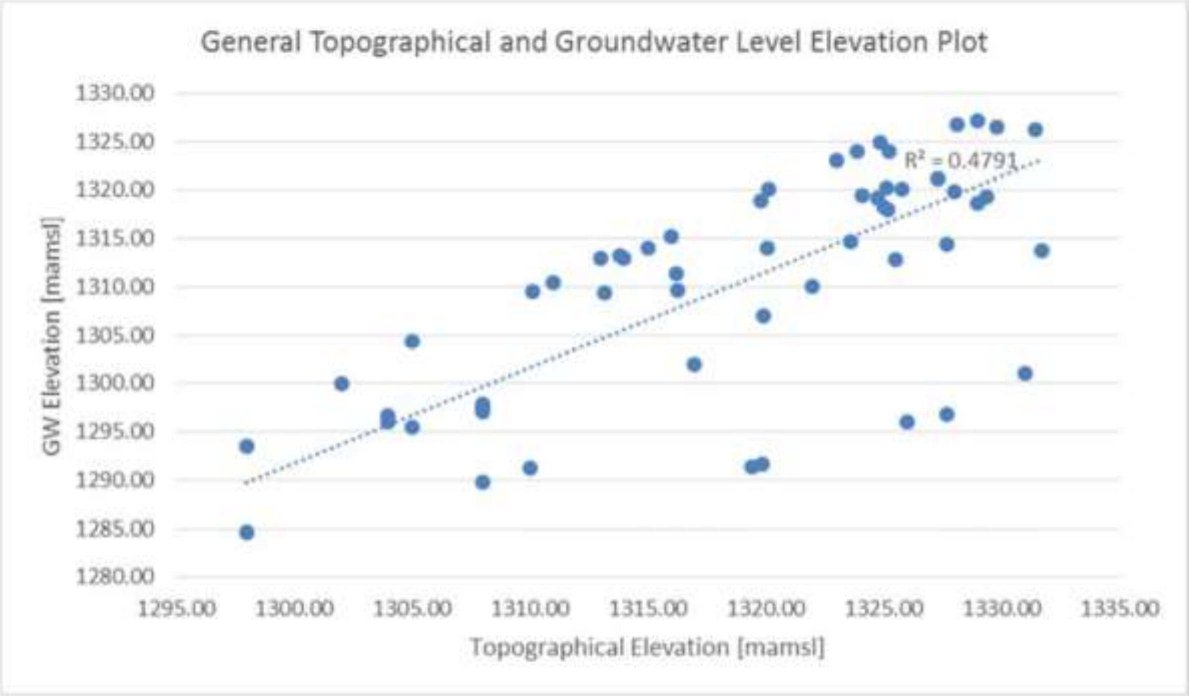


Figure 3.5 Graph showing the correlation between the groundwater elevation and the topographical elevation (GCS, 2018b).

3.5.4.7 Aquifer Parameters

Aquifer tests were completed on most of the boreholes. Tests vary from constant rate pump tests to slug tests (falling and rising head tests) with recovery monitoring. Table 3.1 lists hydraulic conductivity values as obtained from the aquifer test analyses using Cooper Jacob, Theis Recovery and Bower-Rice analyses methods.

Table 3.1 Summary of hydraulic conductivity values obtained from various aquifer test analysis (GCS, 2018b).

Lithology	Summary of Hydraulic Conductivity Values (m.day^{-1})		
	Average	Geometric Mean	Maximum
Chert/ Dolomite (limited data - only 2 dry boreholes)	0.001	0.001	0.1
Andesite	0.152	0.019	0.2
Quartzite, Lava, Shale	0.074	0.074	0.1
Shale and diabase	0.325	0.207	0.8
Predominantly Shale	0.42	0.355	0.8
Diabase, weathered (unsaturated) with shales	0.497	0.497	0.8
Diabase, weathered with Clay	0.172	0.064	0.45
Diabase, weathered clay and boulders	0.217	0.216	0.5
Diabase, highly weathered and fractured on contact	2.754	1.93	8.68

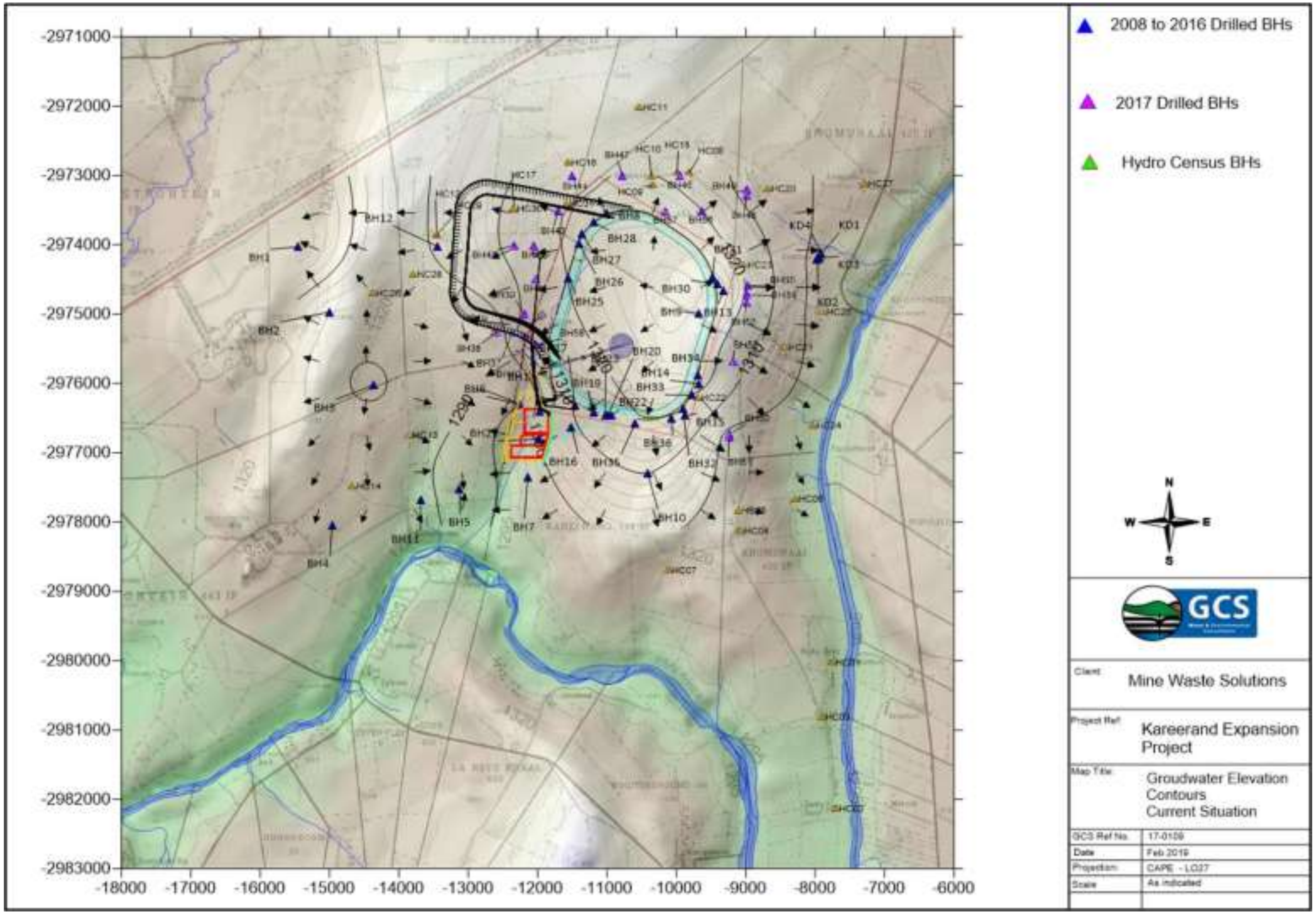


Figure 3.6 **Graphical representation of the groundwater level elevations and flow directions as derived from the available groundwater level data (GCS, 2018b).**

3.5.5 Meteorological Conditions

3.5.6 General

Meteorological conditions can have a significant influence on the behaviour and dispersion of airborne contaminants released from a mining and mineral processing operation. Assessment of the possible impacts on air quality from the Kareerand Project thus requires a good understanding of the regional climate and local air dispersion potential of the area.

The regional climate is the typical Southern African Highveld climate with moderately wet, warm summers and cold dry winters. The area is characterised by summer rainfall with thunderstorms occurring frequently between October and April. Airshed (2018) presents a detailed description of the prevailing meteorological conditions of the areas and associated air quality impacts, using two years of data available from the Kareerand TSF weather station.

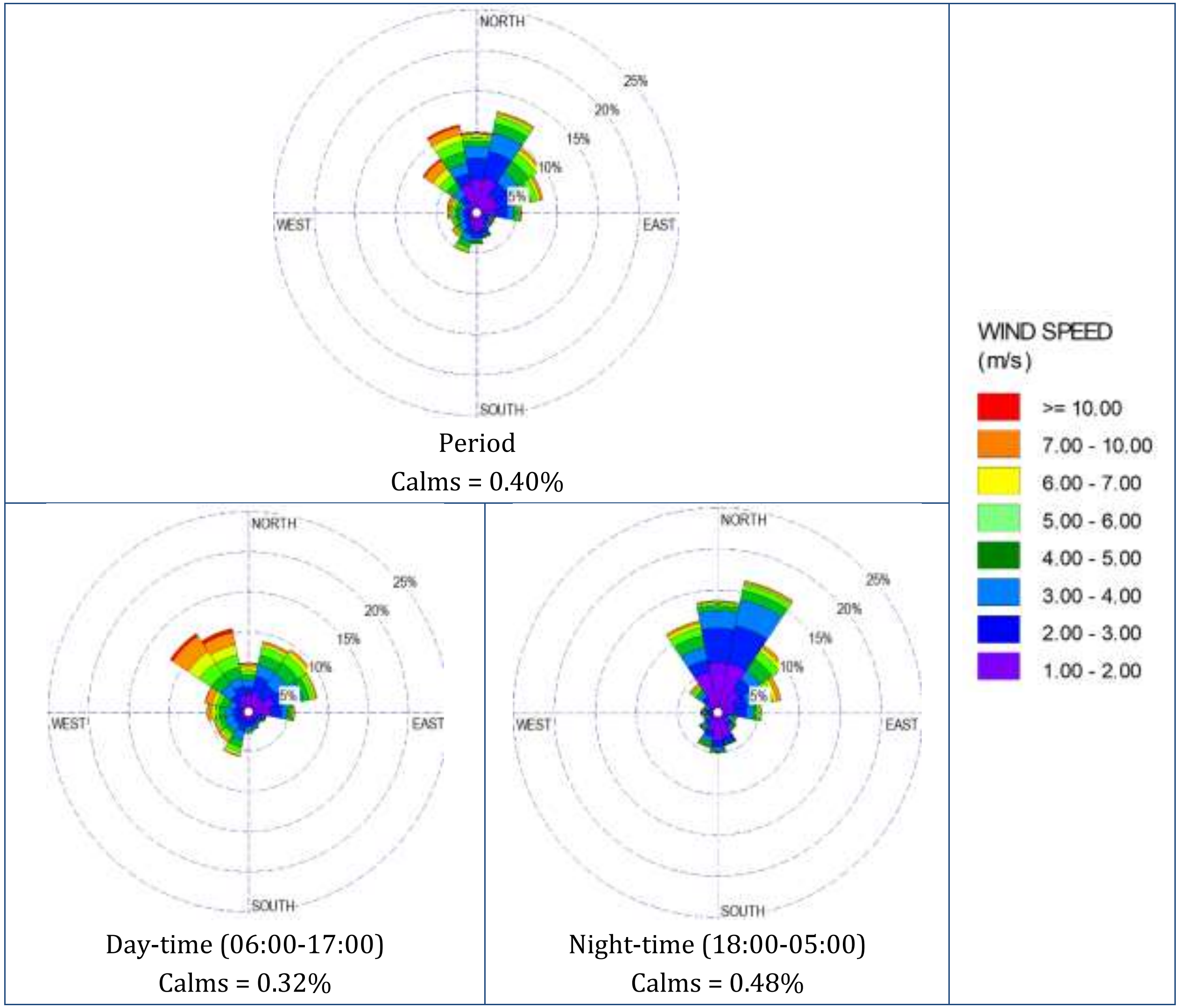
3.5.7 Wind

Airshed (2018) presents information on wind speed and direction measured at the for the period January 2018 to December 2019. The measurements are summarised in wind roses, which are graphical representations of measured wind speed and direction, each comprising 16 spokes that show the directions from which winds blew during a specific period. The colours used in the wind roses reflect the different categories of wind speeds; the yellow area, for example, representing winds between 2.1 and 3.6 m.s^{-1}. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The frequency with which calms occurred, i.e. periods during which the wind speed was below 1m.s^{-1} are also indicated.

Figure 3.7 presents the period wind field and diurnal variability in the wind field, while Figure 3.8 presents the seasonal variation in the wind field. The wind field is dominated by winds from the north-northeast. The strongest winds (>6 m.s^{-1}) occurred mostly from the north-west and north-north-west. Calm conditions occurred 0.4% of the time (for 70 hours), with an average wind speed of 3.06 m.s^{-1}. Wind speeds increased during the day with a slight decrease in calm conditions (0.32% during the day to 0.48% during the night). Strong winds above 6 m.s^{-1} occurred most frequently during the spring months. Calm conditions occurred most frequently during the winter months.

3.5.8 Precipitation

Precipitation is important to air quality studies since it represents an effective removal mechanism for atmospheric pollutants and inhibits dust generation. The Kareerand Project falls within the summer rainfall region of South Africa and rainfall is almost exclusively due to showers and thunderstorms falling mainly from October to May, with the maximum precipitation occurring in December to February. Figure 3.9 presents the monthly rainfall as obtained from the measured Klerksdorp station data. Total annual rainfall from January 2016 to December 2016 amount to 479 mm. The model simulations did not include rainfall data.

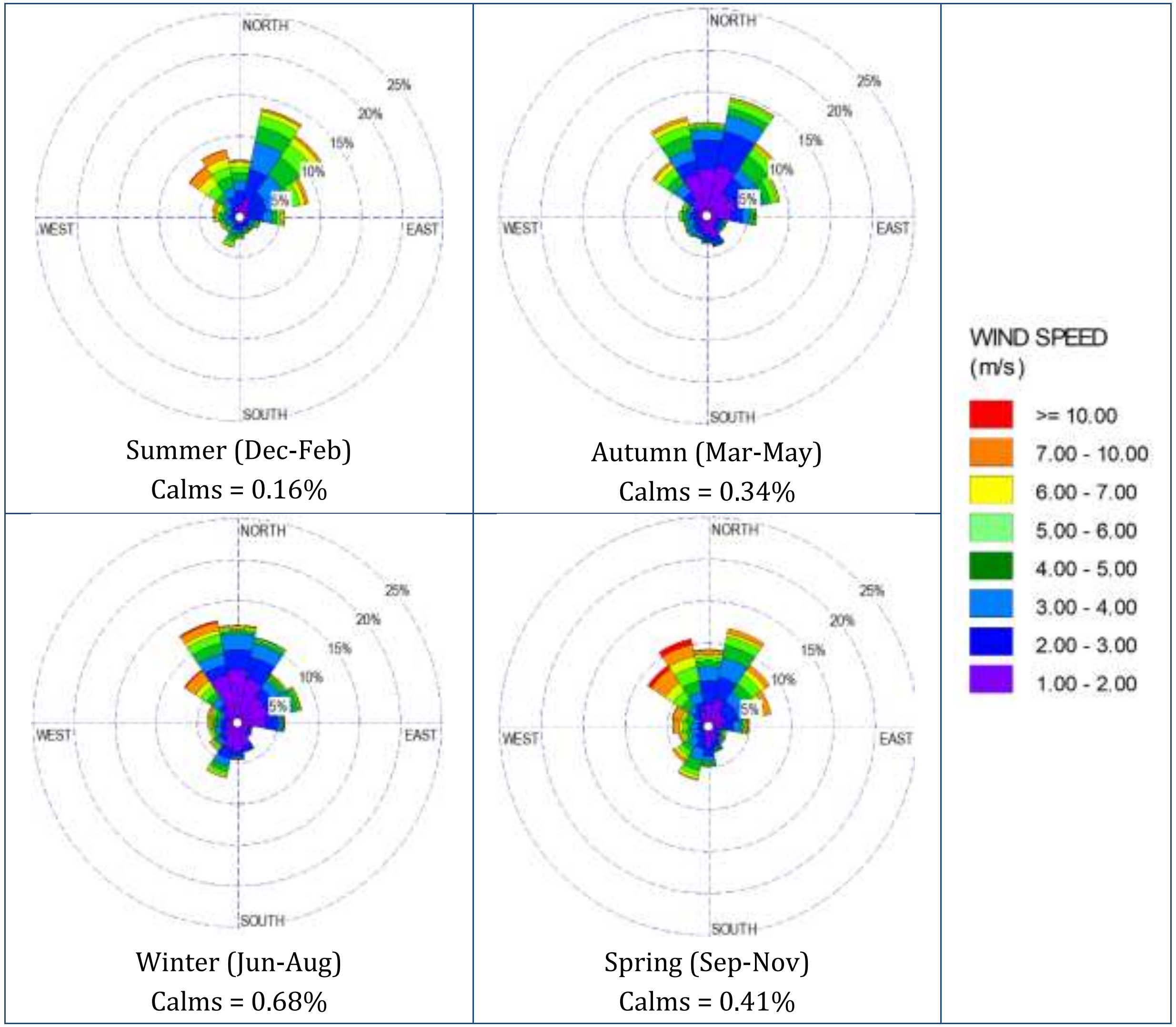


Period
Calms = 0.40%

Day-time (06:00-17:00)
Calms = 0.32%

Night-time (18:00-05:00)
Calms = 0.48%

Figure 3.7 Period, day- and night-time wind roses (measured data, January 2018 to December 2019) as reported in Airshed (2018).



Summer (Dec-Feb)
Calms = 0.16%

Autumn (Mar-May)
Calms = 0.34%

Winter (Jun-Aug)
Calms = 0.68%

Spring (Sep-Nov)
Calms = 0.41%

Figure 3.8 Seasonal wind roses (measured data, January 2018 to December 2019) as reported in Airshed (2018).

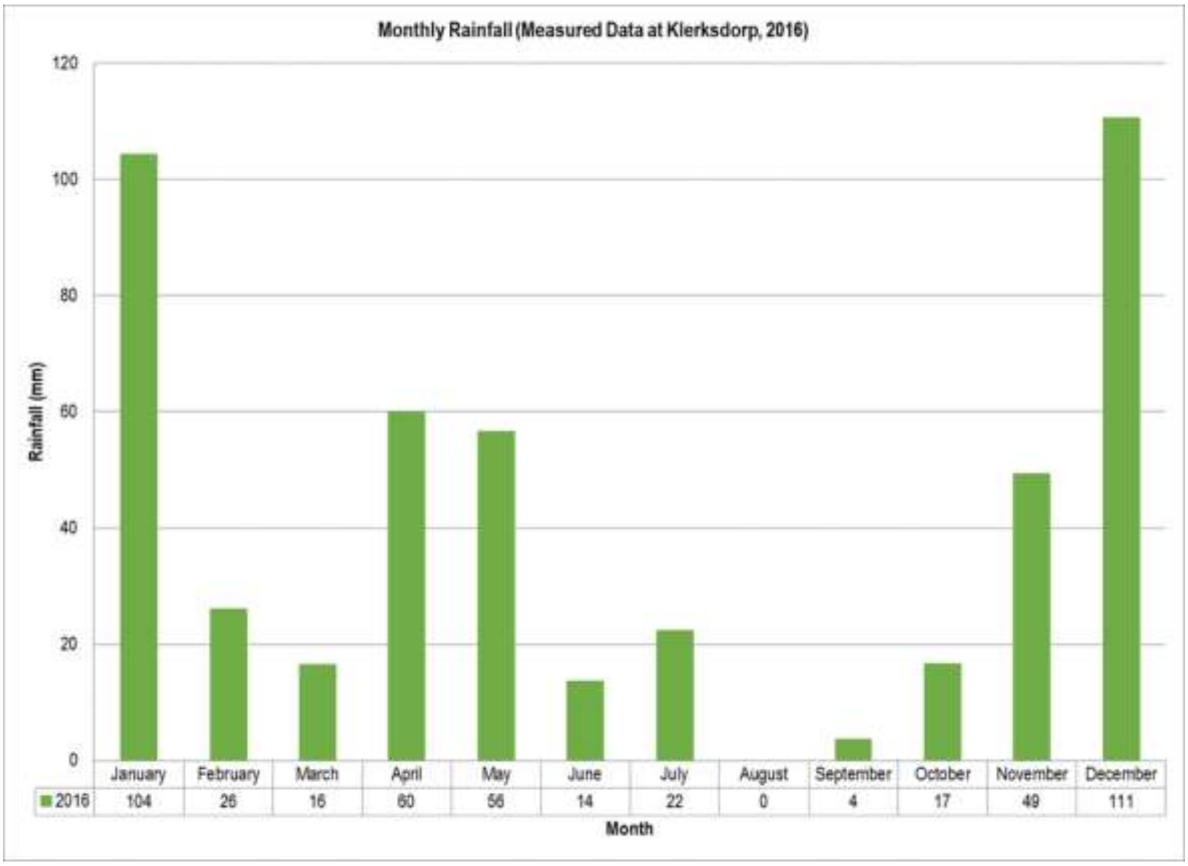


Figure 3.9 **Monthly rainfall (measured data at Klerksdorp, January 2016 to December 2016) as reported in Airshed (2018).**

3.5.9 Temperature and Evaporation

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the emissions plume and the ambient air, the higher the plume can rise), and determining the development of the mixing and inversion layers. Daytime temperatures peak during the summer months while decreasing during the winter months.

Monthly mean, maximum and minimum temperatures are given in Table 3.2. Diurnal temperature variability is presented in Figure 3.10. Temperatures ranged between -6°C and 38°C. The highest temperatures occurred in December and the lowest in June and July. During the day, temperatures increase to reach a maximum at around 14:00. Ambient air temperature decreases to reach a minimum at around 06:00 i.e. just before sunrise.

Table 3.2 **Monthly temperature summary (measured data, January 2018 to December 2019) as reported in Airshed (2018).**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	24	22	21	17	13	9	9	15	17	21	23	23
Minimum	37	33	34	28	28	26	27	29	34	36	37	38
Maximum	10	11	10	4	-1	-6	-6	-3	-3	3	5	10

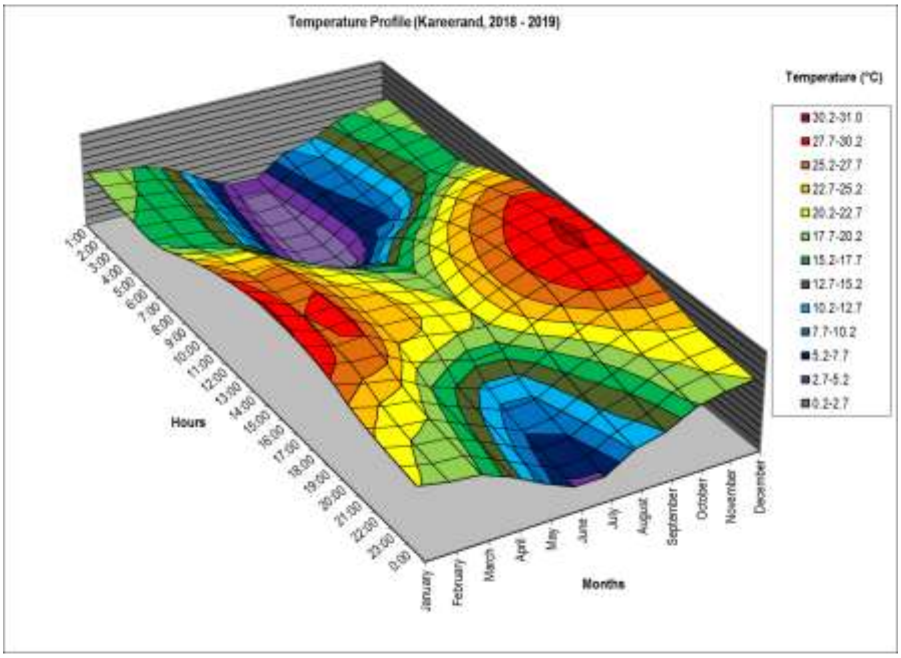


Figure 3.10 Diurnal temperature profile (measured data, January 2018 to December 2019) as reported in Airshed (2018).

3.6 Human Behavioural Conditions

Equispectives Research and Consulting Services (Equispectives, 2015) provides an in-depth analysis of the human behavioural conditions in the wider Vaal River region and further supported by a Baseline Social and Land Use Assessment performed in 2009 by Golder Associates Africa (Golder Associates Africa, 2009).

The area near the Kareerand Project is less densely populated than in the remainder of the area, agricultural, leisure (along the Vaal river) and residential (Khuma) land use conditions the most dominant land use conditions. The community groupings that are represented include formal and informal residential dwellings, as well as commercial and small-scale agricultural farming.

Farming activities practised in the area include crop farming, livestock and game. Some of the farms offer tourist activities. Most farms have a residence where the landowner or employee of the landowner that manages the farm, lives. Dwellings on agricultural land are diverse, while some farms include double-storey residences, others have small houses that serve as accommodation for farmers or workers.

The Khuma residential area is located adjacent to Stilfontein, between the N12 and the R502 roads. Khuma consists of three residential blocks with open space in between. Each of the three residential blocks tends to include different types of houses. Houses in the area closest to R502 tend to be more diverse in appearance and consist of a mix of RDP type houses and formal houses. The houses closer to Stilfontein tend to be smaller RDP type houses. In certain areas, informal structures used to dominate, but have been replaced with brick buildings. However, on some of the yards, there are still zinc structures observed. Cattle are being housed in kraals on the outskirts of Khuma with the herders staying in informal structures at the kraal.

The social infrastructure in the area around the Kareerand Project is very differed and vary from one location to the next. In Khuma, there are schools and crèche facilities, as well as clinics, a library, and a police station. Some of the crèches operate from private homes, but others are licenced nursery schools on their premises. There are some open space and a few soccer fields, churches, and community vegetable gardens, but no other recreational facilities. In the area of Khuma where the RDP houses are (nearest to Stilfontein), the social infrastructure is limited. This area has a few small supermarkets and some taverns. In the part of Khuma closest to the R502 where the bigger houses are, there are spaza shops and tuck shops, hair salons, a post office, filling station with a convenience store, clothing shops and other speciality stores.

The main source of water in the residential areas (including Khuma), is a municipal supply inside their homes. Equispectives (2015) notes that some residents of Khuma only have access to communal taps or water tanks. In agricultural areas, most farmers use borehole water for domestic purposes, while some have rainwater tanks. Some farmers use borehole water for agricultural purposes, while others use water from the Vaal River. The water for agricultural use is sourced from the river and the water for domestic use is obtained from a borehole.

In residential areas, those people who do not work spent there day doing house and garden work, while some will be wondering the streets and socialising. In the agricultural areas, farmers and farm workers spend the entire day outside, busy with farming activities. The farmers' wives spend less time outside. They would do mostly gardening when they are outside. The family members that do not reside on the farm are mostly there on weekends. On weekends some people will engage in activities such as horseback riding, bicycle riding and hiking.

In the Khuma, people have a very basic diet. Not everyone can afford to buy food, and some people depend on the goodwill of other people for food. Bread, pap and vegetables form the staple of most diets in this area. Meat such as chicken is consumed when people can afford it and some of the shops sell chicken feet sosaties. As people's socio-economic circumstances improve, their diets become more varied. Home cultivation of fruit and vegetables occur in residential areas.

The eating habits of the farmers and their families vary based on personal preferences. General, red meat is consumed daily to more than once a week, with poultry more than once a week and pork and fresh fish less often. Eggs are eaten daily to less than once a week. Homemade bread is baked once a week or less. Mielie pap is consumed daily to never. Almost everyone uses milk daily to more than once a week. Vegetables are consumed daily to more than once a week. Tomatoes are consumed most often. Some farmers source milk from their farms. Most buy their fruit and vegetables in town, but some grow their own. The diet of the farmworkers tends to mainly consist of pap, samp, vegetables and chicken. The vegetables that they eat they have often grown themselves, and often the chickens are their own as well.

In agricultural areas, not all farmers grow crops commercially. Crops grown commercially include maize, sunflowers, lucerne, wheat and soy. Some grow oats for their sheep. Many of the farms have vegetable gardens for their use. Vegetables grown in gardens on the farms include pumpkin, maize, beans, tomatoes, potatoes, leafy vegetables (marogo, cabbage, and spinach), root vegetables (beetroot, onions, and carrots), sugar cane and sweet potatoes. Fruit trees include pecan nuts, plums, peaches, pears and apples. Prickly pears are grown in the hills.

Equispectives (2015) report that in Khuma large numbers of livestock are kept on the outskirts of the residential area. Cattle owners organise themselves in groups and pay someone to look after the collective herd of cattle. During the day the livestock grazes in the area. The farmers farm commercially with cattle, sheep, pigs and chickens. Some farmers keep game.

3.7 Radiological Conditions

3.7.1 General

The purpose of this section is to provide a summary overview of the radiological conditions associated with the Kareerand Project. Section 3.7.2 discusses the radionuclide concentrations in residue materials and waste products directly associated with the Kareerand Project, as well as the radioactivity released to the environment (e.g., radon gas) from the relevant facilities. Section 3.7.3 presents the radioactivity in various environmental media as observed through the monitoring and sampling programmes relevant to the Kareerand Project. Section 3.7.4 presents the baseline conditions observed in the area where the Extension will be implemented.

3.7.2 Radioactivity Associated with the Kareerand Project

3.7.2.1 General

As part of the MWS Operations, the Kareerand Project is not isolated but are associated with various operational features of the MWS Operations. Table 3.3 lists those features that are deemed relevant to the radiological impact assessment of the Kareerand Project and that is known to contain or emit radioactive material to the environment.

Table 3.3 Operational features of the MWS Operations that deemed relevant to the Kareerand Project and that are known to contain radionuclides.

Source Category	Individual Sources
Tailings Storage Facilities	Hartbeesfontein 1&2 TSF
	Hartbeesfontein 5&6 TSF
	Hartbeesfontein 7 TSF
	MWS 2&3 TSF (footprint)
	MWS 4 TSF
	MWS 5 TSF
	Buffelsfontein 1,2,3&4 TSF
	Buffelsfontein 5 TSF
	Existing Kareerand TSF
Surface Water Features	Kareerand return water dam

3.7.2.2 Tailings Storage Facilities

Table 3.4 summarises the full spectrum radioanalysis results for tailings samples from all the MWS Operations TSFs and two remaining footprints of recovered TSFs submitted to the Necsa Laboratories in October 2014. The tailings samples were collected as part of the campaign to characterise the geochemical behaviour of the various TSFs in the area.

Table 3.4 Full spectrum analysis results of tailings samples from the MWS Operations TSFs submitted to the Necsa Laboratories in October 2014 (RA-16569 dated 17 December 2014).

Nuclide	MWS Dam 5		MWS Dam 4		MWS Dam 2 footprint		Harties Dam 1		Harties Dam 2		Harties Dam 5		Harties Dam 6		Harties Dam 7 footprint	
	RA-16569X001		RA-16569X002		RA-16569X003		RA-16569X004		RA-16569X005		RA-16569X006		RA-16569X007		RA-16569X008	
	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.
	$Bq.kg^{-1}$															
U-238	783	12	670	11	852	13	206	4	1,010	20	862	14	470	8	836	13
U-234	789	12	676	11	859	14	208	4	1,020	20	869	14	474	8	843	13
Ra-226	1,100	40	846	34	399	22	637	27	1,220	40	741	30	848	30	2,360	60
Pb-210	1,400	60	Not requested		Not requested		Not requested		Not requested		Not requested		Not requested		Not requested	
U-235	36	0.6	30.9	0.5	39.2	0.6	9.49	0.18	46.7	0.7	39.7	0.6	21.7	0.4	38.5	0.6
Th-232	79.1	3.2	58.8	2.8	75.1	3.2	48.3	1.2	69.4	3.2	68.2	2.8	53.6	2	100	4
Ra-228	91.5	25.5	< MDA		41	20	< MDA		64	27	57	23	50	22	86	31
Th-228	56	16	60	17	63	13	41	15	91	20	41	15	25	16	87	26

Nuclide	Buffels Dam 1		Buffels Dam 2		Buffels Dam 3		Buffels Dam 4		Buffels Dam 5		Kareerand	
	RA-16569X018		RA-16569X019		RA-16569X020		RA-16569X021		RA-16569X022		RA-16569X024	
	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.	Value	Uncert.
	$Bq.kg^{-1}$											
U-238	635	10	770	12	4,460	70	2,270	30	903	14	647	10
U-234	640	10	777	12	4,490	70	2,290	30	910	14	652	10
Ra-226	453	24	3,610	80	1,820	50	2,800	70	721	29	1,060	30
Pb-210	Not requested		Not requested		Not requested		Not requested		Not requested		714	43
U-235	29.2	0.5	35.5	0.6	205	3	105	2	41.6	0.7	29.8	0.5
Th-232	24.7	1.3	434	12	76.3	6.9	54.4	4.5	24.7	1 .9	61.7	2
Ra-228	<9		416	57	56	27	74	33	< MDA	-	53	21
Th-228	51	14	461	81	168	55	42	23	< MDA	-	77	18

Table 3.5 Full spectrum analysis results of tailings samples from the Buffelsfontein No.2 TSF (RA-09733 dated 25 May 2009).

Radionuclide	Top Buffelsfontein No.2 TSF	North Slope Buffelsfontein No.2 TSF	West Slope Buffelsfontein No.2 TSF
	Bq.kg^{-1}		
U-238	831	1,010	641
U-234	838	1,020	646
Ra-226	3,450	3,150	4,060
U-235	38.3	46.5	26.5
Th-232	147	99	121
Ra-228	134	87.2	111
Th-228	137	79.9	100
K-40	323	348	467

Table 3.6 Full spectrum analysis results of tailings samples from the Buffelsfontein No.2 and No.4 TSFs (RA-11707 dated 1 March 2012).

Radionuclide	Buffelsfontein No.2 TSF Rec 1	Buffelsfontein No.4 TSF Rec 2
	Bq.kg^{-1}	
U-238	1,270	917
U-234	1,280	925
Ra-226	2,450	3,780
U-235	2,910	4,740
Th-232	58.6	42.2
Ra-228	164	84.8
Th-228	129	128
K-40	134	97.5
Gross Alpha	443	497
Gross Beta	24,800	26,800

In addition to the results presented in Table 3.4, there are two sets of samples available for the Buffelsfontein No.2 TSF and Buffelsfontein No.4 TSF. Table 3.5 lists results of tailings samples collected from the top, north slope and west slope of the Buffelsfontein No.2 TSF, while Table 3.6 further presents results of tailings sample collected from the Buffelsfontein No.2 TSF and Buffelsfontein No.4 TSF collected in 2011.

Table 3.7 lists the spectrum analysis results for the Kareerand TSF, as well as the average of all the tailings samples available for the MWS TSFs. The values estimated by assuming secular equilibrium are highlighted (text in red).

3.7.2.3 Radon Exhalation from TSFs

Parc Scientific (2006) summarised radon exhalation rates measured from residue storage facilities in the South African gold mining industry and reported a methodology that can be used to estimate radon exhalation rates from TSFs and WRDs. The report used radon exhalation rates measures from a variety of TSFs and WRDs over 8 years to derive source characteristic radon diffusion coefficients. These diffusion coefficients are used with concentrations of Ra-226 measured in the tailings material to estimate the radon exhalation rate in units of $Bq.m^{-2}.s^{-1}$. Parc Scientific (2006) presented the measured data as 'average' and 'maximum' values based on the statistical distribution of the data. The equations and coefficients used for deriving radon exhalation rates from tailings are as follows (Parc Scientific, 2006):

Average: Radon exhalation rate ($Bq.m^{-2}.s^{-1}$) = (0.000554 ±0.0000014) x Ra-226 ($Bq.kg^{-1}$)

Maximum: Radon exhalation rate ($Bq.m^{-2}.s^{-1}$) = (0.000609 ±0.0000017) x Ra-226 ($Bq.kg^{-1}$)

Table 3.7 Full spectrum analysis results for the Kareerand TSF, as well as the average of all the tailings samples available for the MWS TSFs. The values estimated by assuming secular equilibrium are highlighted (text in red).

Radionuclide	Kareerand	Average of all MWS Samples
	$Bq.kg^{-1}$	
U-238	647	1,045
U-234	652	1,053
Th-230	652	1,053
Ra-226	1,060	1,330
Pb-210	714	1,205
Po-210	714	1,205
Th-232	61.7	89
Ra-228	53	105
Th-228	77	102
U-235	29.8	48
Pa-231	29.8	48
Ac-227	29.8	48
Ra-223	29.8	48

Table 3.8 lists the average and maximum radon exhalation rates estimated from the Ra-226 concentration listed in Table 3.7.

Table 3.8 Estimated average and maximum radon exhalation rates for the MWS Operation TSFs and footprints of recovered TSFs.

Tailings Storage Facilities	Average	Maximum
	$Bq.m^{-2}.s^{-1}$	
Kareerand TSF	0.602	0.664
MWS Operations TSFs (Average)	0.755	0.833

As input into the radiological public safety assessment of the Kareerand Project. ParcScientific recently measured the radon exhalation rate from several samples collected at the existing Kareerand TSF (Parc Scientific, 2019). A total of 32 samples taken outside the wet beach and pool area of the TSF were analysed. The results presented in Table 3.9 show an average of 0.165 $Bq.m^{2}.s^{-1}$, with a standard deviation of 33.5%. The 90% percentile of the cumulative frequency histogram of measured values indicated that the distribution can be represented by the average measured value.

Table 3.9 Radon generation and transport properties and exhalation rate as measured for sampling points at the Kareerand TSF (Parc Scientific, 2019).

Sample point	Mw	Density	Diffusion length	Diffusion coefficient	Production Rate	Calculated Ra-226 ε = 0.23	Calculated Ra-226 ε = 0.27	Exhalation rate
	-	[kg.m^{-3}]	[m]	[m^{2}.s^{-1}]	-	Bq.kg^{-1}]		[Bq.m^{-2}.s^{-1}]
1	7.5	1813.8	0.24	1.20E-07	79.42	345	294	7.17E-02
2	7.8	1934.2	0.61	7.81E-07	85.29	371	316	2.09E-01
3	5.2	1748.7	0.36	2.74E-07	86.18	375	319	1.13E-01
4	5.6	1778.9	0.6	7.61E-07	77.15	335	286	1.72E-01
5	6.8	1882.9	0.27	1.52E-07	78.86	343	292	8.30E-02
6	7.6	1811.2	0.25	1.28E-07	98.17	427	364	9.12E-02
7	9.6	1913.2	0.39	3.13E-07	71.48	311	265	1.10E-01
8	10.2	1871.7	1.11	2.60E-06	31.16	135	115	1.35E-01
9	9.9	1992.1	0.55	6.45E-07	100.79	438	373	2.31E-01
10	6.1	1836.2	0.37	2.88E-07	86.05	374	319	1.22E-01
11	6.3	1827.6	0.43	3.79E-07	136.28	593	505	2.20E-01
12	6	1924.3	0.35	2.59E-07	120.17	522	445	1.69E-01
13	4.8	1952.6	0.74	1.14E-06	65.06	283	241	1.94E-01
14	5.7	1910.5	0.52	5.58E-07	91.98	400	341	1.88E-01
15	6.3	1854.6	0.46	4.49E-07	92.73	403	343	1.65E-01
16	7.2	2016.4	0.22	1.05E-07	159.02	691	589	1.49E-01
17	8.3	1903.9	0.49	5.07E-07	84.39	367	313	1.64E-01
18	6.7	1907.9	1.34	3.77E-06	40.84	178	151	2.17E-01
19	8.4	1937.5	0.63	8.44E-07	110.85	482	411	2.83E-01
20	7.3	1805.9	0.47	4.69E-07	90.85	395	336	1.61E-01
21	9.7	1930.3	0.36	2.66E-07	136.45	593	505	1.95E-01
22	9.4	1978.3	0.49	4.97E-07	62.03	270	230	1.24E-01
23	13.4	1935.5	0.52	5.69E-07	144.94	630	537	3.04E-01
24	8.2	1784.9	0.55	6.37E-07	94.21	410	349	1.93E-01
25	13.5	1846.1	0.59	7.21E-07	99.48	433	368	2.24E-01
26	14	2087.5	0.53	5.78E-07	59.9	260	222	1.36E-01
27	6.8	1802	0.5	5.16E-07	103.2	449	382	1.92E-01
28	7.8	1895.4	0.76	1.22E-06	33.2	144	123	9.99E-02
29	4.8	1850	0.62	8.01E-07	45.36	197	168	1.08E-01
30	6.4	1914.5	0.5	5.20E-07	56.83	247	210	1.13E-01
31	4.6	1936.8	0.54	6.11E-07	84.76	369	314	1.84E-01
32	9.2	1864.5	0.48	4.87E-07	92.78	403	344	1.73E-01
							Average	1.65E-01
							90% Percentile	2.24E-01
							Standard Deviation	5.55E-02

3.7.2.4 Surface Water Dams

No full-spectrum analysis results for the relevant surface water infrastructure associated with the Kareerand Project (e.g., the return water dam) are available at present.

3.7.3 Radiological Conditions in the Environment

3.7.3.1 General

AngloGold Ashanti has been monitoring radionuclide concentrations in surface and groundwater regularly since 2003. Some of these monitoring locations are located near the Kareerand Project that may be affected in future.

3.7.3.2 Surface Water

Figure 3.11 shows the locations of AngloGold Ashanti surface water monitoring points. Those most relevant to the Kareerand Project include KM9, KM12, and VRS23.

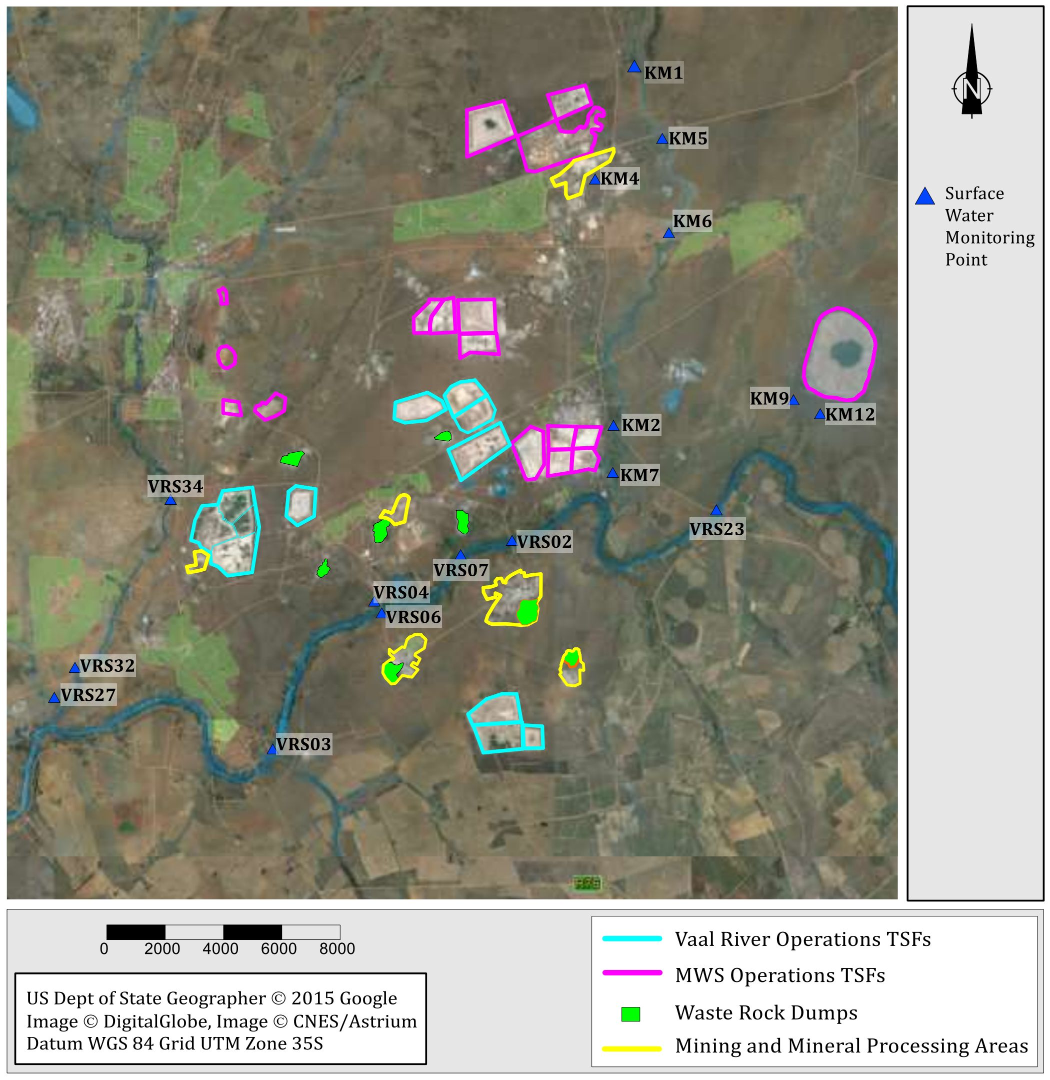


Figure 3.11 Map indicating surface water monitoring locations at the Kareerand Project (Van Blerk and Potgieter, 2016).

Table 3.10 to Table 3.12 summaries the available monitoring data from 2011 to 2015 for the three surface water monitoring locations listed above.

Table 3.10 Summary of nuclide specific data for surface water samples from monitoring point VRS23 (Vaal River - Vermaas Drift).

Necsa Report Number	Report Date	Sampling Date	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224	Gross α	Gross β
			mBq.L^{-1}													
RA-12278X5	2012/06/01	2011/10/19	124	128	16	11.1	5.94	5.94	5.33	4.25	-1.1	0.96	4.74	13.4	-94	170
RA-13662X4	2013/04/17	2012/10/04	59.6	67.4	44.1	0.75	7.26	7.26	2.75	-1.2	0.22	4.1	4.1	12.6	-55	450
RA-12827X6	2012/11/20	2012/04/05	31.5	41 .9	11	1.69	3.08	3.08	1.45	0.6	1.1	0.78	5.03	0.71	-78	370
RA-14208X5	2013/10/31	2013/04/03	33.2	59.8	117	3.69	3.41	3.41	1.53	9.5	0.95	7.3	12	0.59	-110	230
RA-15083X6	2014/05/25	2013/10/16	104	261	41 .7	3.76	4.04	4.04	4.8	2.12	1.9	7.84	4.2	1.6	-4.9	72
RA-15734X6	2014/10/30	2014/04/08	16.6	57.3	28.9	10.8	5.37	5.37	0.764	8.9	-0.98	5.9	7.7	<2.1	-89	170
RA-16535X6	2015/03/25	2014/10/02	51.3	69.6	29.3	7.55	4.2	4.2	2.36	3.6	0.61	5.81	6.9	<2.1	146	240
Average from 2005 to 2010			47.97	67.29	45.79	6.07	3.69	4.78	2.21	7.53	-	9.38	15.27	-	9.56	142.36

Table 3.11 Summary of nuclide specific data for surface water samples from monitoring point KM09.

Necsa Report Number	Report Date	Sampling Date	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224	Gross α	Gross β
			mBq.L^{-1}													
RA-15082X3	2014/05/25	2013/10/16	125	159	152	604	15	15	5.76	5.1	-99	7.32	7.22	<3.2	1360	808
RA-15740X3	2014/11/13	2014/04/09	120	256	36	178		3.9	5.53	10.3	8.35	16.3	38.5	86.9	140	350
RA-16534X3	2015/03/25	2014/10/02	782	743	33.1	122	5.6	5.6	36	9.2	3.51	7.83	6.2	<4.2	1150	1100

Table 3.12 Summary of nuclide specific data for surface water samples from monitoring point KM12.

Necsa Report Number	Report Date	Sampling Date	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224	Gross α	Gross β
			mBq.L^{-1}													
RA-15082X4	2014/05/25	2013/10/16	77.5	81	45.9	24.9	17.6	17.6	3.57	11.8	-4.7	4.41	8.11	0.7	-240	-51
RA-16534X4	2015/03/25	2014/10/02	94.1	134	15.8	4.2	15.2	15.2	4.33	9.73	1.3	6.34	5.35	0.73	-100	466

3.7.3.3 Groundwater

Figure 3.12 shows the approximate locations of groundwater monitoring boreholes from which samples have been submitted for full spectrum radionuclide analysis. Groundwater monitoring data indicating nuclide specific activity concentrations are available for the period 2011 to 2015. The Necsa laboratory reports are attached as Annexure A to this report. The results show that radionuclide concentrations vary greatly.

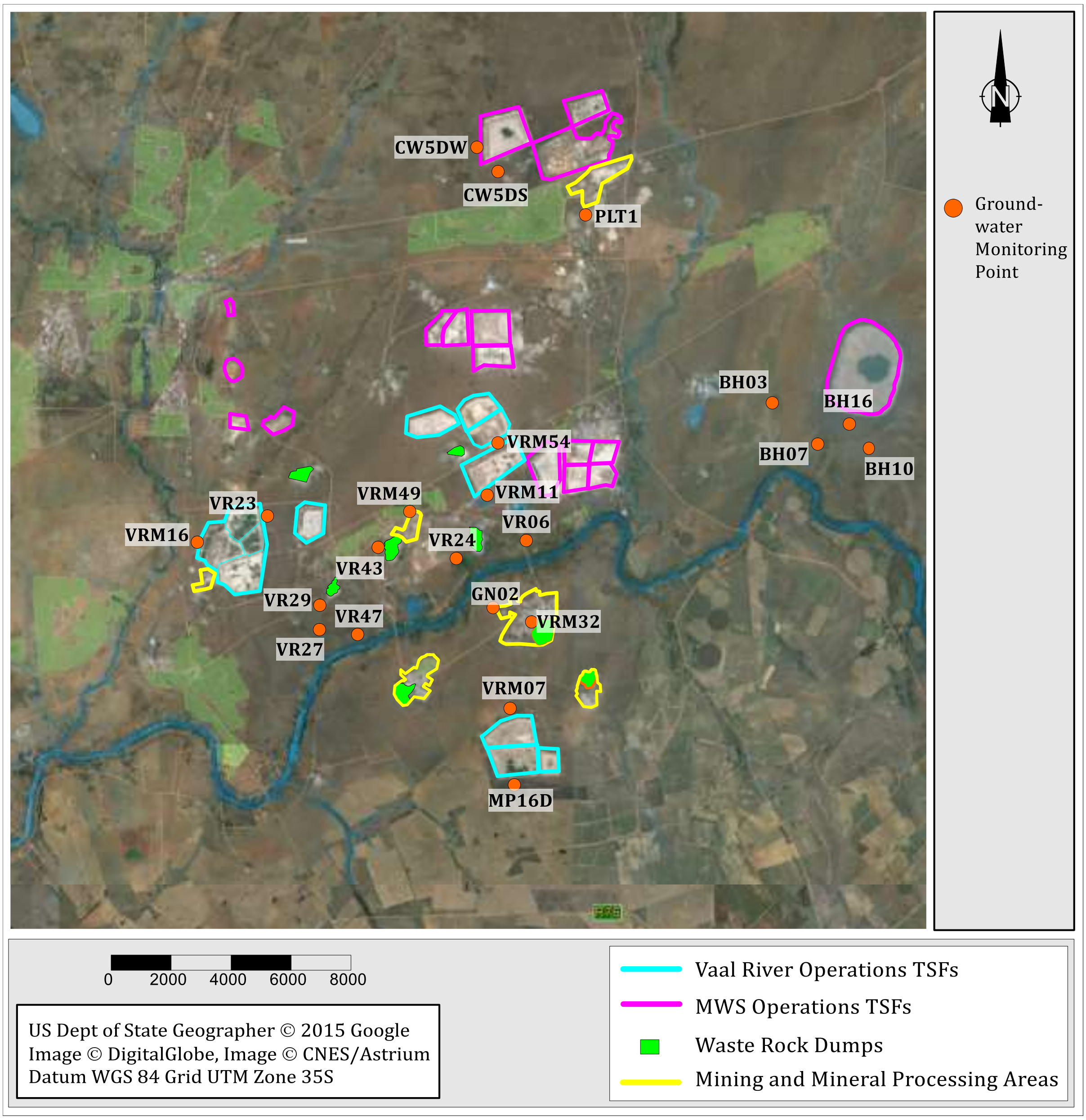


Figure 3.12 Map indicating groundwater monitoring locations at the Kareerand Project (Van Blerk and Potgieter, 2016).

During the planning phase of the Kareerand TSF, monitoring boreholes were installed, and samples collected to determine baseline levels of radionuclides in the groundwater at the site. Table 3.13 summarises the results for groundwater samples from the site of the Kareerand TSF. The results date from 2011, before construction of the TSF.

Table 3.13 Analyses of groundwater from boreholes at the new Kareerand site before construction of the TSF.

Necsa Report Number	RA-11664		RA-12427					
Sample Delivery Date	23/06/2011		29/11/2011					
Field Code	B/H No.10	B/H HC02	BH No.7	VIR 1	BH 10	BH No.3	BH HC 02	BH HC 01
Radionuclide	mBq.L^{-1}							
U-238	26.6	208	10.2	4,640	15.9	6.51	215	46.5
U-234	29.2	459	20.9	4,550	40.3	15.1	398	348
Th-230	39.5	32.5	5.9	22	57	43.3	26.8	14
Ra-226	2.13	6.9	6.32	148	12.4	1.2	2.65	53.3
Po-210	-	-	2.58	7.17	1.4	8.54	3.09	6.44
U-235	1.22	9.56	0.46	213	0.73	0.3	9.89	2.14
Th-227	12.6	10.56	1.3	-1.2	5.91	2.6	2.5	7.29
Ra-223	1.03	0.61	-0.55	-2.3	-2.6	-0.1	-1	-5.4
Th-232	6.52	2.1	0.73	2.8	1	1.81	1.3	< MDA
Th-228	13	6.15	1.4	8.02	3.1	1.8	7.5	14.6
Ra-224	< MDA	< MDA	7.96	25.7	1.2	8.41	-0.84	15.3
Gross Alpha	-	-	-130	7,530	-150	-70	73	190
Gross Beta	-	-	89	6,840	-100	-78	2400	10

After construction and operation of the Kareerand TSF samples of groundwater from four boreholes to the south of the TSF has been submitted for radiological analysis. Table 3.14 to Table 3.17 summarise the results for samples collected from 2013 to 2015. Figure 3.12 shows the locations of the boreholes. The Necsa laboratory reports are attached as Annexure A.

3.7.3.4 Radiological Conditions in Air

AngloGold Ashanti periodically measures airborne radon concentrations in the environment with passive radon gas monitors (RGM's) deployed in sets of two or three in locations around their operations.

The most recent radon monitoring campaign saw RGMs deployed in pairs at 27 of the 34 dust fallout monitoring locations. The RGMs were deployed for a period of two to three months from August 2017 to November 2017. As a further check, radon monitors were also deployed at the houses of two AngloGold Ashanti employees in Klerksdorp. RGMs were placed both inside and outside the homes. These values can be referenced as background concentrations of radon, largely unaffected by the radon sources at the broader Kareerand Project.

Table 3.18 lists the recorded radon concentrations in the area. Five of the sampling locations listed in Table 3.18 (Kareerand TSF, Kareerand Tailings, Kareerand Tailings North West, Kareerand Tailings South and Kareerand Tailings North) are near the Kareerand Project. Table 3.19 list the results for the houses in Klerksdorp.

Table 3.14 Summary of nuclide specific data for groundwater samples from monitoring point BH03.

Necsa Report Number	Report Date	Sampling Date	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224	Gross α	Gross β
			mBq.L^{-1}													
RA-15152X9	2014/07/14	2013/10/24	4.95	15.6	86	8.47	5.3	5.3	0.228	7.6	1.77	17.4	5.3	2	31	55
RA-15741X1	2014/10/30	2014/04/09	10.3	16	21	8.07	13	1.2	0.475	3.7	1	11.6	6.8	1	-40	68
RA-16530X4	2015/03/25	2014/10/02	16.4	26.5	8.4	13.1	7.32	7.32	0.754	3.7	0.46	1.5	< 9	9.74	-22	58

Table 3.15 Summary of nuclide specific data for groundwater samples from monitoring point BH07.

Necsa Report Number	Report Date	Sampling Date	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224	Gross α	Gross β
			mBq.L^{-1}													
RA-14206X1	2013/10/31	2013/04/04	9.71	40.8	90.9	5.97	10.5	1.5	0.447	12.9	-0.91	7	6	< 2.4	-100	240
RA-15084X3	2014/07/07	2013/10/16	50	95.4	76.9	2.28	6.22	6.22	2.3	7.9	2.17	36	11.4	3.87	11	-11

Table 3.16 Summary of nuclide specific data for groundwater samples from monitoring point BH10.

Necsa Report Number	Report Date	Sampling Date	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224	Gross α	Gross β
			mBq.L^{-1}													
RA-14206X4	2013/10/31	2013/04/04	14.6	24.9	42.4	3.13	12.6	0.031	0.674	4.8	-5.1	10.5	22.4	-2.1	-180	150
RA-15084X?	2014/07/07	2013/10/16	74.6	146	23	1.17	1.2	1.2	3.43	31.8	-0.15	1.9	9.04	< 2.7	190	60

Table 3.17 Summary of nuclide specific data for groundwater samples from monitoring point BH16.

Necsa Report Number	Report Date	Sampling Date	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224	Gross α	Gross β
			mBq.L^{-1}													
RA-15152X10	2014/07/14	2013/10/24	35.7	36.8	62	5.94	4.99	4.99	1.64	11	0.39	25.6	11.8	0.91	20	110
RA-15741X2	2014/10/30	2014/04/09	8.52	22.7	32.4	5.12	12.5	0.62	0.392	11	-1 .2	7.04	8.44	< 2.7	-130	42
RA-16530X5	2015/03/25	2014/10/02	16.7	35.7	41.4	6.4	-16	15.9	0.768	11.5	-0.51	12.4	6.8	2.9	-130	13

Table 3.18 Summary of the environmental radon survey conducted in the area in September 2017.

Map No.	Latitude	Longitude	RGM	W/Place (Dust Buckets)	Reading	Exp Time	Bq.m^{-3}
AMW 01	26:54:07.4010 S	26:42:10.2403 E	H59820	North East of Harties 7 TSF	1.12E+05	1848	60.78
			H59821		1.12E+05	1848	60.42
AMW 02	26:49:51.9900 S	26:47:58.8099 E	H59812	Golden Village	1.22E+05	1848	66.27
			H59813		1.15E+05	1848	62.10
AMW 04	26:50:23.1800 S	26:45:55.9019 E	H59826	N12 West	1.06E+05	1848	57.36
			H59827		1.07E+05	1848	57.82
AMW 05	26:51:04.3000 S	26:45:58.9099 E	H59852	Gamtos Street (South)	1.18E+05	1848	63.85
			H59853		9.38E+04	1848	50.73
AMW 06	26:50:36.6034 S	26:44:29.3224 E	H59844	Palm Tree Nursery	1.08E+05	1848	58.67
			H59845		1.10E+05	1848	59.74
AMW 08	26:53:13.3736 S	26:46:54.2362 E	H59808	East of Harties TSF	1.20E+05	1848	64.89
			H59809		1.13E+05	1848	61.36
AMW 10	26:54:52.3968 S	26:49:06.3078 E	H59824	DWA Weir	1.26E+05	1464	86.05
			H59825		1.04E+05	1464	70.98
AMW 11	26:57:30.8999 S	26:47:08.7000 E	H59804	Great Noligwa	1.45E+05	1464	98.76
			H59805		1.45E+05	1464	99.26
AMW 12	26:58:03.5000 S	26:46:05.5999 E	H59854	West of Great Noligwa	1.55E+05	1464	105.87
			H59855		1.72E+05	1464	117.36
AMW 13	26:55:27.4380 S	26:44:37.6159 E	H59822	Vaal Reefs Town	1.51E+05	1464	102.92
			H59823		1.68E+05	1464	114.80
AMW 14	26:55:41.7266 S	26:47:42.6300 E	H59800	Midvaal WC	1.53E+05	1464	104.77
			H59801		1.45E+05	1464	98.98
AMW 15	26:54:18.5999 S	26:40:04.8999 E	H59838	Ragz	1.40E+05	1464	95.67
			H59839		1.69E+05	1464	115.26
AMW 18	26:54:32.1354 S	26:41:43.1907 E	H59818	South West of Harties 7 TSF	1.20E+05	1464	81.92
			H59819		1.13E+05	1464	77.45
AMW 20 DW	26:49:49.4699 S	26:47:58.6700 E		Golden Village Dustwatch (RGM's on dust bucket)	1.22E+05	1848	66.27
					1.15E+05	1848	62.10
AMW 21 DW	26:49:11.6109 S	26:48:52.8223 E	H59842	East of Chemwes 2 TSF Dust Watch	1.20E+05	1848	65.00
			H59843		1.14E+05	1848	61.77
AMW 22 DW	26:57:30.8000 S	26:47:08.7000 E		Great Noligwa Dust Watch (RGM's on dust bucket)	1.45E+05	1464	98.76
					1.45E+05	1464	99.26
AMW 19	26:56:07.6199 S	26:51:19.6999 E	H59840	Wouter De Wet	8.16E+04	1464	55.71
			H59841		8.50E+04	1464	58.06
AMW 23	26:52:09.9231 S	26:46:29.3875 E	H59810	North of Harties 1&2 TSF	9.45E+04	1848	51.14
			H59811		1.19E+05	1848	64.58
AMW 24	26:53:32.9653 S	26:52:33.3085 E	H59868	Kareerand TSF	1.22E+05	1608	75.78
			H59869		1.30E+05	1608	81.04
AMW 26	26:52:16.1709 S	26:53:16.5790 E	H59858	Kareerand Tailings North West	1.18E+05	1608	73.62
			H59859		1.16E+05	1608	72.08
AMW 29	26:54:21.3999 S	26:52:43.4999 E	H59856	Kareerand Tailings	1.30E+05	1608	80.76
			H59857		1.38E+05	1608	85.86
AMW 30	26:54:29.1000 S	26:53:36.5999 E	H59864	Kareerand Tailings South	1.09E+05	1608	67.74
			H59865		1.77E+05	1608	110.36
AMW 31	26:52:53.7099 S	26:54:25.6999 E	H59846	Kareerand Tailings North	1.31E+05	1608	81.51
			H59847		1.33E+05	1608	82.48
AMW 32	26:53:18.0999 S	26:55:12.5999 E	H59850	Umfula Eco	1.12E+05	1608	69.58
			H59851		1.29E+05	1608	79.95
AMW 33	26:50:03.6278 S	26:47:07.7124 E	H59832	South of MWS 5 TSF	1.05E+05	1848	56.74
			H59833		9.65E+04	1848	52.22
AMW 34	26:48:54.8284 S	26:46:52.9756 E	H59828	East of MWS 5 TSF	1.24E+05	1848	66.97
			H59829		1.46E+05	1848	79.14
AMW 35	26:48:32.4205 S	26:46:22.9330 E	H59848	North of Chemwes 5 TSF	1.13E+05	1848	61.41

Table 3.19 Airborne radon activity concentrations measured at two houses in Klerksdorp.

Monitoring Location	Location Coordinates		Description	Radon Activity Concentration (Bq.m^{-3})	
				RGM 1	RGM 2
Wilkoppies, Klerksdorp	26.8462 S	26.6675 E	Outside House	17.3	24.3
			Inside House	47.4	51.3
Flamwood, Klerksdorp	26.8462 S	26.6675 E	Outside House	18.6	21.0
			Inside House	39.6	49.7

3.7.4 Baseline Conditions

3.7.4.1 General

Some radiological baseline characterisation studies were performed for the Kareerand Project. This includes a baseline gamma survey of the Extension area, soil sampling and full-spectrum analysis of selected locations, and an environmental radon survey using RGMs at the same selected locations. Figure 3.13 is a Google image showing the locations near the Kareerand TSF where soil samples were collected and RGM employed.

Figure 3.13 Google image showing the locations near the Kareerand TSF where soil samples were collected and RGM employed.

3.7.4.2 Gamma Survey

A gamma survey was performed during July 2017 over the Extension area of the Kareerand TSF. Table 3.20 summarises the gamma radiation survey results. The full record of the data is included as Appendix E. The data is presented as isopleth maps of Uranium and Thorium in Figure 3.14 and Figure 3.15, respectively. The maximum Uranium concentration is 74 Bq.kg^{-1}, while the maximum Thorium concentration is 47 Bq.kg^{-1}.

Table 3.20 Summary of the gamma radiation survey results that were performed in the Extension area of the Kareerand TSF.

Parameter	U		Th		Dose Rate
	(ppm)	(Bq.kg^{-1})	(ppm)	(Bq.kg^{-1})	(nSv.h^{-1})
Minimum	0.00	0.00	0.00	0.00	0.00
Maximum	6.00	73.88	11.60	47.10	71.70
Average	1.64	20.23	5.62	22.82	35.75
90th Percentile	2.60	32.01	7.60	30.86	44.40

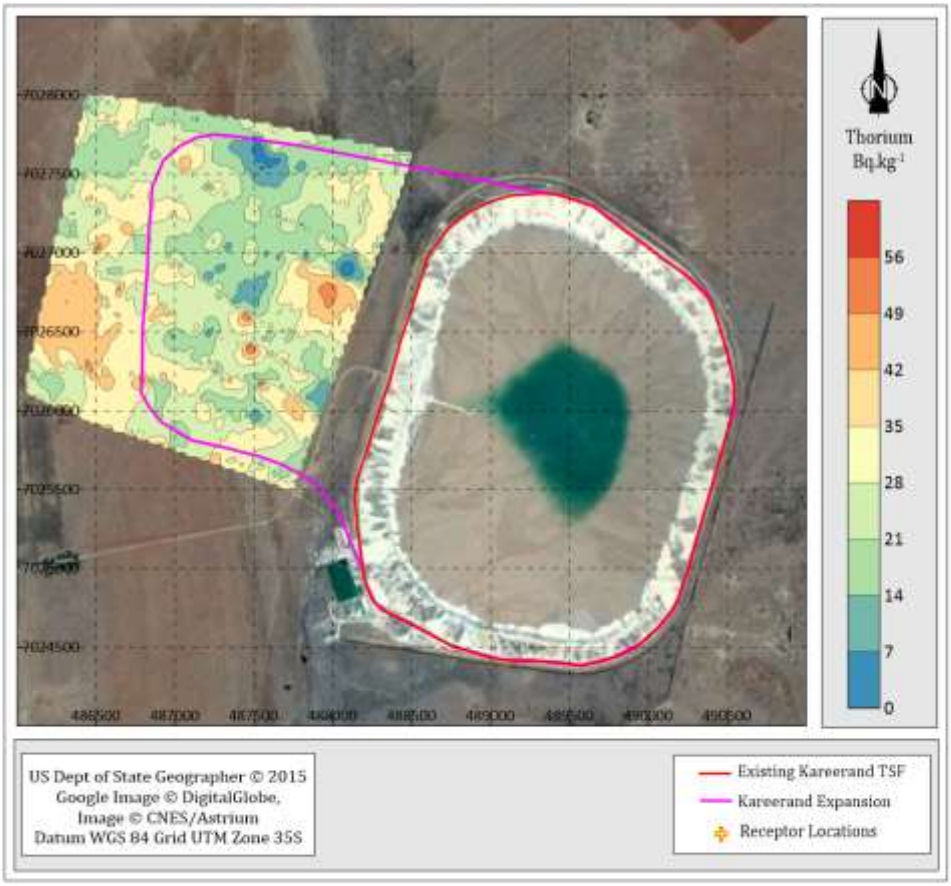


Figure 3.14 Isopleth map of the Uranium concentration (in Bq.kg^{-1}) observed in the Extension area.

3.7.4.3 Soil Analysis

Soil samples were collected at the four locations shown in Figure 3.13 within the Extension area for full spectrum analysis. Table 3.21 summarises the full spectrum analysis results from the Necsa Radioanalytical Laboratory (Report No. RS2018-2224-01 dated 1 November 2018). The Uranium and Thorium results are within the range of values observed in the gamma survey. The results are typical of what one would expect for background conditions.

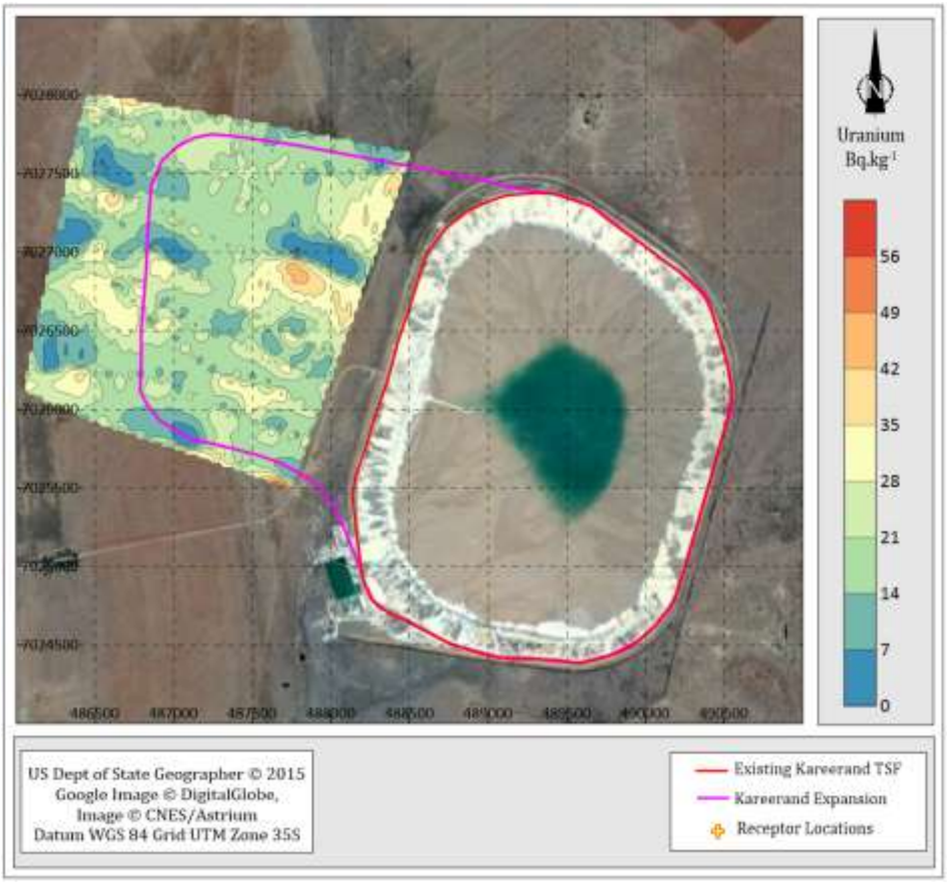


Figure 3.15 Isopleth map of the Thorium concentration (in Bq.kg^{-1}) observed in the Extension area

Table 3.21 Summary of the full spectrum analysis of 4 soil samples collected in the area where the Kareerand TSF Extension will be constructed(Necsa Radioanalytical Laboratory Report RS2018-2224-01 dated 1 November 2018).

Field Code	Middle Kareerand			South Kareerand			West Kareerand			North Kareerand		
Lab Code	RS2018-2224X001			RS2018-2224X002			RS2018-2224X003			RS2018-2224X004		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
	Bq.kg^{-1}											
U-238	20.7	0.7	0.45	18.8	0.9	0.44	25.1	0.7	0.43	14.2	0.5	0.43
U-234	20.9	0.7	0.46	18.9	0.9	0.45	25.3	0.7	0.44	14.3	0.5	0.43
Ra-226	27.8	3.6	9.5	18.5	3.4	9.8	23.5	3.6	9.8	16.3	3	8.2
Pb-210	<MDA		61	<MDA		55	<MDA		69	<MDA		54
U-235	0.955	0.031	0.021	0.864	0.042	0.02	1.15	0.03	0.02	0.0654	0.025	0.02
Th-232	24.3	0.8	1.6	23.3	0.8	1.6	30.4	0.8	1.9	14.2	0.4	1.2
Ra-228	25	5.6	15	22.2	5.4	15	19.6	6	18	6.8	3.9	13
Th-228	20.9	7.3	19	23	3.4	30	37.2	8.9	20	16	3.5	28
K-40	131	24	64	128	25	67	242	30	67	73.1	20.4	60
Gross α	450	180	560	230	170	560	1130	220	570	330	170	550
Gross β	333	23	56	285	22	55	402	25	60	161	20	56

3.7.4.4 Environmental Radon

RGM was employed for 2 months at the four locations shown in Figure 3.13. The results presented in Table 3.22 show that the radon concentration at these locations varies between 67 and 90 Bq.m^{-3}. Given its relative proximity, one can expect the exiting Kareerand TSF to influence these results.

Table 3.22 Summary of the environmental radon survey conducted in the area in September 2017.

Latitude	Longitude	RGM	W/Place (Dust Buckets)	Reading	Exp Time	Bq.m^{-3}
26°53'48.11"S	26°51'35.09"E	H59862	South of Kareerand Extension	1.44E+05	1608	89.35
		H59863		1.09E+05	1608	67.89
26°51'43.74"S	26°52'21.24"E	H59836	North of Kareerand Extension	1.26E+05	1608	78.10
		H59837		1.41E+05	1608	87.56
26°52'28.03"S	26°52'20.20"E	H59866	Middle of Kareerand Extension	1.14E+05	1608	70.97
		H59867		1.18E+05	1608	73.39
26°53'9.55"S	26°51'17.26"E	H59834	West of Kareerand Extension	1.16E+05	1608	71.95
		H59835		1.24E+05	1608	76.99

4 Source-Pathway-Receptor Analysis

4.1 Introduction

The main objective is to assess the potential radiological impact to members of the public that may occur during the operational phase of the Kareerand Project, with due consideration of the radiological impact that may occur during the post-closure phase. How members of the public are exposed to radiation-induced by the Kareerand Project may be different depending on the operational conditions and the specific point in time (either present or future). The radiological impact is evaluated through the development of site-specific public exposure conditions. As used here, an exposure condition is defined as follows:

> *An exposure condition is a sequence of features, events and processes (FEPs) and is one of a set devised for illustrating normal or probable situations of radiation exposure to receptors, which may include emergency exposure situations and existing exposure situations.*

The purpose of this section is to use the current understanding of the Kareerand Project and its surroundings (see Section 3), bounded by the conditions and assumptions defined in the assessment context (see Section 2), to develop relevant public exposure conditions for the Kareerand Project. Different approaches can be used to derive a discrete set of public exposure conditions. Consistent with the assessment framework presented in Figure 1.2, a Source-Pathway-Receptor (SPR) analysis approach was judged appropriate for the assessment. The SPR analysis approach is inherently systematic, traceable, and transparent, and provides the opportunity to identify and evaluate all possible exposure situations that may exist both now and in the future.

The section is structured as follows. Section 4.2 defines a few key concepts used in the SPR analysis approach, while the elements of the Source-Pathway-Receptor linkages relevant to the Kareerand Project are evaluated and discussed in Section 4.3 to Section 4.5. Section 4.6 introduces the way conceptual models are represented in the definition of the exposure conditions. The outcome of the SPR analysis approach is then used for the definition and justification of the public exposure conditions in Section 4.7.

4.2 Key Concepts used in the SPR Analysis Approach

The SPR analysis approach consists of three interrelated steps. The first step is to identify all current, future and historical *sources* of radiation exposure associated with the Kareerand Project. As used here, *sources* refer to any entity that contains radioactivity *and* have the potential to release the radioactivity into the environment to pose a potential radiological risk to humans and the environment. The sources are characterised in terms of its unique composition (i.e. specific radioactive substances present or emitted) and its characteristics that will determine how contaminants may be distributed in the environment.

Secondly, all relevant pathways and routes of exposure that relate to the identified sources must be evaluated. In this context, *pathways* refer to how radionuclides may be dispersed or transferred within or between compartments of the environmental system, to a point where humans interact with the compartment. An *exposure route* refers to the route of entry into the human body to pose a radiation risk, such as ingestion, inhalation, or external exposure. Finally, *receptors* are defined and characterised. Receptors refer to humans that potentially may be subject to radiation exposure (i.e. a radiation dose) from the applicable sources and through the exposure pathways of concern.

4.3 Source Identification

4.3.1 General

In terms of the SPR approach, all relevant sources of radiation exposure associated with the Kareerand Project must be identified. Sources of radiation exposure associated with mining and mineral processing facilities are induced by activities that enhance concentrations of naturally occurring radionuclides in the accessible environment. To pose a radiological risk to members of the public and the environment, these radionuclides first must be released from the sources of radiation exposure into the environment. Release mechanisms can be generalised into the following natural and human-induced conditions:

- Solid-, water-, and gas mediated release of radionuclides (natural);
- Direct gamma radiation (natural); and
- Controlled or uncontrolled releases of radionuclides into the environment (human-induced).

The sources are characterised in terms of their unique composition (i.e. specific radioactive substances present or emitted) and their characteristics, which will determine how contaminants may be distributed in the environment. Based on the description of the Kareerand Project (see Section 3.4), two main types of sources can be identified: those that release airborne contaminants, and those that release waterborne contaminants.

Also, note that distinction can be made between primary and secondary sources of radiation exposure. The *primary sources* are associated with physical features or entities at a mining and mineral processing operation where naturally occurring radionuclides are released or stored as NORM with the potential to be released to the environment. *Secondary sources* are a consequence of primary sources and refer to the build-up of radioactivity in the environment.

4.3.2 Sources of Airborne Contaminants

The only source of airborne contaminants associated with the Kareerand Project is the TSF itself, both in its current state and in the extended state.

Generally, a TSF serves as a source of airborne dust as PM_{10} and Total Suspended Particulate (TSP) as well as airborne radon gas. Windblown dust that may be emitted from the TSF contains long-lived alpha radiating isotopes, which are dispersed into the atmosphere (solid-mediated release of contaminants, resulting in an *airborne activity concentration*). This radioactive dust is generally referred to as long-lived radioactive dust (LLα). Also, the Ra-226 content of the tailings material may result in the emission of radon gas in the air (gas-mediated release of contaminants, increasing *airborne activity concentrations*).

4.3.3 Sources of Waterborne Contamination

The main source of waterborne contaminants expected at the Kareerand Project is the TSF itself. Infiltration and subsequent percolation of water through the TSF may induce leaching of radionuclides to the underlying aquifer (water-mediated release of contaminants, resulting in a *groundwater activity concentration*).

Several water management facilities are associated with the Kareerand Project. These include return water dams, stormwater dams and buffer dams, as well as channels for the transfer of water. The nature of these water management facilities is such that their contribution as a source of radiation exposure is largely limited to water infiltration and subsequent leaching of radionuclides to the underlying aquifer (water-mediated release of contaminants, resulting in a *groundwater concentration*). However, the rate of infiltration is expected to be low compared to that of the larger area sources such as the TSF.

4.3.4 Radiological Characteristics of the Sources

Section 3.7 summarised the available radiological data and information available for the Kareerand Project. At present, no radiological data is available for water management facilities. For the Kareerand TSF, Table 3.7 summarises the radionuclide specific activity concentration for the Kareerand TSF, as well as the average of all the MWS TSFs. It was argued that these facilities will be reprocessed, and the resulting tailings material deposited as part of the Kareerand Project. Using these higher concentrations would, therefore, be conservative.

4.4 Pathways

4.4.1 General

The most significant environmental pathways through which members of the public may be exposed to radiation at a mining and mineral processing operation may be generalised as follows (IAEA, 2002):

- Atmospheric pathways that can give rise to doses due to inhalation of airborne gases (e.g. radon and its progeny) and airborne radioactive particles;
- Atmospheric and associated terrestrial pathways that can give rise to doses resulting from the ingestion of contaminated soil and foodstuff and external radiation; and
- Aquatic pathways that can give rise to doses from the ingestion of contaminated water, foods produced using contaminated irrigation water, fish, and another aquatic biota, food derived from animals drinking contaminated water, and from external radiation.

This is consistent with the potential sources of radiation exposure listed in Section 4.3. The purpose of this section is to illustrate how contaminants may be released and dispersed through the different pathways into the environment and how the interaction between pathways may redistribute contaminants to receptor locations. A distinction is made between the atmospheric and aquatic pathways and their associated routes of exposure.

4.4.2 Atmospheric Pathway

The significance of the atmospheric pathway is due to the presence of naturally occurring radionuclides in the particulates and gases released into the atmosphere from the activities and features associated with the Kareerand Project. The contribution of the atmospheric pathway to the total effective dose is expected to occur through the following pathways:

- The release and distribution of radon gas into the atmosphere and the subsequent inhalation of these gases by members of the public;
- The release and distribution of dust particulates containing radionuclides (associated with the PM_{10} particulates and (generally referred to as Long-Lived Alpha particles or LLα) into the atmosphere and the subsequent inhalation of the dust by members of the public; and
- The deposition of airborne dust particulates containing radionuclides (associated with the Total Suspended Particulates or TSP) onto the ground, and the subsequent interaction of members of the public with the deposited dust on the soil surface or crops.

Airborne particulates and radon gas concentrations are expected to be the highest close to the source and decrease with distance from the source depending on meteorological conditions, the physical characteristics of the contaminants and facilities from which the contaminants are released.

The atmospheric dispersion modelling for Kareerand Project uses information on dust emission from the sources identified in Section 4.3.2, together with meteorological data of the area to estimate dust concentrations and dust deposition rates at various distances from the sources. Figure 4.1 is a graphical representation of airborne PM_{10} concentrations (in units of $\mu g.m^{-3}$), dispersed from all the atmospheric pathway sources associated with the Kareerand Project, as derived from data presented in Airshed (2018).

The modelled concentrations are shown as shaded zones with similar concentrations presented by a single colour (concentration isopleths) overlaid on a map of the Kareerand Project and surrounding areas. The graphical edges of these concentration zones should not be interpreted as concentration boundaries, but rather as a continuum with some overlap between the indicated concentration values. Also, the outside boundary of the concentration isopleths is not a cut-off beyond where there are no more airborne contaminants. It is a representation of the extent of the airborne pollutants at the lowest concentration value on the scale. Airborne pollutant concentrations continue beyond this boundary but are all lower than the lowest concentration value on the scale.

A similar representation of the annual average daily dust deposition rate (in units of $mg.m^{-2}.day^{-1}$) for the same sources is presented in Figure 4.2, while Figure 4.3 presents the airborne radon gas dispersion concentrations as derived from all radon sources. From Figure 4.1 and Figure 4.2 it is clear that the airborne dispersion of particulates and the subsequent deposition of TSP are predominantly towards the south and southeast of the Kareerand TSF. What is also clear from Figure 4.1 to Figure 4.3 is that the area of impact diminishes very quickly, with the result that nearby receptor locations (e.g., Khuma residential area) seem unaffected.

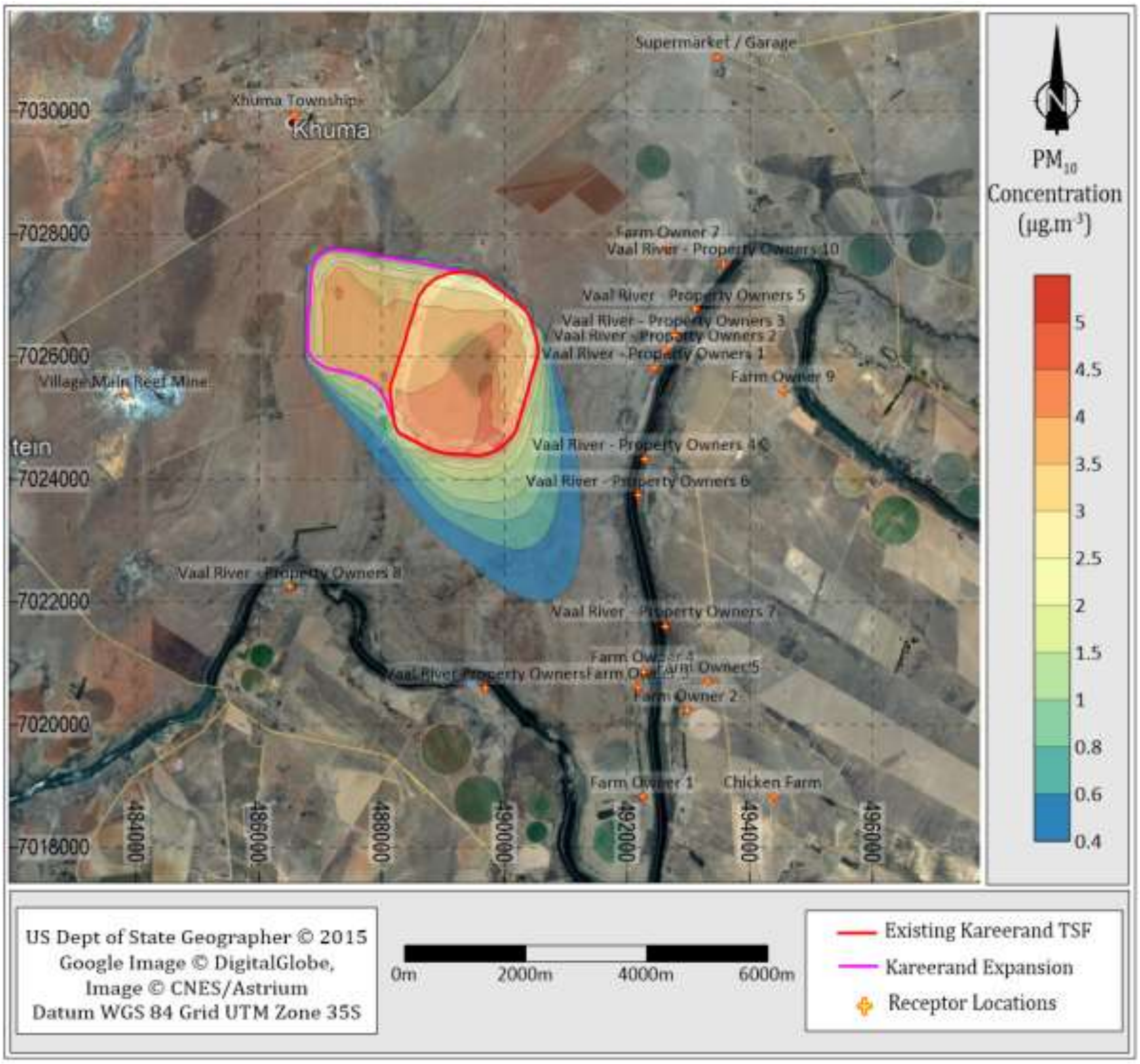


Figure 4.1 Annual average airborne PM_{10} concentrations associated with the Kareerand Project using data from Airshed (2018).

The flow diagram in Figure 4.4 can be used to evaluate the contribution of the atmospheric pathway to a quantitative total effective dose. As shown in Figure 4.4, airborne contaminants may be deposited onto surface soil, increasing the concentration of radionuclides in the soil. Depending on the prevailing atmospheric conditions, the contaminants deposited onto the soil may go into re-suspension, resulting in the further distribution of airborne contaminants.

Exposure to the contaminated soil also contributes to an external gamma radiation dose (ground shine). Similarly, airborne contaminants may be deposited onto the surface water bodies, contributing to the contamination of surface water pathway (see Section 4.4.4). The deposition of airborne contaminants can introduce secondary pathways that may contribute to a total effective dose. Of importance is the uptake of radioactive contaminants into the food chain. Several processes influence the transfer of airborne contaminants to crops (including animal feed and human food) as part of the atmospheric pathway:

- Direct deposition and interception of contaminants onto crops;

- Deposition of airborne contaminants onto the soil surface, followed by root uptake of contaminants from the soil; and
- Transfer (through translocation) of the deposited contaminants to the plant structure.

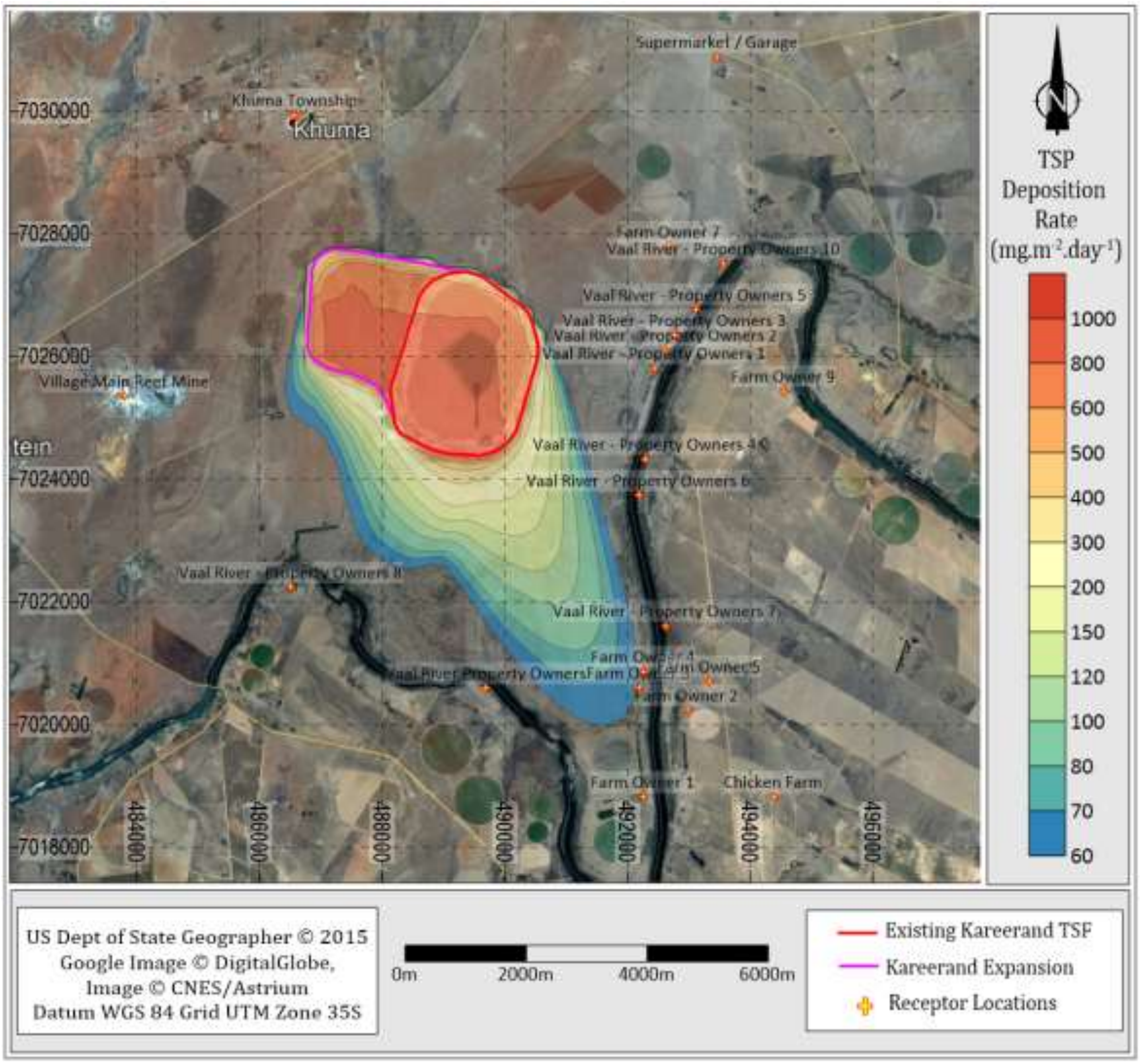


Figure 4.2 Annual average dust deposition rate of TSP at Kareerand Project using data from Airshed (2018).

Some of the contaminants will be lost during food preparation, while some will be washed off plants (contributing to the radionuclide concentration of the soil). Contaminants deposited on the soil can be taken up by plants and so contribute to the annual effective dose of individuals that consume the plants. Animal ingestion of contaminated crops or soil or inhalation of airborne radioactivity may lead to the contamination of animal products such as dairy, eggs, and meat.

Humans may receive a dose through consumption of the contaminated animal products. Human ingestion of contaminated crops, soil, or animal products or the inhalation of airborne radioactivity will result in an internal dose. The total effective dose of radiation received through the atmospheric pathway is the sum of the individual doses received through the ingestion, inhalation, and external gamma exposure routes.

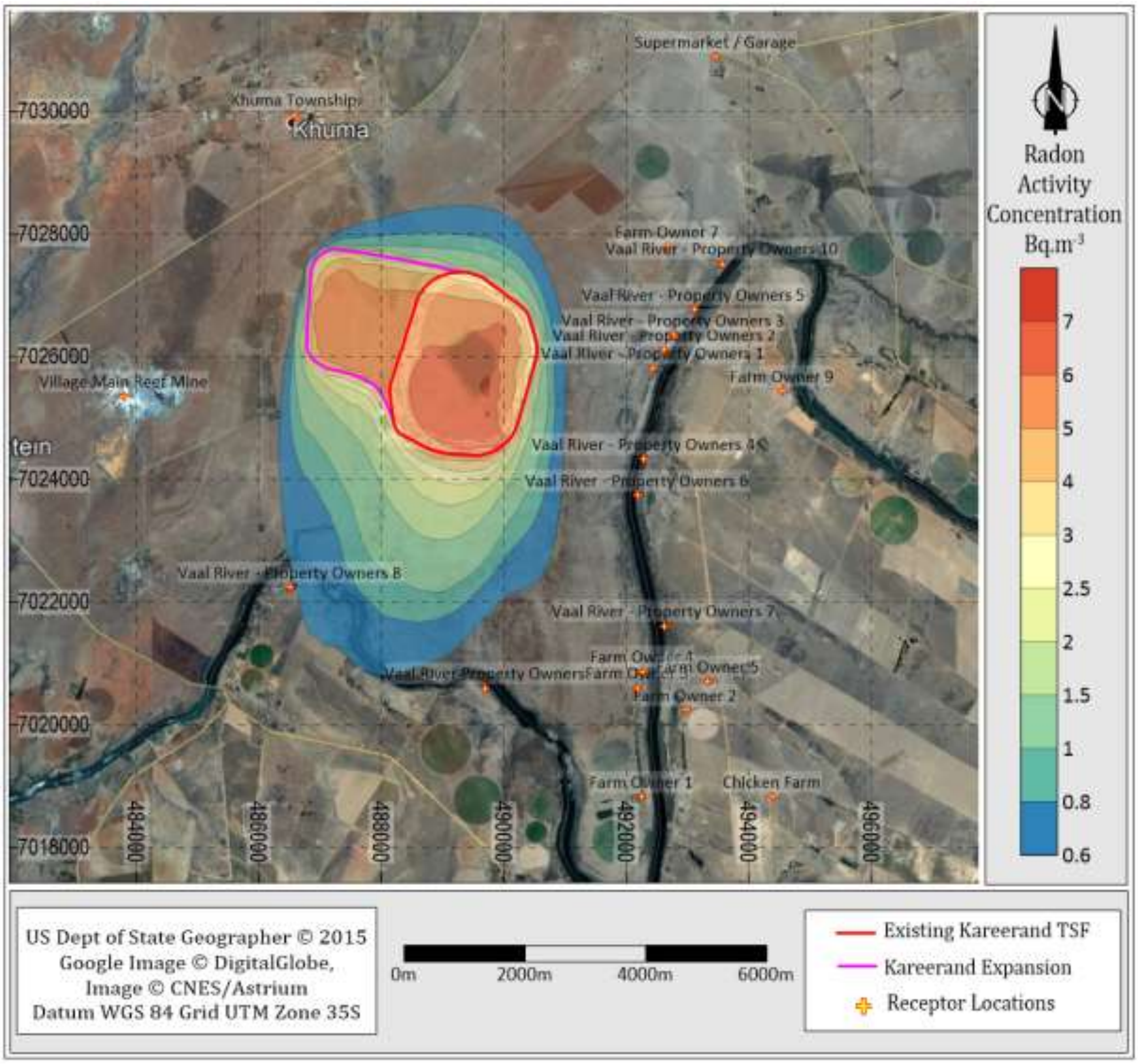


Figure 4.3 Annual average radon concentration for Kareerand Project, using the radon exhalation rates listed in Section 3.7.2 for the TSF.

4.4.3 Groundwater Pathway

The significance of the groundwater pathway is due to naturally occurring radionuclides associated with some of the waterborne sources at the Kareerand Project (see Section 4.3.3). During and after the operational period of Kareerand Project, these radionuclides may be released to the underlying aquifer.

The groundwater flow regime at Kareerand Project is documented in the currently available groundwater specialist studies (GCS, 2018b). A good correlation exists regionally between the groundwater levels and the topography, which means that generally, the flow would be towards the low-lying areas (see Figure 3.6). However, one can assume that on a local scale the regional flow regime could be disturbed by the presence of the Kareerand TSF where a mound is visible in the groundwater level data.

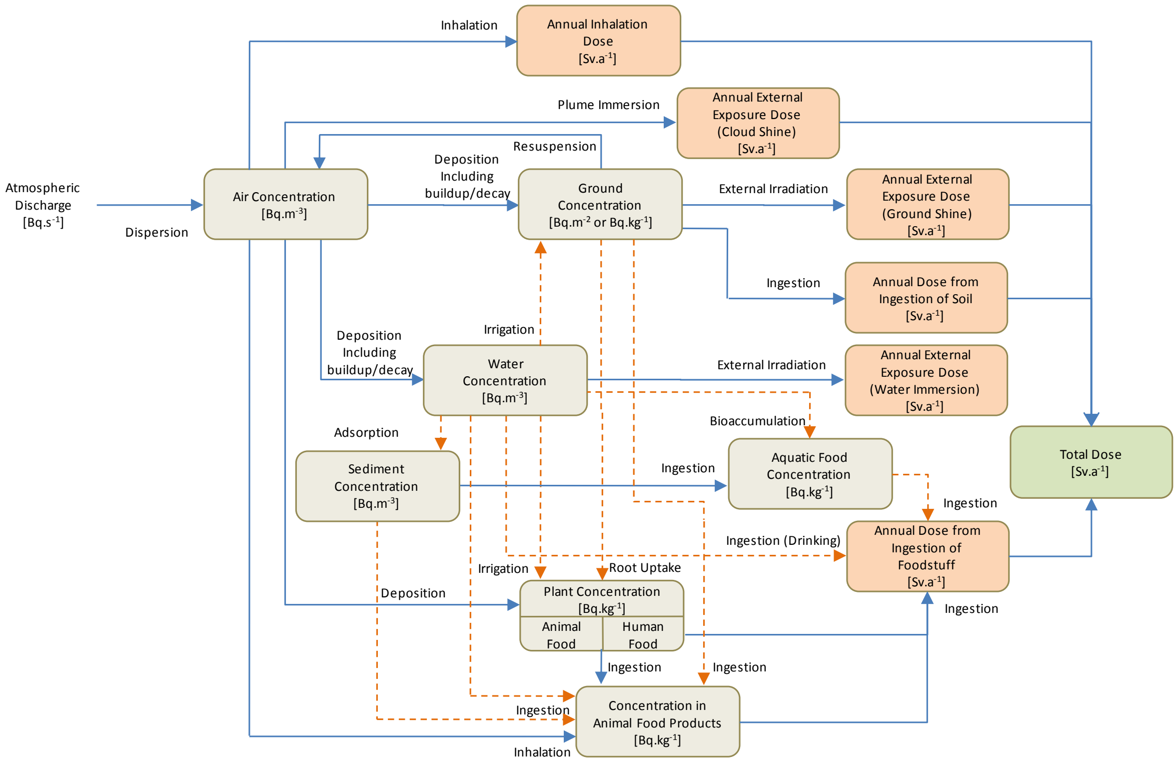


Figure 4.4 **Features, processes and associated exposure modes that should be considered to calculate the contribution of the atmospheric pathway to a total dose.**

The contribution of the groundwater pathway to the total effective dose is expected to occur through the release of naturally occurring radionuclides to the underlying aquifer, the subsequent migration of these radionuclides along the groundwater flow pathway to a point where members of the public abstract the groundwater. The total effective dose depends on how the abstracted groundwater is used, i.e., for personal (household) purposes, to irrigate a household garden, or to irrigate and sustain a farm system.

The flow diagram in Figure 4.5 can be used to calculate the contribution of the groundwater pathway to a quantitative total effective dose. Varying flow and the geochemical process will cause contaminants to leach from the various groundwater pathway sources to the underlying aquifer, resulting in a groundwater concentration. Through groundwater flow and radionuclide transport processes (e.g. advection, dispersion and diffusion), migration to various discharge points (e.g. surface water streams, rivers, dams, springs or boreholes) will occur. This will result in an increase in the groundwater concentration at these points. Groundwater movements may be very slow and geochemical reactions may retard the movement of radionuclides relative to the groundwater flow even further. Consequently, the radionuclides may take tens to thousands of years to migrate to groundwater discharge points such as boreholes (e.g. monitoring, drinking or irrigation borehole), fountains, and surface water bodies.

Depending on the radionuclide concentration of the groundwater as well as the human habit and behavioural characteristics, various secondary pathways can contribute to a total effective dose, as illustrated in Figure 4.5. These pathways are very similar to those described for the atmospheric pathway, except that instead of deposition of airborne contaminants onto crops or soils, irrigation of water contributes to the concentrations of radionuclides in crops or soil.

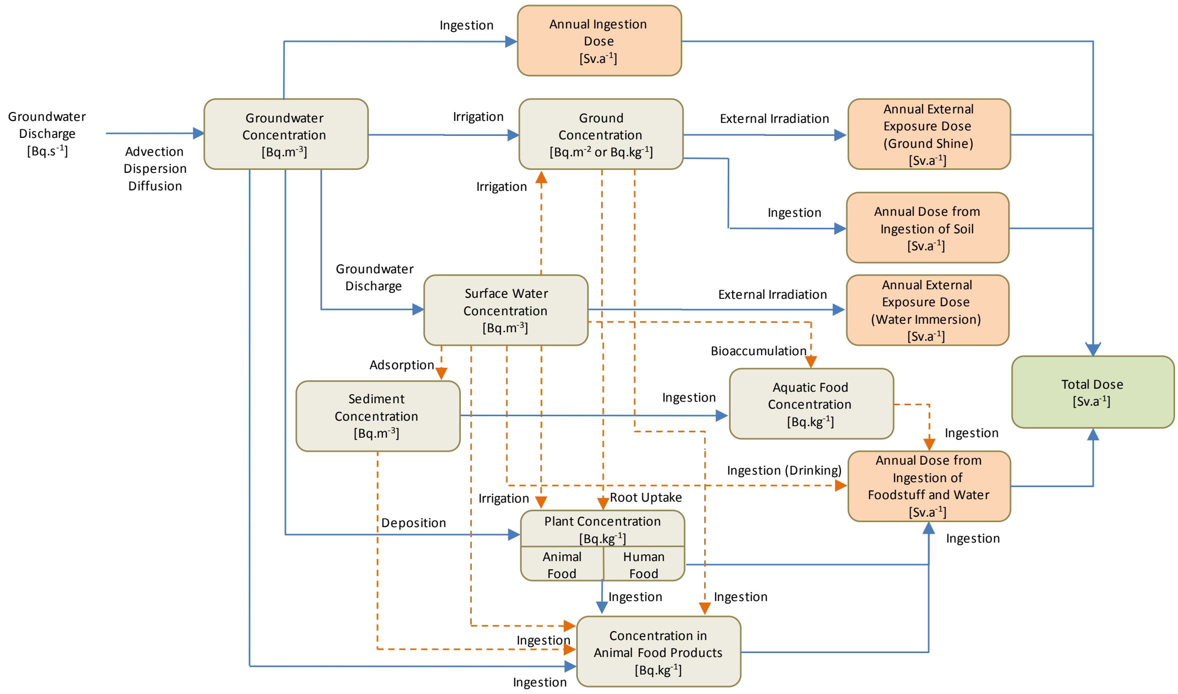


Figure 4.5 Features, processes and associated exposure modes that should be considered to calculate the contribution of the groundwater pathway to a total dose.

4.4.4 Surface Water Pathway

Under normal operational conditions, the surface water pathway is an extension of the groundwater pathway and to a lesser extent the atmospheric pathway. However, the controlled or uncontrolled release of contaminated water or mine residue material may serve as a direct source of radiation exposure associated with the surface water pathway.

Once discharged into the surface watercourse, radionuclides are subject to a series of physical and chemical processes that affect their transport from the point of discharge. These processes illustrated in Figure 4.6 include the following (IAEA, 2001):

- Flow processes, such as down-current transport (advection) and mixing processes (turbulent dispersion);
- Sediment processes, such as adsorption/desorption on suspended, shore/beach and bottom sediments, and down-current transport, deposition and re-suspension of sediment, which adsorbs radionuclides;
- Other processes, including radionuclide decay and other mechanisms that will reduce concentrations in water, such as radionuclide volatilization (if any).

The distribution of radionuclides into the surface water environment is thus much faster than in the case of radionuclides in groundwater and large volumes of surface water and sediment can potentially become contaminated. However, the radionuclide concentrations in a surface watercourse may be diluted, depending on the volume of water that will be discharged into the surface watercourse and the volume of water flowing past the point of discharge.

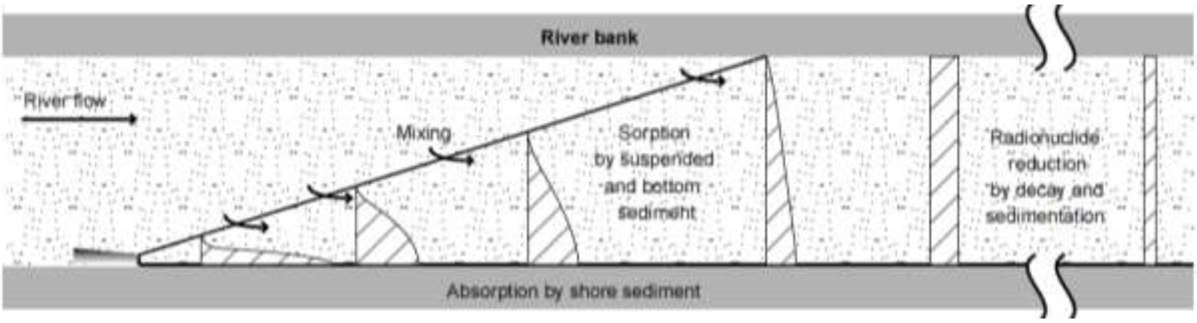


Figure 4.6 **Processes affecting the movement of radionuclides from the point of discharge into a surface water body (IAEA, 2001).**

The area is drained locally by small tributaries towards the Vaal River and a lessor extends the Koekemoer Spruit. Apart from these natural drainage courses, several water management facilities such as Return Water Dams are associated with the Kareerand Project.

The flow diagram in Figure 4.7 can be used to calculate the contribution of the surface water pathway to a total effective dose. Deposition of airborne radionuclides onto surface water bodies may contribute to the concentration of radionuclides in surface water. Factors that will influence the migration of radionuclides in surface water include surface water/groundwater interaction (e.g. discharge rates), mean annual flow rates, seasonal variation, and adsorption of radionuclides onto sediments.

Depending on the radionuclide concentration of the surface water, as well as the human habit and behavioural characteristics, various secondary pathways can contribute to a total effective dose, as illustrated in Figure 4.7. These pathways are very similar to those described for the atmospheric pathway, except that instead of deposition of airborne contaminants onto crops or soils, irrigation with contaminated water contributes to radionuclide concentrations in crops or soil.

Direct exposure to the contaminated surface water (e.g. swimming) also contributes to an external gamma radiation dose (water immersion). Adsorption of the contaminants onto the sediments will result in a transfer and accumulation (build-up) of contaminants in the sediments (sediment concentration). Contaminants in the surface water can be transferred to aquatic animals such as fish (bioaccumulation), as well as from the ingestion of contaminated sediments.

4.4.5 External Gamma Radiation

Although not a contaminant in the usual sense, the inherent radiological properties of some of the primary sources of radiation may result in the continuous emission of gamma radiation (*external gamma radiation*). The main sources that are associated with external gamma radiation are the TSF. Gamma radiation from releases of contamination to the environment (secondary sources) is expected to be limited. Noted that the external gamma radiation would be the highest close to the source as radiation levels decrease by a factor of the square of the distance (i.e., inversely proportional to the square of the distance) away from the source (Martin, 2006a).

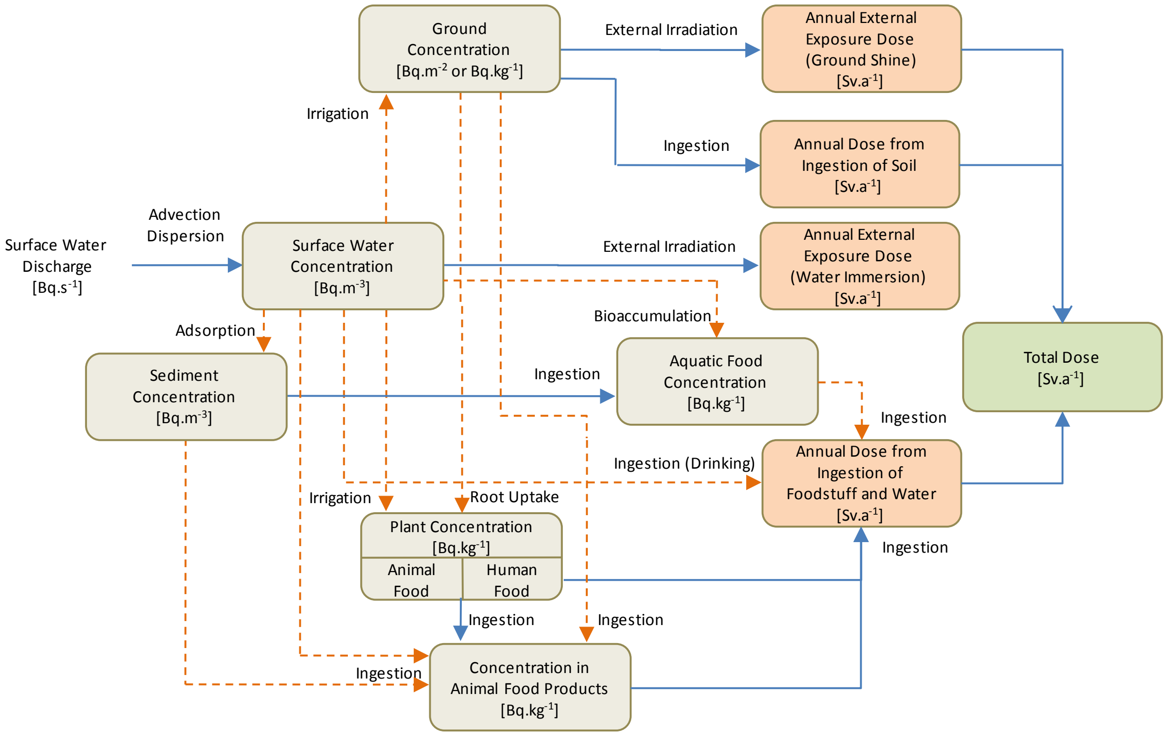


Figure 4.7 Features, processes and associated exposure modes that should be considered to calculate the contribution of the surface water pathway to a total dose.

4.5 Receptors

Receptors, as defined in Section 4.2, refer to members of the public that may potentially be subject to radiation exposure (i.e. a radiation dose) from releases from the applicable sources and through the exposure pathways of concern. The aim is to identify one or more groups of people whose habits, location, age or other characteristics could cause them to receive a higher dose than the rest of the potentially exposed population.

Figure 4.8 is a map compiled by Equispectives (2015) showing individual structures and dwellings, mostly on agricultural or open land, near the Kareerand Project. Also, the larger residential settlements are indicated.

Based on the results of the air dispersion modelling, specific receptor areas may be influenced by different contaminant emissions. Figure 4.1 indicates that airborne PM_{10} deposition will influence areas to the south of the Kareerand Project. Figure 4.2 shows that TSP (deposition) affect areas in a south and southeasterly direction, as well as to the east and west of the Kareerand Project. Figure 4.3 shows that the radon dispersion is more concentric around the Kareerand Project, but with dominant components towards the south, east-west and north. The potentially affected areas, therefore, largely include open land used for agricultural activities that may include residential structures towards the Vaal River, as indicated in Figure 4.8.

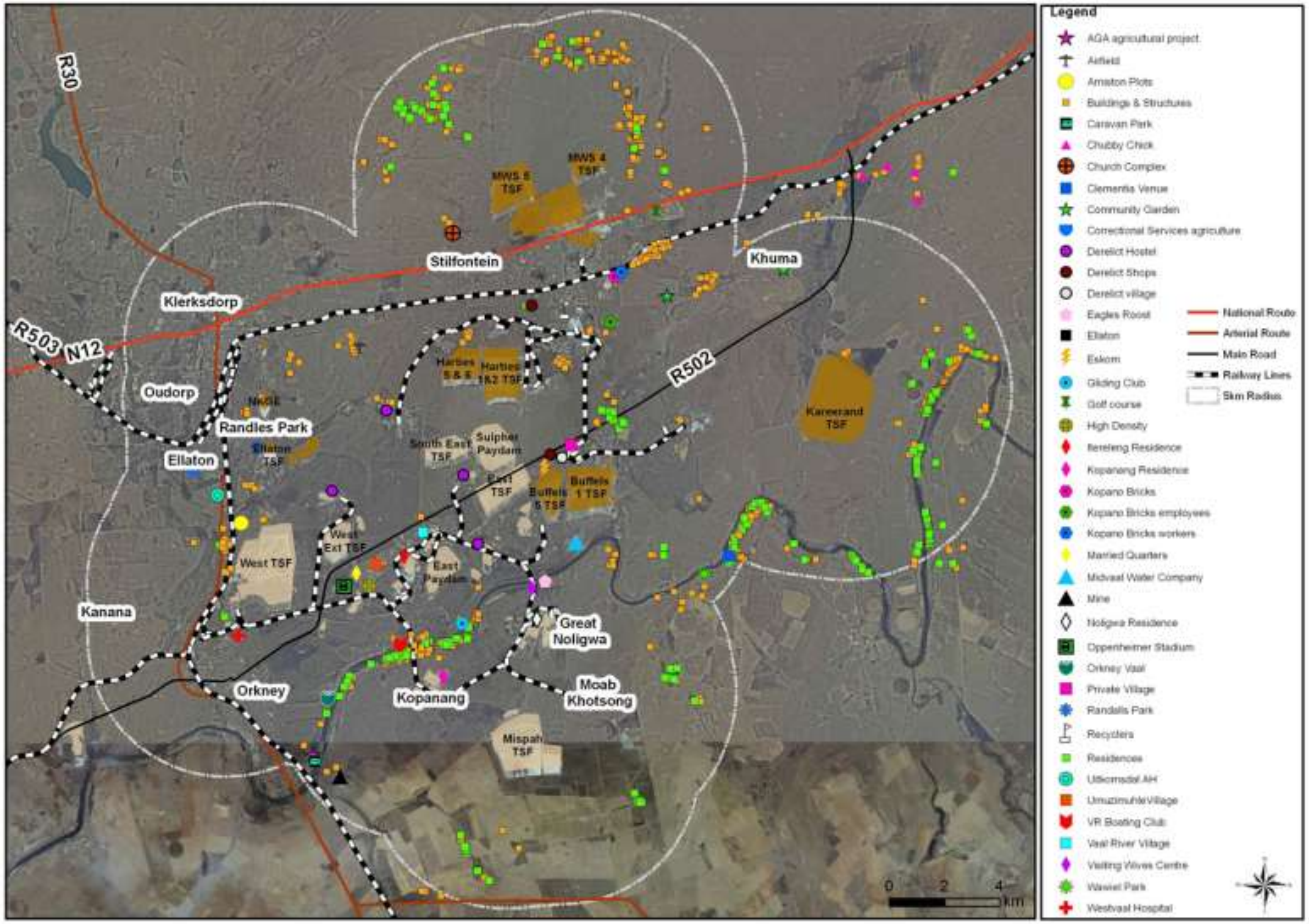


Figure 4.8 Map showing major residential settlements and individual dwellings and structures in the vicinity of the Kareerand Project (Equispectives, 2015).

Water released to the environment from the surface infrastructure associated with the Kareerand Project would migrate towards the Vaal River located towards the south and south-east of the Kareerand TSF that could potentially expose residents of agricultural land along these watercourses that use the water for agricultural purposes.

It can thus be summarised that the receptors most likely to be affected by the Kareerand Project are commercial and subsistence agricultural communities, and to a lesser extent receptors practising recreational activities along the Vaal River.

4.6 Conceptual Model Development

4.6.1 General

Models representing natural systems are often viewed as comprising two distinct but interconnected components: a *conceptual model* and a *mathematical model.* A conceptual model is expressed by ideas, words, and figures, while a mathematical model is expressed as mathematical equations. The two are closely related and, in essence, the mathematical model results from translating the conceptual model into a mathematical problem that can be solved (NRC, 2003).

It is recognised that in the field of natural sciences, the term conceptual model is applied diversely. Its interpretation and use often depend on the field and purpose of the application. Various definitions of conceptual models can thus be found in the scientific and technical literature. These definitions are generally consistent in their fundamental meaning and differ mainly in scope, detail and context. The statement of the conceptual model often reflects the key questions to be investigated (NRC, 2003). In its simplest form, a conceptual model can be considered as a representation and simplification of reality as seen by the observer or analyst.

As applied in other fields of science, conceptual models are extensively used in radiological public safety assessments. The use of conceptual models in the development of exposure conditions is captured in Figure 1.2 and Figure 4.9.

4.6.2 Conceptual Models for Environmental Pathway Analysis

Three environmental pathways tend to be of importance in radiological public safety assessments of mining and mineral processing operations, namely the atmospheric pathway, the groundwater pathway, and the surface water pathway. Specialist studies to quantify the behaviour of some of these environmental pathways have been done as part of the EIA process (Airshed, 2018; GCS, 2018b). Conceptual models developed as part of these studies will not be repeated here.

4.6.3 Representation of Conceptual Models for Exposure Conditions

The conceptual model for the development of exposure conditions is a schematic representation of reality, aimed at increasing the readability, transparency, and traceability of the assessment process. Viewed from this perspective, it may also be regarded as a *conceptual schema* or *conceptual data model*, which is a map of concepts and their relationships. Minor as it may seem, it all contributes to the overall confidence in the assessment process.

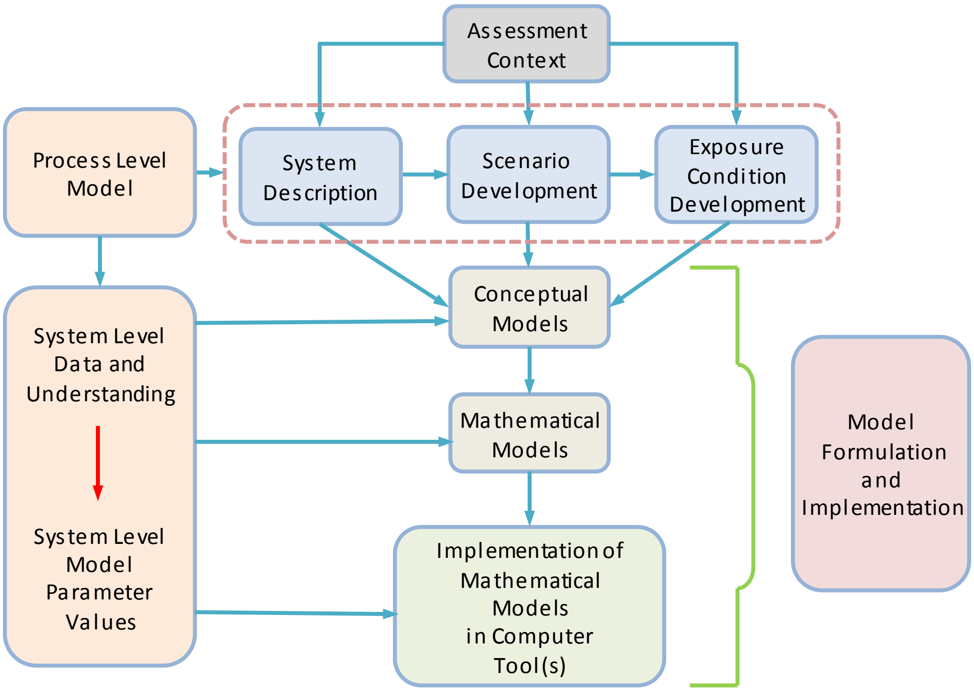


Figure 4.9 The model development process in relation to other elements of the assessment framework presented in Figure 1.2.

Two methods are used to represent the exposure conditions conceptually: a process flow diagram and a RES Matrix or Interaction Matrix (Kozak and Zhou, 1998). In an Interaction matrix, the main variables or parameters are identified and listed along the leading diagonal of a square matrix. The interactions between the parameters occur in the off-diagonal terms. A simple example of a 2x2 matrix is illustrated in Figure 4.10, with the atmospheric (radioactive dust concentration) and topsoil layer as diagonal elements. Deposition represents an interaction between the atmosphere and the surface soil, while some of the deposited dust may be re-suspended back into the atmosphere.

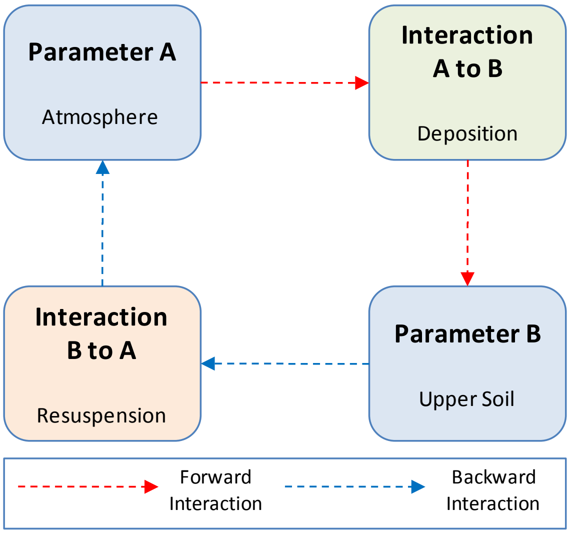


Figure 4.10 A simple 2x2 Interaction Matrix, showing the interaction between features, events and processes in a safety assessment.

It is thus clear that the different elements of the system can be included in the Interaction Matrix and analysed in detail by creating one or more sub-matrices. This approach suggests that the elements on the main diagonal can be represented by a specific theme, such as the migration pathway of radionuclides from the sources to receptors. The off-diagonal elements represent the interaction of events and processes that cause or influence the migration of the radionuclides from one diagonal element (system feature) to another along the identified pathway. Those above the diagonal represent the influence on forwarding motion, while those below influences the backward moment. This is illustrated in Figure 4.11, which represents a 5x5 matrix and the potential migration pathway of radionuclides from element D, through various interactions between diagonal and off-diagonal elements, to element E.

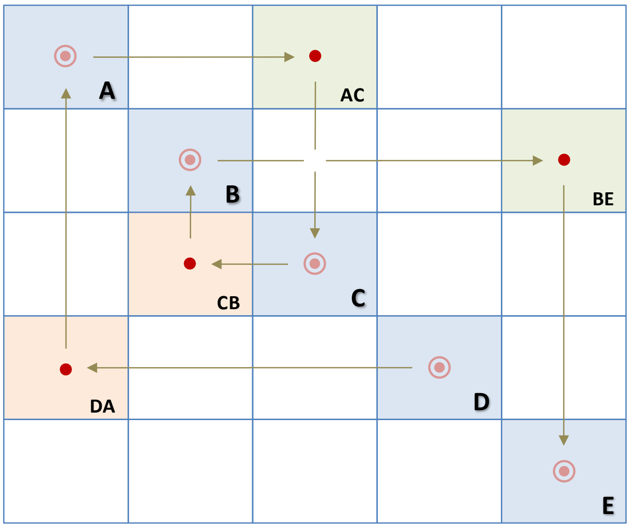


Figure 4.11 Principle of a radionuclide migration path through the Interaction Matrix.

Figure 4.12 is an example of a flow diagram as a conceptual model, showing the pathway of concern (e.g. atmospheric sources), the exposure pathways, and their relationship through processes with the different components or compartments in the system of concern. Similar to the Interaction Matrix, the transfer of radioactivity from the source to the receptor can be traced.

4.7 Public Exposure Conditions for Kareerand Project

4.7.1 General

It follows from Section 4.1 that the radiological impact on members of the public can be evaluated through the development of a discrete set of site-specific public exposure conditions. Consistent with the provisions of RG-002 (NNR, 2013), the definition of an exposure condition can be further explained with the aid of a graphical representation that indicates all possible elements and parameters in the model, as well as the interactions between these elements (see Section 4.6).

4.7.2 Identification of Exposure Groups and Exposure Conditions

The SPR analysis presented in Section 4.3 to Section 4.5 identified population groups, whose habits, location and other characteristics could cause them to receive a higher potential total effective dose than the rest of the exposed population. The three groups identified based on the available social and land use data as the most likely to be exposed to radionuclides released from the Kareerand Project are:

- Residents (members of the public) residing in formal and informal residential areas such as the Khuma;
- The community near the Kareerand Project that practice small-scale and commercial farming; and
- Workers at adjacent mines and other industries near the Kareerand Project.

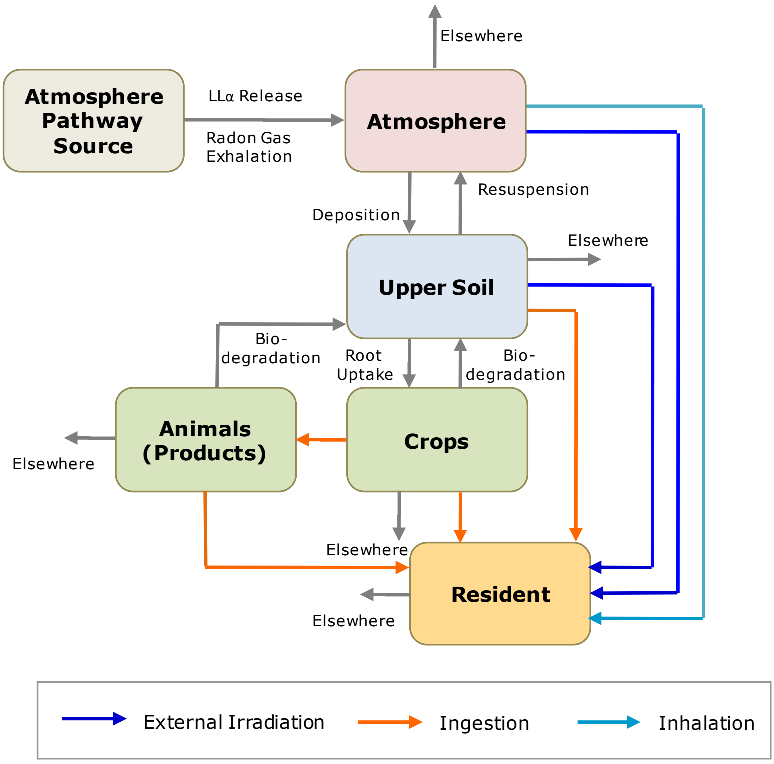


Figure 4.12 A flow diagram as an example of a conceptual model for a specific exposure condition, showing the exposure pathways and the relationship between the different compartments of the system.

Understandably, defining all exposure conditions for every potential receptor of radiation exposure at a mining and mineral processing operation is an impossible task, especially to evaluate the potential radiological consequences. For this reason, the approach is to revert to a discrete number of exposure conditions that capture the diversity and complexity associated with the environment. With due consideration of the sources, pathways and receptors described above, a Commercial Agricultural Exposure Condition was judged to be comprehensive and inclusive of all public exposure conditions that are necessary to evaluate the potential radiological impact of the Kareerand Project to members of the public under normal operating conditions.

More exposure conditions can be defined that would be relevant to the area and Kareerand Project. The key point of judgement whether the discrete set of exposure conditions are representative for the radiological public safety assessment is whether potential receptors of radiation exposure can relate to at least one of these exposure conditions. The potential radiation exposure to nearby industry workers, for example, will be less than those members of the public residing in residential areas. Similarly, the potential radiation exposure to small-scale agricultural farmers on smallholdings, for example, would be less than a conservatively defined Commercial Agricultural Exposure Condition.

4.7.3 Commercial Agricultural Exposure Condition

The purpose of the Commercial Agricultural Exposure Condition is to evaluate the radiological consequences to members of the public practising commercial farming near the Kareerand Project. However, the exposure condition is equally relevant to agricultural activities practices anywhere near the Kareerand Project. This means that this exposure condition relates to any farming activity for the conditions and assumptions presented below.

The main contributor to a total effective dose is from the atmospheric, groundwater and associated secondary pathways. This includes contributions from external gamma radiation, internal exposure following ingestion of contaminated water, crops (fruits, vegetables and cereal), soil, and animal products (meat, milk and eggs), and internal exposure from the inhalation of airborne radon and LLα dust. Contributions to the total effective dose from external gamma radiation are also expected from airborne LLα (cloud immersion) and radionuclides deposited on the upper soil layer (ground shine). In addition to the conditions and assumptions presented above, the following are assumed for the Commercial Agricultural Exposure Condition:

- The exposure groups (farmer and farm workers) consist of members of the public from all age groups.
- The exposure group maintain a commercial farm system consisting of fruits, vegetables and cereal (mealies). It is conservatively assumed that the farm contributes 100% to their annual consumption of these foodstuffs.
- The exposure group keep animals in the form of chickens, sheep and cattle. These serve as a source of protein in the form of eggs, milk and meat. For the assessment, it is conservatively assumed that it contributed to 100% to their annual consumption rate.
- Some food preparation methods are used (e.g. peeling or boiling) that may contribute to a reduction in radioactivity concentrations. However, for this assessment, it is assumed that no food preparation takes place.
- The exposure group uses groundwater abstracted from boreholes for their consumption and to maintain a commercial farm system (i.e. irrigation and water supply), consisting of crops, poultry, sheep, and cattle.
- As a conservative assumption, the rate of incidental soil ingestion is maintained at 100% of the value published in RG-002 guidelines (NNR, 2013).
- Consistent with RG-002 guidelines (NNR, 2013), the occupancy factors assumed for the assessment is 7 050 indoor and 1 710 hours outdoor per annum (see Table C 11).
- The conceptual model for the Commercial Agricultural Exposure Condition is presented in Figure 4.13 and Figure 4.14 using a flow diagram and Interaction Matrix, respectively.

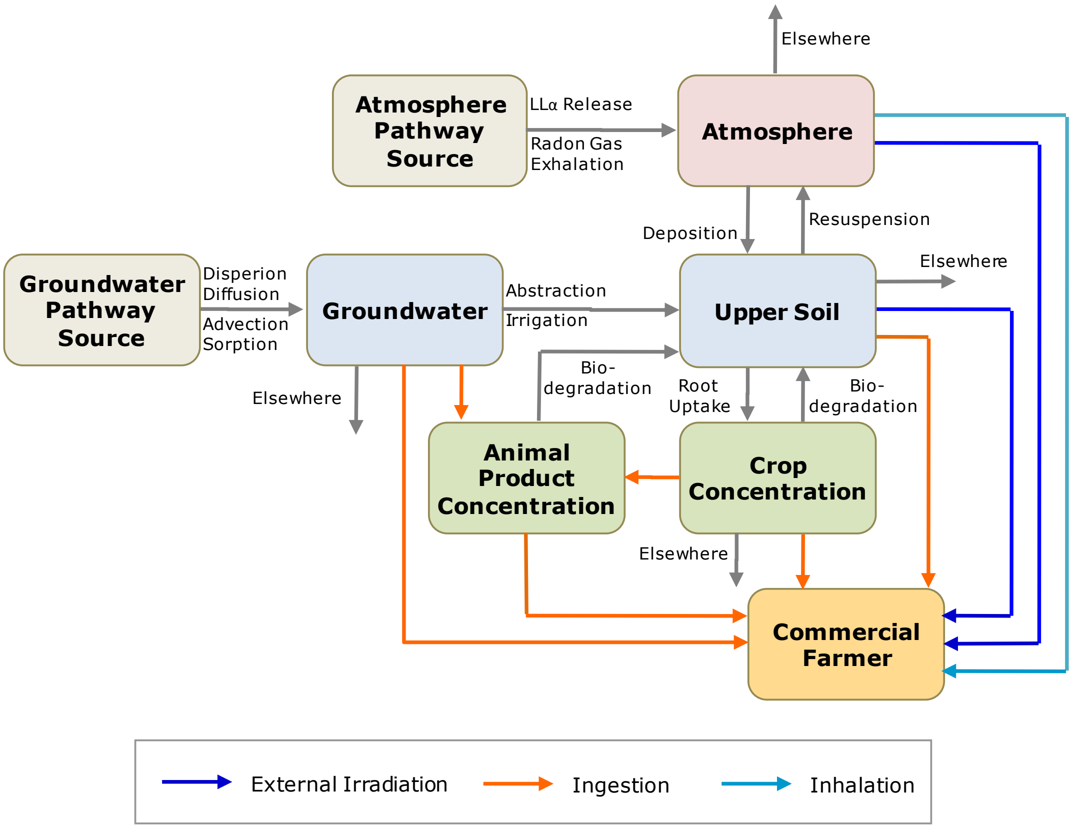


Figure 4.13 Conceptual flow diagram of the exposure pathways associated with the Commercial Agricultural Exposure Condition.

Radionuclides leached from the groundwater pathway sources enter the underlying aquifer, from where it dispersed into the groundwater and potentially the surface water environments. Members of the public practising agriculture use groundwater abstracted from a borehole for their consumption and to maintain a commercial farm system (i.e. irrigation and water supply), consisting of crops, poultry, and cattle. Radionuclides in the water are deposited onto the crops, contributing to the radionuclide concentration in the crops and an upper layer of soil. Root uptake processes transfer some of the radionuclides from the soil to the crops. Products such as meat, milk and eggs from animals that consume the contaminated water and crops, can contain increased concentrations of radionuclides.

Radon gas and LLα released from the atmospheric pathway sources are dispersed into the environment, contributing to an airborne activity concentration. Some of the airborne radionuclides are deposited onto the crops (fruits, vegetables and cereal), contributing to an increased concentration of radionuclides in crops and the upper layer of soil. Root uptake processes transfer some of the radionuclides from the soil to the crops. Radionuclides leached from the groundwater pathway sources enter the underlying aquifer, from where it dispersed into the groundwater and surface water environments.

Members of the public practising agriculture use groundwater abstracted from a borehole for their consumption and to maintain a commercial farm system (i.e. irrigation and water supply), consisting of crops, poultry, and cattle. Radionuclides in the water are deposited onto the crops, contributing to the radionuclide concentration in the crops and an upper layer of soil. Root uptake processes transfer some of the radionuclides from the soil to the crops. Products such as meat, milk and eggs from animals that consume the contaminated water and crops, can contain increased radionuclide concentrations.

	1	2	3	4	5	6	7	8	9	10
A	Atmospheric Pathway Sources		LLα Suspension Dispersion	Radon Exhalation Dispersion						
B		Groundwater Surface Water Pathway Sources			Advection Dispersion Diffusion Sorption					
C			Atmosphere LLα Conc.			Deposition	Deposition Interception		Inhalation External Exposure	Dispersion
D				Atmosphere Radon Conc.					Inhalation	Dispersion
E					Water (Borehole)	Deposition	Interception	Ingestion	Ingestion	Advection Dispersion Diffusion Sorption
F			Re-suspension			Upper Soil	Root Uptake Crop Contam.	Ingestion	External Exposure Ingestion	Erosion Leaching
G						Bio-degradation	Crops	Ingestion	Ingestion	Washed Away Weathering
H						Bio-degradation Excrement		Animals	Ingestion	
					Abstract	Irrigation Tilling Ploughing	Plant crops Food preparation	Feed	Commercial Farmer	Excrement
J										Elsewhere

Figure 4.14 Conceptual Interaction Matrix of the exposure pathways associated with the Commercial Agricultural Exposure Condition.

Note that, as illustrated in Figure 4.13 and Figure 4.14, biodegradation of crop material may also contribute to the concentration of radionuclides in the upper layer of soil, while resuspension of deposited dust may contribute to airborne radioactivity. Also illustrated in Figure 4.13 and Figure 4.14, is the transfer of some of the radioactivity released from the atmospheric pathway sources, to "elsewhere" through processes such as dispersion, leaching, washing, weathering and excrement. "Elsewhere" as used here refers to a place where humans will not be affected by the radionuclides of concern

5 Consequence Analysis

5.1 Introduction

Consistent with the safety assessment methodology (see Figure 1.2) and technical approaches therein, the purpose of this section is to assess and analyse the potential radiological consequences of the public exposure conditions in terms of the total annual effective dose as regulatory compliance criteria (see Section 2.3.7). The methodological approach used to calculate the total effective dose is described in Appendix B.

The section is structured as follows. Section 5.2 evaluates the potential contribution of the groundwater pathway included in the Commercial Agricultural Exposure Condition, while Section 5.3 assess and represent the estimated total effective dose for the exposure conditions defined in Section 4.7.

5.2 Contribution from Groundwater Pathway

5.2.1 General

The Commercial Agricultural Exposure Condition assumes that groundwater abstracted from a borehole can be used to sustain the farm system. In principle, the groundwater abstracted from the borehole may be contaminated following the leaching from the Kareerand TSF. However, the leaching and subsequent lateral migration of radionuclides are a very slow process. This is because the radionuclides migrate at a much slower rate than the advective flow due to isotope specific adsorption properties of the tailings material and aquifer properties.

Presented here is a simplified numerical groundwater model using a compartmental modelling approach to represent the migration and fate of radionuclides leached from the Kareerand TSF and into the environment. The conceptual representation of the System Level model as implemented in Ecolego® (Version 6) is presented in Appendix D.

5.2.2 Parameter Values

To evaluate the potential radionuclides concentration in groundwater and the subsequent water ingestion dose, hypothetical conditions complemented with site-specific conditions was used to illustrate the relative insignificance of the groundwater pathway over a short period (e.g. operational period). The higher activity concentrations listed in Table 3.7 were used as the initial activity concentrations, while Table 5.1 summarises a few additional parameter values assumed for the leaching analysis.

The most sensitive parameter in the TSF radionuclide leaching equation is the distribution coefficient (or K_d-value) and the solubility limits. Table 5.2 lists soil distribution coefficients for selected radionuclides published in RG-002 (NNR, 2013), as well as the range of values from the literature for different soil types as published by the Argonne National Laboratory (Yu *et al.*, 1993). The comparison shows that the value of the distribution coefficient can vary significantly.

Table 5.1 Summary of facility-specific parameter values necessary to calculate the leaching of radionuclides from the Kareerand TSF.

Parameter			Units	Kareerand TSF (Current)	Kareerand TSF (With Extension)
Mean Annual Precipitation (MAP)			[mm]	625	
Recharge (Infiltration) Rate Through TSF as % of MAP	< 50 years	15%	[m.year^{-1}]	9.38E-02	
	50 to 75 years	10%		6.25E-02	
	75 to 100 years	5%		3.13E-02	
	> 100 years	3%		1.88E-02	
Volumetric Moisture Content			[m^3.m^{-3}]	3.00E-01	
Density of Tailings Material			[kg.m^{-3}]	1.40E+03	
Average Height			[m]	20	120
Average Area			[m^2]	2.87E+06	8.68E+06
Assumed Length and Width (√Area)			[m]	1.69E+03	2.946E+03
Volume			[m^3]	5.74E+07	1.042E+09

Table 5.2 Distribution coefficients from literature for the elements of concern, as well as the K_d values in the analysis for illustrative purposes (NNR, 2013; Yu *et al.*, 1993).

Element	RG-002	Comparative Values				K_d-values Used
		Sand	Loam	Clay	Resrad Default	
	K_d-values (m^3.kg^{-1})					
Th	1.90E+00	3.20E+00	3.30E+00	5.80E+00	6.00E+01	2.00E-01
Ra	2.50E+00	5.00E-01	3.60E+01	9.10E+00	7.00E-02	3.00E-01
U	2.00E-01	3.50E-01	1.50E-02	1.60E+00	5.00E-02	2.00E-02
Pb	2.00E+00	2.70E-01	1.60E+01	5.50E-01	1.00E-01	2.70E-01
Po	2.10E-01	1.50E-01	4.00E-01	3.00E+00	1.58E+00	1.50E-01
Pa	2.00E+00	5.50E-01	1.80E+00	2.70E+00	5.00E-02	5.50E-01
Ac	1.70E+00	4.50E-01	1.50E+00	2.40E+00	2.00E-02	4.50E-01

Low K_d values were used as distribution coefficients for the TSF, unsaturated zone, and aquifer. This is a very conservative, assuming very little absorption to retard the migration of radionuclides through the system. For this assessment, no solubility limits were applied, which implies that all activity in the tailings is available for dissolution and leaching. *In practice, this is not the case and represents a very conservative approach*.

For this analysis, the areal extent (area) of the TSF listed in Section 3.4.3 was used. Also, the unsaturated zone underneath the TSFs is conservatively assumed to be only 1 m thick, with a dry bulk density of 1,800 kg.m^{-3}, and a volumetric moisture content of 0.3 m^3.m^{-3}. A thicker unsaturated zone will retard the migration of radionuclides to the point of abstraction even further. The Mean Annual Precipitation (MAP) of the areas is assumed to be 625 mm (GCS, 2018b). The recharge (or infiltration) rate of water through the TSF decreases with time after the assumed operational period of 50 years to a natural recharge rate of 3% of the MAP. It is further assumed that the TSF remain as a source at the surface for 1,000 years. This is conservative, given the uncertainty of how long the TSF will remain at the surface in the future.

To estimate the potential migration of radionuclides in the underlying aquifer with time and distance, the following is further assumed for the underlying aquifer in each area:

- A conservative constant effective porosity of 0.1 (10%);
- A Longitudinal Dispersivity (α_L) of 50 m;
- A dry bulk density of 1,800 kg.m^{-3};
- A conservative aquifer thickness of 20 m; and
- A distance of 300 m to the nearest borehole.

Figure 5.1 presents a frequency histogram of the distribution of seepage velocities derived from the groundwater flow model presented in GCS (2014), with an average of 0.039 m.day^{-1}. Using a very conservative 0.5 m.day^{-1} and an effective porosity of 0.1, the resulting Darcy velocity is 0.05 m.day^{-1} or 18.25 m.year^{-1}.

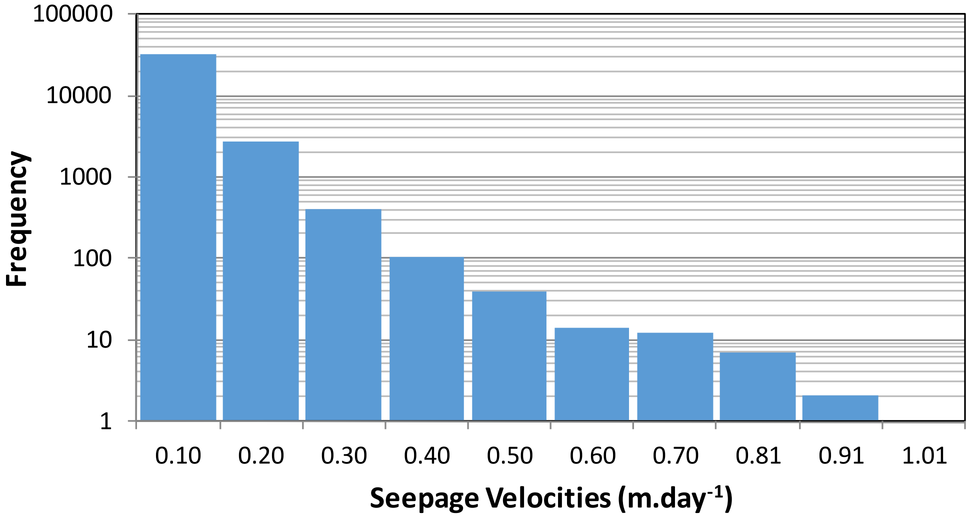


Figure 5.1 Distribution of seepage velocities derived from the groundwater flow model presented in GCS (2014).

5.2.3 Kareerand TSF (Current)

The Kareerand TSF drains mainly towards the Vaal River, which is in the order of 2.4 km away from the TSF. Assuming a conservative groundwater seepage velocity of 0.3 m.day^{-1} for the area between the Kareerand TSF and the Vaal River, the resulting Darcy velocity for this area is 10.95 m.year^{-1}.

Figure 5.2 presents the resulting nuclide specific activity concentrations in the groundwater abstracted from the borehole, which suggests that the initial peak concentration is only visible in about 4,000 years (associated with the Uranium isotopes), and the second peak induced by the remaining isotopes only become visible after 30,000 years. If one assumes the RG-002 (NNR, 2013) water ingestion rates for the different age groups, the groundwater activity concentrations in Figure 5.2 translate into the ingestion doses as presented in Figure 5.3. It illustrates that for the assumed conditions, the potential contribution from the groundwater pathway at a point 300 m from the Kareerand TSF is only visible in thousands of years, and at doses that are well below 100 µSv.year^{-1}.

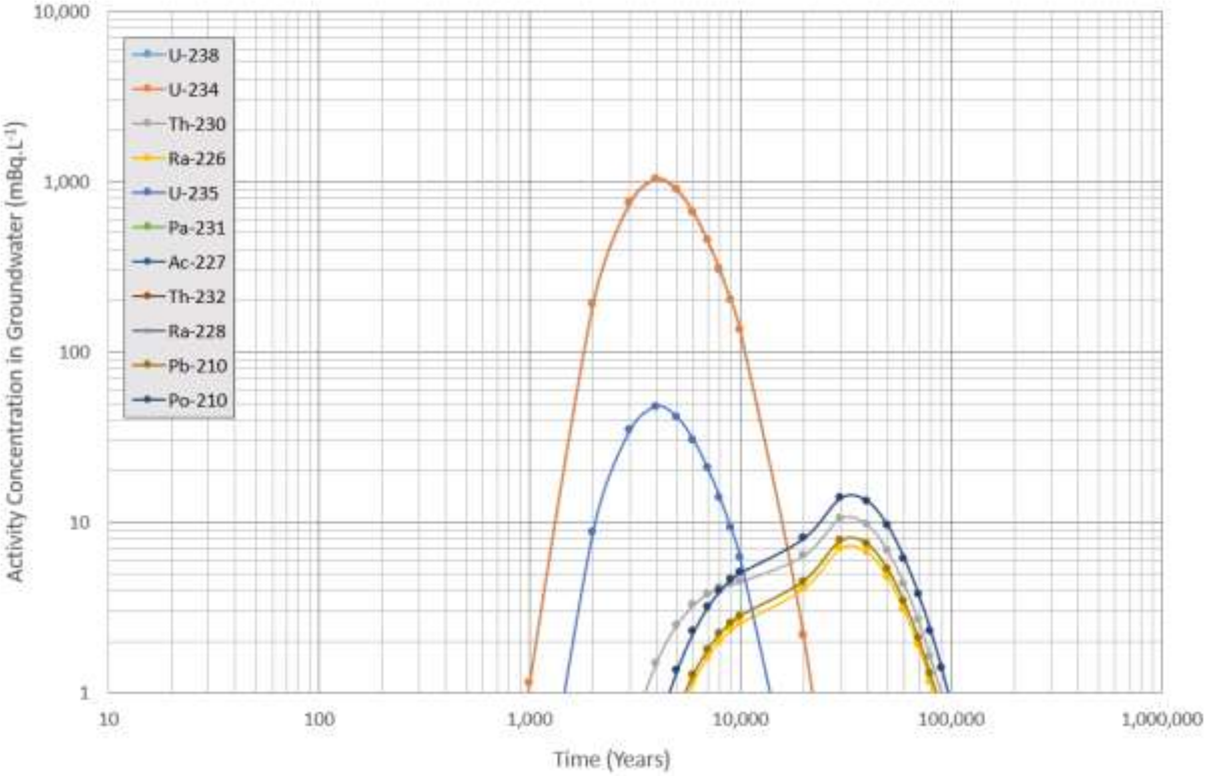


Figure 5.2 **The simulated activity concentration in groundwater abstracted from a borehole 300 m from the Kareerand TSF (current).**

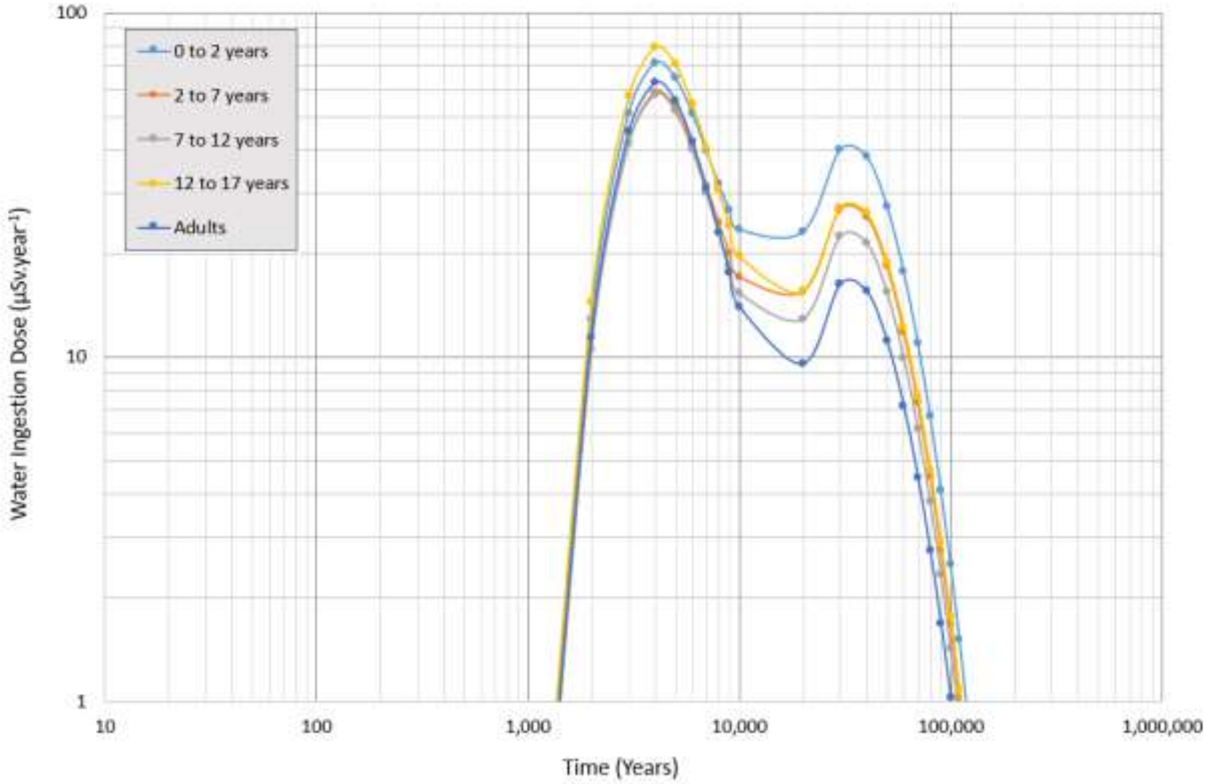


Figure 5.3 **The simulated water ingestion dose to the different age groups 300 m from the Kareerand TSF (current), using the activity concentrations in Figure 5.2.**

5.2.4 Kareerand TSF (With Extension Included)

Figure 5.4 presents the water ingestion doses for the different age groups for the extension of the Kareerand TSF included if one assumes the RG-002 water ingestion rates (NNR, 2013). As expected, the larger source area results in higher doses, but still in the order of 100 µSv.year^{-1} or less. It illustrates that for the assumed conditions, the potential contribution from the groundwater pathway at a point 300 m from the Kareerand TSF, the initial peak concentration is only visible after 4,000 years (the Th-232 decay chain only become visible after 30,000 years).

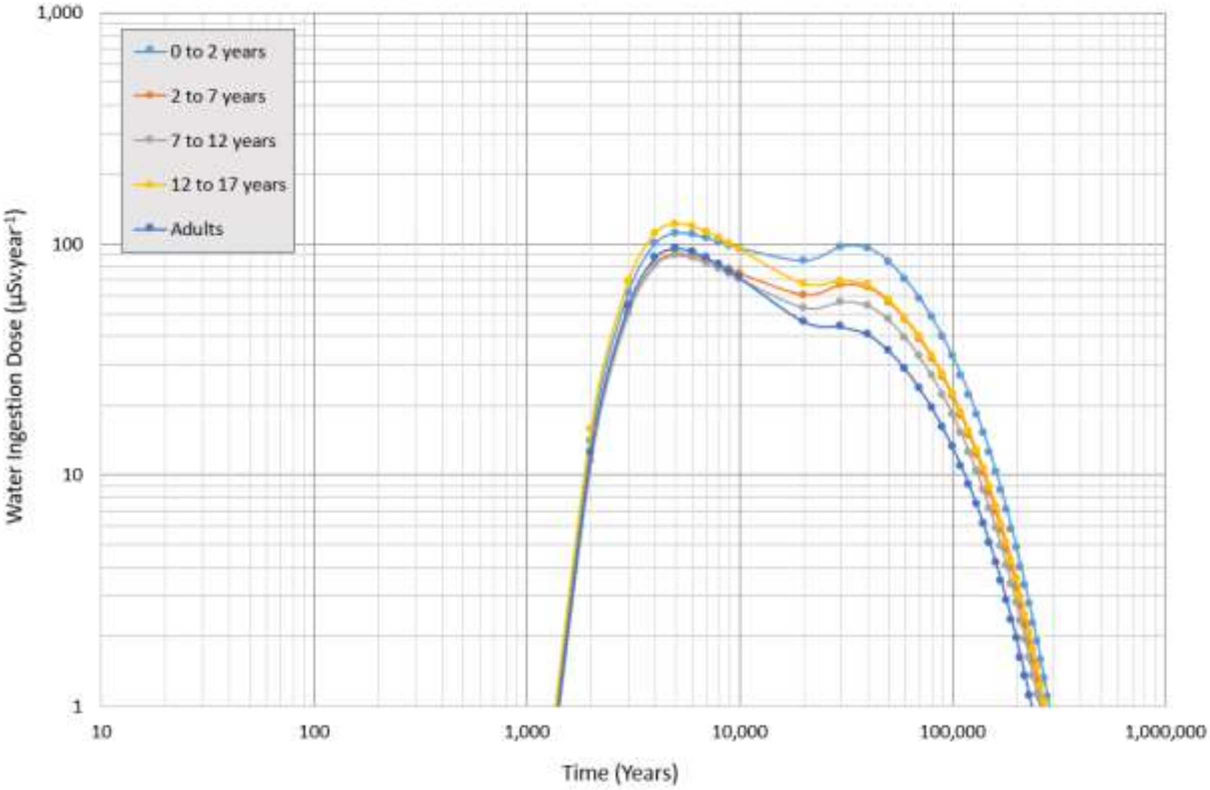


Figure 5.4 The simulated water ingestion dose to the different age groups 300 m from the Kareerand TSF (with extension included).

The results presented in Figure 5.3 and Figure 5.4 assumed a source duration of 1,000 years. To illustrates the sensitivity of this assumption, the source duration was increased to 2,000 years. Figure 5.5 illustrates that an increase in the source duration increases the total effective dose but are still less than 250 µSv.year^{-1}.

5.2.5 Discussion of Results

The potential water ingestion doses induced by radionuclides released from the Kareerand TSF (through leaching) will only occur in the far future at doses that are below the dose constraint of 250 µSv.year^{-1}. The extension of the Kareerand TSF will result in a marginal increase in the radiological impact compared against the current situation. The behaviour of radionuclides that may leach from surface water features such the return water dam is expected to be similar, except that leach will be limited due to a liner, while these facilities will be removed following mine closure.

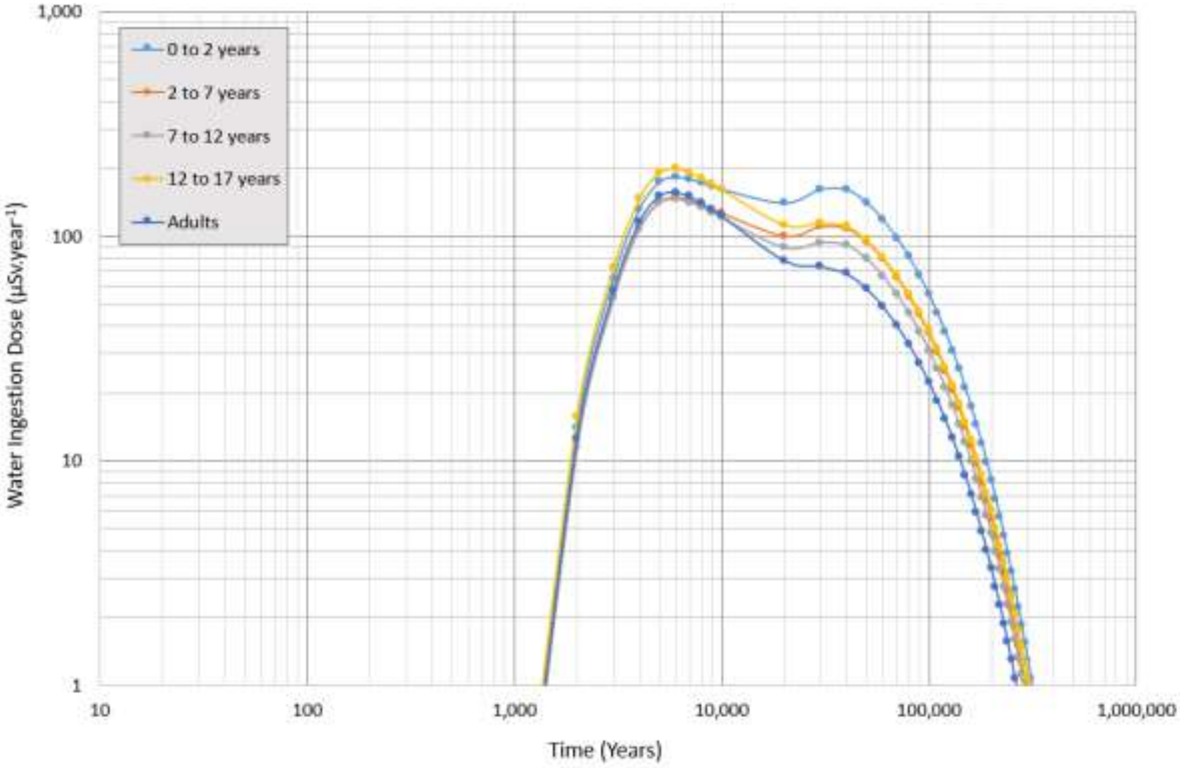


Figure 5.5 **The simulated water ingestion dose to the different age groups 300 m from the Kareerand TSF (with extension included) (source duration 2,000 years).**

The evaluation of the groundwater pathway presented here considered water abstracted from a borehole. A similar evaluation can be done for discharge into a surface water body such as the Vaal River. However, it is expected that the water ingestion dose under those conditions would be less due to the dilution of the discharged water in the river.

The result presented here justifies the assumption that the groundwater pathway is excluded from the Commercial Agricultural Exposure Condition since the timescales of concern for the groundwater pathway is very different that dose that will be evaluated for the atmospheric pathway.

5.3 Total Effective Dose Calculation for Exposure Conditions

5.3.1 General

The purpose of this section is to present the results of the total effective dose calculations for the public exposure condition defined in Section 4.7 for the Kareerand Project. Due to the nature of these exposure conditions and the potential contribution of the different environmental pathways to the total effective dose, the focus of the results presented here is the contribution through the atmospheric pathway.

5.3.2 Radon Inhalation Dose

The radon inhalation dose is the dominant contributor to the total effective dose calculated for the Commercial Agricultural Exposure Condition (see Section 5.3.3). Using the airborne radon concentration presented in Figure 4.3, Figure 5.6 presents the resulting radon inhalation dose using the dose conversion factor listed in Table B 2.

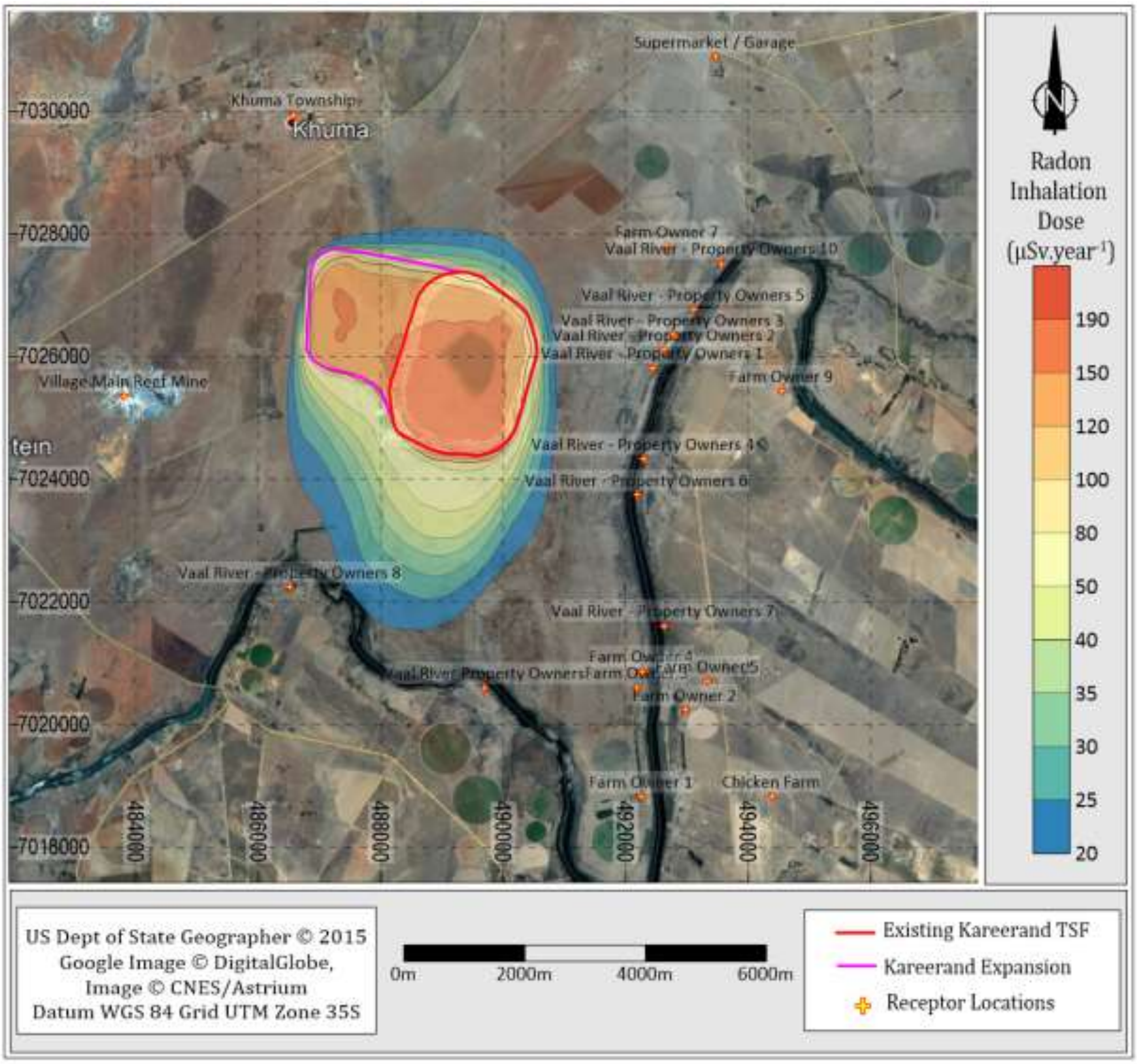


Figure 5.6 The distribution of the radon inhalation dose induced by the facilities associated with Kareerand Project, using the airborne radon concentration distribution in Figure 4.3.

Figure 5.6 shows that radon inhalation doses of less than 200 μSv.year^{-1} are associated with the TSF itself. The contribution from the radon inhalation dose is less than 100 μSv.year^{-1} 200 m outside the southern TSF boundary.

Note that the estimated radon inhalation dose is dependent on several factors. The first is the outcome of the radon air dispersion modelling that is a factor of the meteorological conditions used in the modelling. The second is the Ra-226 concentration associated with some of the TSFs in the Vaal River region. Finally, the radon inhalation dose is directly associated with the radon dose conversion factors used for the dose calculation.

5.3.3 Commercial Agricultural Exposure Condition

5.3.3.1 Dose Assessment

The purpose of the Commercial Agricultural Exposure Condition is to evaluate the radiological consequences to members of the public practising commercial farming near the Kareerand Project. However, the exposure condition is equally relevant to agricultural activities practices anywhere near the Kareerand Project. This means that this exposure condition relates to any farming activity for the conditions and assumptions presented in Section 4.7.3.

It follows from Section 4.7.3 that the main concern for the Commercial Agricultural Exposure Condition is the atmospheric, groundwater and associated secondary pathways. However, as illustrated in Section 5.2, it is highly unlikely that the groundwater or surface water pathways will make a significant contribution to a radiological impact, especially during the timescales of concern. The only remaining pathway is thus the atmospheric and associated secondary pathways (i.e., the ambient air conditions). Consistent with the definition of the Commercial Agricultural Exposure Condition in Section 4.7.3, the total annual effective dose was calculated for a member of the public exposed through the following routes:

- Internal exposure following the inhalation of airborne radon and long-lived radioactive dust (LLα);
- External exposure from airborne long-lived radioactive dust (cloud shine), as well as from deposited dust on the soil surface (ground shine);
- Internal exposure following the ingestion of contaminated crops (cereal, fruit, leafy and root vegetables) and animal products (mutton, beef, milk, poultry and eggs); and
- Inadvertent ingestion of contaminated soil induced by the deposition of dust.

A dust deposition period of 100 years is assumed to calculate the build-up of radionuclides in the topsoil layer, which is very conservative. The calculations further assume that soil, crops and animal products are ingested at 100% of the published annual ingestion rate (see Section 4.7.3).

5.3.3.2 Results

The results are presented in graphical form as dose isopleths overlain on a map of Kareerand Project and surrounding area. Figure 5.7 shows the dose isopleths for each of the five age group categories listed in Table B 1. Based on the doses estimated, the ’0 to 2 years’ age group was shown to receive the highest annual total effective dose. Figure 5.8 presents the dose isopleths for the 0 to 2 year age group.

5.3.3.3 Interpretation of Results

From Figure 5.7 and Figure 5.8 the dose isopleths for the different age groups are very similar. If compared with Figure 5.6, the results are showed that the radon inhalation dose is a major contributor to the total effective dose. This trend is similar for all the age groups.

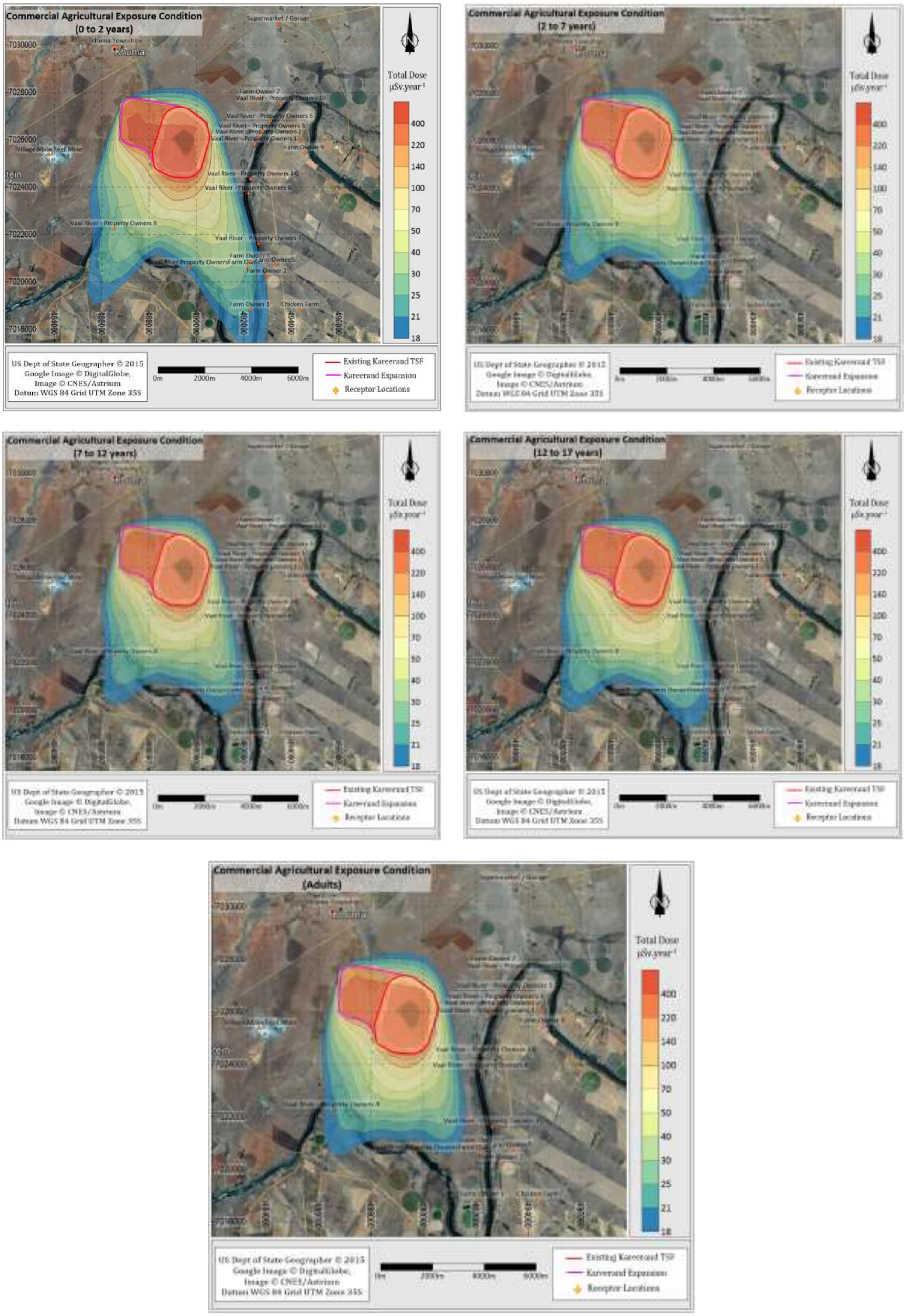


Figure 5.7 Age group specific dose isopleths representing the air pathway portion of the total effective dose associated with the Commercial Agriculture Exposure Condition.

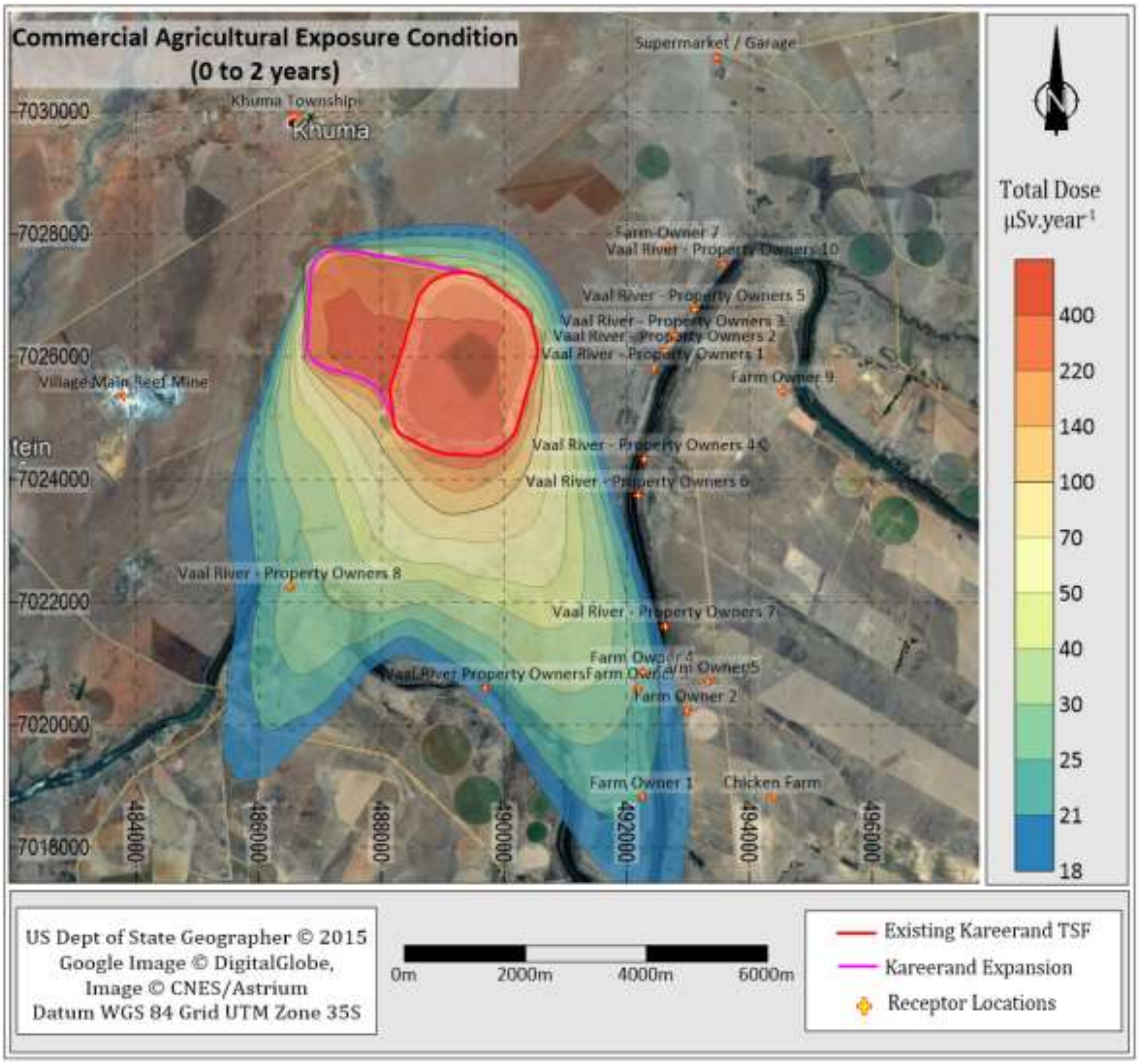


Figure 5.8 Dose isopleths representing the total effective dose associated with the 0 to 2 year age group for the Commercial Agriculture Exposure Condition for Kareerand Project.

The dose isopleths presented in Figure 5.7 and Figure 5.8 represents a Commercial Agricultural Exposure Condition in any of the areas covered by the isopleths. However, not all these areas are necessarily agricultural areas. To the south and south-east of the Kareerand TSF, the impact is the most significant and the total effective dose is less than 250 µSv.year^{-1} within 200 m from the edge of the TSF. Within 1,000 m, the total effective doses for the'0 to 2 years' age group is less than 100 µSv.year^{-1}.

Figure 5.9 to Figure 5.11 present age and pathway specific total effective doses for selective Receptor locations near the Kareerand Project (see Figure 5.8 for locations). The results show that at actual receptor locations along the Vaal River and around the Kareerand Project, the total effective doses are all less than 30 µSv.year^{-1} with the radon inhalation and food and soil ingestion the dominant pathways. In evaluating these results, it is important to note that the Commercial Agricultural Exposure Condition used for this purpose is very conservative. The actual doses are expected to be less.

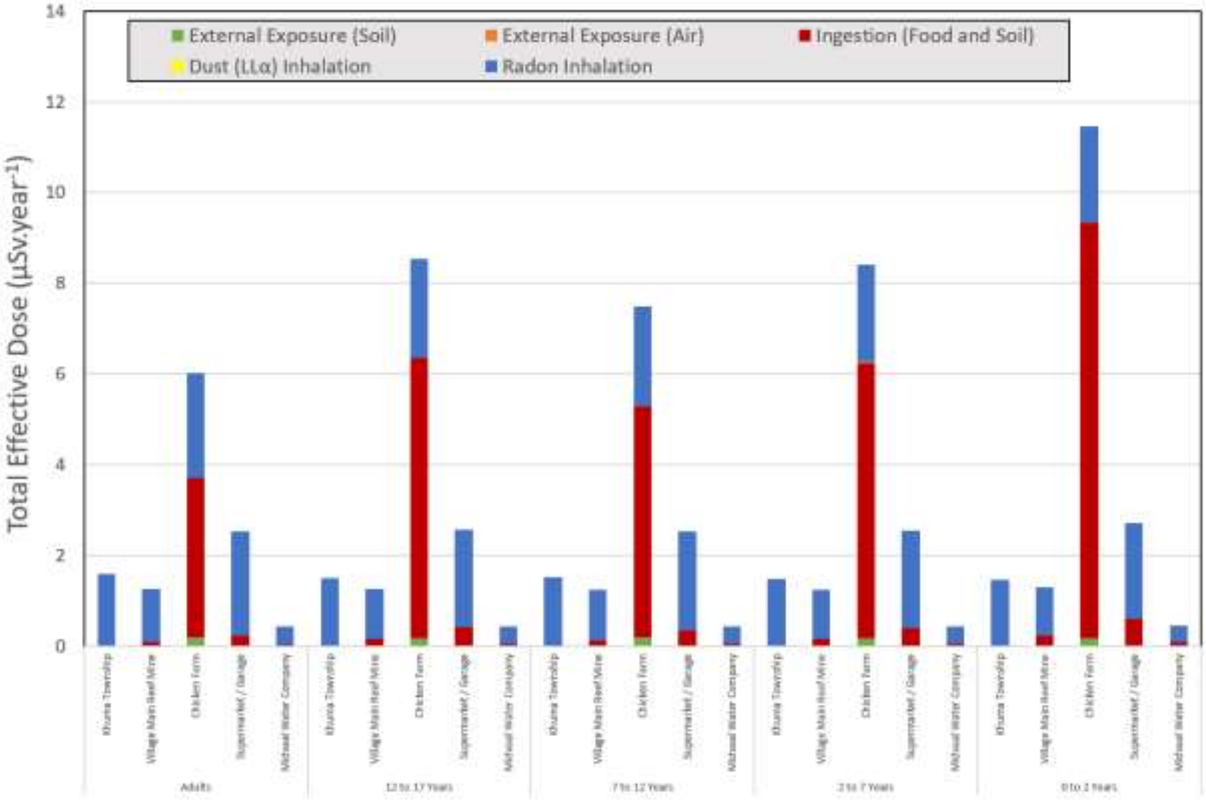


Figure 5.9 Age and pathway specific total effective doses for selective Receptor locations near the Kareerand Project (see Figure 5.8 for locations).

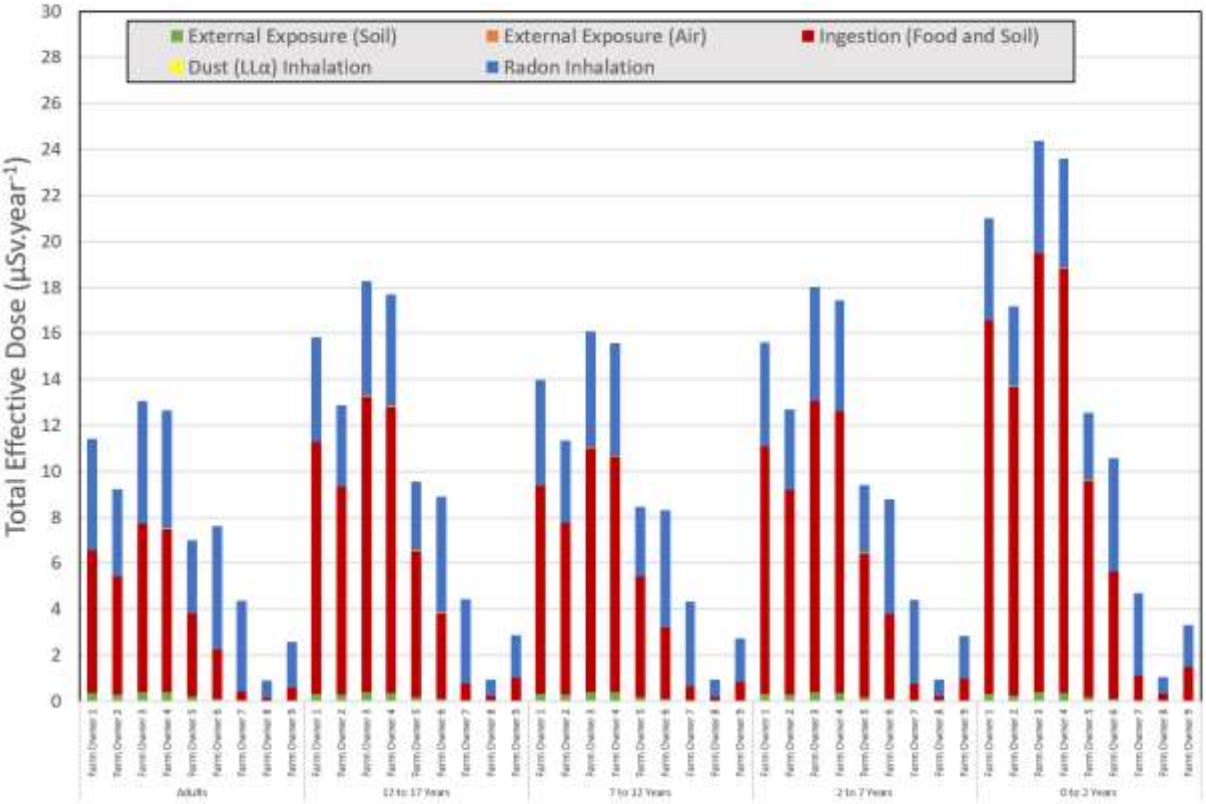


Figure 5.10 Age and pathway specific total effective doses for selective Receptor locations near the Kareerand Project (see Figure 5.8 for locations).

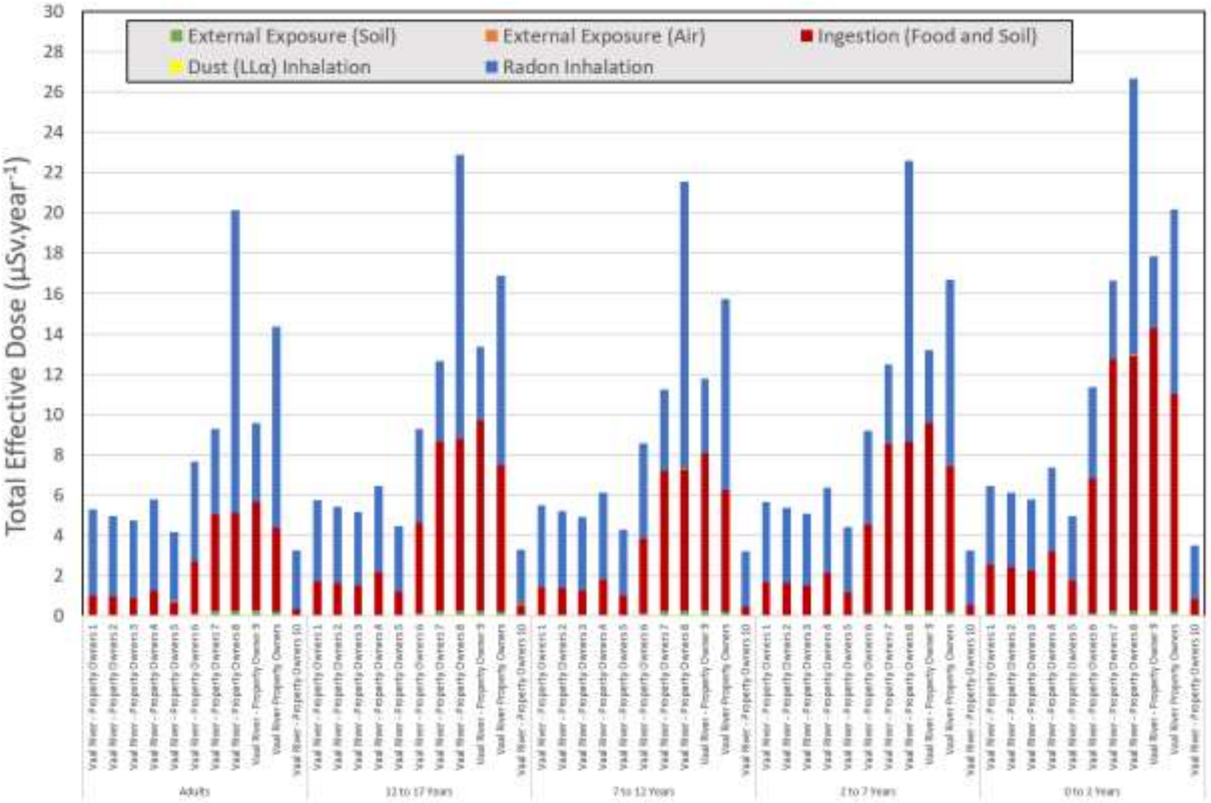


Figure 5.11 **Age and pathway specific total effective doses for selective Receptor locations near the Kareerand Project (see Figure 5.8 for locations).**

5.3.4 Conclusions

5.3.4.1 *General*

The conclusions presented here are based on the conditions and assumptions that were considered in the definition of the public exposure conditions for the Kareerand Project and the values of the associated parameters that were used to derive the assessment results. Also, the results are dependent on to results and information available from specialist studies for the environmental pathways, notably the surface water, groundwater, and atmospheric pathways.

5.3.4.2 *Contribution from the Groundwater Pathway*

Hypothetical conditions and parameter values supplemented with available site-specific information were used to evaluate the potential contribution of the groundwater pathway to a total effective dose.

The simulation results presented in Section 5.2 showed that radionuclides will be released (leached) from the Kareerand TSF to the underlying aquifer for as long as the facility remains at the surface. However, the dissolution of radionuclides, the leaching and subsequent migration of radionuclides through the aquifer is a slow process and it would take hundreds to thousands of years to migrate a few hundred meters from the TSF to an abstraction borehole. Even then the effective dose from the ingestion of the water is relatively low compared to the dose constraint (assuming the TSF remain at the surface for 2,000 years).

5.3.4.3 Contribution from Radon Inhalation

A site-specific radon dispersion study was performed for the Kareerand Project, using radon exhalation rates that were determined for the existing Kareerand TSF as reported in Parc Scientific (2019).

The radon inhalation dose is a significant contributor to the total effective dose. This contribution may increase further if a higher radon exhalation rate associated with the Ra-226 concentration is used, or if the proposed revised dose conversion factors for radon inhalation is used. However, adding a covering layer over the TSF will reduce the radon exhalation rate and the radon inhalation doses.

5.3.4.4 Commercial Agricultural Exposure Condition

The definition of the Commercial Agricultural Exposure Condition presented in Section 4.7.3 is conservative and assume that members of the public are dependent on the farm system for 100% of their annual food requirements that include maize, vegetables, fruits, and animal products (eggs, milk and meat). The reason for this approach is to make provision for subsistence farming conditions that might occur in the area.

With the groundwater pathway excluded (see Section 5.3.4.2), the main contribution for this exposure conditions is from the atmospheric pathway, with the results from the air quality impact assessment presented in Airshed (2018) in terms of PM_{10} and TSP the basis of the assessment. The results are, therefore, directly related to the results of the air quality study.

The dose assessment simulation results presented in Section 5.3.3 showed that at a distance of 200 m from the TSF, the maximum total effective dose that can be expected is 250 μSv.year^{-1}. At a distance of 1,000 m from the TSF, the maximum total effective dose that can be expected is 100 μSv.year^{-1}. However, it is unlikely that members of the public would practice commercial agricultural activities within 200 m from the TSF, or that members of the public would spend so much time in those areas. In areas were actual receptors are located, the located effective doses that were calculated is less than 30 μSv.year^{-1}.

6 Impact Assessment

6.1 General

The purpose of this section is to present the radiological impact assessment rating for the Kareerand Project. Section 2.3.7.3 presented the criteria for the impact assessment rating as an endpoint. The basis for the impact assessment rating is the quantitative and qualitative assessment of the potential radiological consequences to receptors identified for the Kareerand Project, as presented in Section 5.

The impact assessment rating makes a distinction between the different phases of the project (i.e., construction, operation, and post-closure) as well as the contribution of the atmospheric, surface water and groundwater pathways, as appropriate. The reason for the latter is because the timescales over which the pathways contribute to a potential radiological impact to members of the public differs. Where required, mitigation measures are proposed for activities during the different phases, followed by an impact rating for the revised (mitigated) conditions.

The section is structured as follows. Section 6.2 presents the radiological impact expected during the construction phase. The most significant radiological impact is expected during the operational phase, as presented in Section 6.3, followed by the post-closure phase presented in Section 6.4. Section 6.5 discusses any cumulative impact that might be of concern.

6.2 Construction Phase

The Kareerand Project includes the construction of new water management facilities and infrastructure to facilitate the deposition of new arisings during the operational period. Where applicable and possible, the existing infrastructure will be used. The duration of these construction activities is expected to be relatively short.

Activities that will be performed during the construction phase of the Kareerand Project will not involve the handling, processing, or releasing radioactive material to the environment *per se*. This means that the potential radiological impact on members of the public through the relevant pathway during the construction phase is negligible.

6.3 Operational Phase

6.3.1 General

The radiological impact assessment for the operational phase considers the potential contribution through all three the environmental pathways. However, due to the slow-moving nature of any radionuclide contaminant plume that originates from the Kareerand Project through the groundwater system, the potential radiological impact through the groundwater pathway will only occur during the post-closure (see Section 6.4).

6.3.2 Activities

During the operational phase of the Kareerand Project, the following activities were identified that may result in a radiological impact on members of the public:

- Exhalation and dispersion of radon gas from the Kareerand TSF;
- Emission and dispersion of particulates matter containing radionuclides from the Kareerand TSF; and
- Controlled and uncontrolled releases of water containing radionuclides to the environment.

Table 6.1 summarises the activities associated with the operational phase that may have a potential radiological impact on the receptors identified for the Kareerand Project.

Table 6.1 Summary of the activities and the impact of the activities during the operational phase.

Interaction	Impact
Exhalation and dispersion of radon gas to the atmosphere	Radon gas generated in the tailings material due to the presence of Ra-226 will be exhaled to the atmosphere. Inhalation of the radon gas contributes to the total effective dose.
Emission and dispersion of particulate matter to the atmosphere	Wind erosion at the Kareerand TSF will cause particulate matter containing radionuclides to be emitted to the atmosphere. The airborne dust (PM_{10}) and deposited dust (TSP) contribute to the total effective dose through inhalation, ingestion and external radiation exposure routes.
Controlled and uncontrolled releases of water containing radionuclides into the environment	Controlled releases refer to authorised discharges of contaminated water into the environment, whereas uncontrolled releases refer to unauthorised discharges as well as runoff from contaminated areas and dirty water discharges into the environment. This may lead to an increase in the soil and/or water activity concentration.

6.3.3 Exhalation and Dispersion of Radon Gas

6.3.3.1 Impact Description

During the operational phase, radon gas generated in the tailings material due to the presence of Ra-226 will be exhaled from the Kareerand TSF. Following the exhalation and subsequent dispersion of the radon gas into the atmosphere, inhalation of the airborne gas contributes to the total effective dose to receptors identified for the Kareerand Project.

6.3.3.2 Management/Mitigation Measures

The management objective would be to first ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint), and secondly to optimise the radiation protection by applying the ALARA principle (As Low As Reasonable Achievable, economic and social factors taken into consideration).

The total effective dose as a contribution from radon gas released from the Kareerand TSF is below the regulatory compliance criteria (less than 200 µSv.year^{-1} – see Figure 5.6). This means that from a compliance perspective no additional management or mitigation measures are required.

From a dose optimisation perspective, the following can be noted. The radon exhalation rate from the surface of tailings material is determined by several factors, of which moisture content is one. This means that at the wet beach and pool areas of the TSF, the radon exhalation rate will be reduced marginally. However, it is not effective to wet the whole TSF deep enough (2 to 4 m) to reduce the radon exhalation rate marginally. The most effective way to reduce the radon exhalation rate is to provide a covering layer. This will increase the diffusion length to allow for the decay of the radon progeny before being released from the tailings surface.

6.3.3.3 Impact Rating

Table 6.2 presents the impact significant rating for the exhalation and dispersion of radon gas during the operational phase of Kareerand Project.

6.3.4 Emission and Dispersion of Particulate Matter

6.3.4.1 Impact Description

During the operational phase, the Kareerand TSF will serve as a source of windblown dust (i.e., wind erosion) to the atmosphere. The emission and subsequent dispersion of the particulate matter into the atmosphere results in an airborne radionuclides concentration associated with the PM_{10}, and a soil radionuclides concentration following the deposition of the TSP. Through secondary pathways, the radionuclides in the soil may be transferred to crops and animal products. Contributions to the total effective dose to receptors identified for Kareerand Project include inhalation of the airborne dust, ingestion of contaminated soil, crops and animal products, and external gamma radiation through cloudshine and groundshine. This was defined and evaluated as part of a Commercial Agricultural Exposure Condition.

6.3.4.2 Management/Mitigation Measures

The management objective would be to first ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint), and secondly to optimise the radiation protection by applying the ALARA principle.

The total effective dose as a contribution from the windblown dust released from the Kareerand TSF (PM_{10} and TSP) is well below the regulatory compliance criteria, which means that from a compliance perspective no additional management or mitigation measures are required. From a dose optimisation perspective, the following mitigation measures can be applied. These measures, which are in line with the measures proposed in the air quality impact assessment, will contribute to a reduction in the total effective dose if applied for the duration of the operational period:

- Develop a dust management plan for Kareerand Project;
- Application of wetting agents, dust suppressant or binders on the exposed area of the TSF;
- The vegetation of exposed area of the TSF.

Table 6.2 Impact significant rating for the exhalation and dispersion of radon gas during the operational phase of Kareerand Project.

Dimension	Rating	Motivation	Significance
Impact Description: Exhalation and dispersion of radon gas to the atmosphere during the operational phase of Kareerand Project			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 135
Severity	Insignificant (1)	The potential impact of the radon exhalation and subsequent dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of airborne radon gas exhaled from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near of the TSF to be affected by radon inhalation above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Exhalation and dispersion of radon and the subsequent contribution to a radon inhalation dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Exhalation and dispersion of radon gas is not visible and require environmental measurements to detect an increase in the airborne radon concentration	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the radon exhalation and subsequent dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of airborne radon gas exhaled from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by radon inhalation above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Exhalation and dispersion of radon and the subsequent contribution to a radon inhalation dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Exhalation and dispersion of radon gas is not visible and require environmental measurements to detect an increase in the airborne radon concentration	

6.3.4.3 Impact Rating

Table 6.3 presents the impact significant rating for the emission and dispersion of particulate matter that contains radionuclides during the operational phase of Kareerand Project.

Table 6.3 Impact significant rating for the emission and dispersion of dust matter that contains radionuclides during the operational phase of Kareerand Project.

Dimension	Rating	Motivation	Significance
Impact Description: Emission and dispersion of particulate matter that contains radionuclides to the atmosphere during the operational phase of Kareerand Project.			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the dispersion of dust that contains radionuclides beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of dust emitted from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near the TSF to be affected by dust dispersed into the environment above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of dust that contains radionuclides and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	Dispersion of dust is visible and can be observed without much effort. Note that the annual averages are used.	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 117
Severity	Insignificant (1)	The potential impact of the dispersion of dust that contains radionuclides beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of dust emitted from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by dust dispersed into the environment above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of dust that contains radionuclides and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	Dispersion of dust is visible and can be observed without much effort. Note that the annual averages are used.	

6.3.5 The Release of Radioactivity to the Environment

6.3.5.1 Impact Description

Authorised discharges of water containing radionuclides to the environment will be within the regulatory compliance criteria (Annual Authorised Discharge Quantities or AADQ) and will not cause a significant radiological impact to members of the public. However, the environment that includes nearby watercourses may become contaminated due to unauthorised discharge of contaminated water as well as runoff from contaminated surfaces within the mining rights area. The dirty water areas associated with Kareerand Project include the Kareerand TSF and associated water management infrastructure.

Unauthorised discharge of contaminated water may lead to the deterioration of soil, water and associated sediments. Contributions to the total effective dose to receptors identified for Kareerand Project include ingestion of contaminated water, soil, crops and animal products, and external gamma radiation through groundshine.

6.3.5.2 Management/Mitigation Measures

The management objective would be to first ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint), and secondly to optimise the radiation protection by applying the ALARA principle.

The conditions for authorised discharge will take into consideration the activity concentration of the water that is released, the volume of water released, the effect of dilution at the point of discharge, and the human behavioural conditions at the discharge point. The potential radiation exposure to members of the public will be below the regulatory compliance criteria for as long as Kareerand Project comply with the conditions of the authorisation.

From a dose optimisation perspective, the following mitigation measures can be applied for the remainder of the activities. These measures, which are in line with the measures proposed in the surface water impact assessment will contribute to a reduction in the total effective dose if applied for the duration of the operational period:

- A surface water management plan should be developed to ensure that all runoff from dirty areas are directed to the existing stormwater management infrastructure (PCDs) and should not be allowed to flow into any of the nearby watercourses;
- Discharge of water that can potentially contain radionuclides to the nearby watercourses should only be allowed if discharge authorisation has been granted by the relevant authorities (including the NNR);
- The PCDs and dirty water channels should be lined either by concrete or High-Density Polyethylene (HDPE) to prevent contamination of groundwater through seepage; and
- Water quality monitoring should continue downstream and upstream of the mine site, and within all surface water circuits at the mine to detect any contamination arising from operational activities.

6.3.5.3 Impact Rating

Table 6.4 presents the impact significant rating for the release of contaminated water that contains radionuclides into nearby watercourses during the operational phase of Kareerand Project.

6.4 Post-Closure Phase

6.4.1 General

Before the actual closure of Kareerand Project and as part of the NNR licensing (CoR) conditions and requirements, a decommissioning plan will be prepared for submission and approval by the NNR. This plan will define in detail all the activities that will be performed and how the associated radiological impact during the decommissioning and closure phase will be managed.

6.4.2 Activities

Considering that a decommissioning plan for Kareerand Project is not available at present, but will be defined and implemented as mentioned in Section 6.4.1, the following activities were identified that may result in a radiological impact to the receptors identified for the Kareerand Project during the post-closure phase:

- Implementation of the NNR approved decommissioning plan;
- Exhalation of radon gas and the emission of particulates matter (PM_{10} and TSP) that contain radionuclides from the Kareerand TSF; and
- Leaching and migration of radionuclides from the Kareerand TSF.

Table 6.5 summarises the activities associated with the post-closure phase that may have a potential impact on the receptors identified for Kareerand Project.

6.4.3 Implementation of the Decommissioning Plan

6.4.3.1 Impact Description

The implementation of the decommissioning plan results in a positive impact in the sense that all surface infrastructure that contained or that are contaminated with radionuclides are demolished, decontaminated (to the extent possible), and removed from the site once compliance with clearance criteria has been demonstrated. A gamma radiation survey is performed at the infrastructure sites, followed by rehabilitation and clean-up for conditional or unconditional clearance from the NNR. Also, an area that becomes contaminated during or because of operational activities will be rehabilitation and clean-up for conditional or unconditional clearance.

Rehabilitation measure for the Kareerand TSF may include the establishment of vegetation to reduce dust emissions and installation of a covering later to reduce dust emissions and radon exhalation rates during the post-closure period.

Table 6.4 Impact significant rating for the release of contaminated water that contains radionuclides into the environment during the operational phase of Kareerand Project.

Dimension	Rating	Motivation	Significance
Impact Description: Release of contaminated water that contains radionuclides into the environment during the operational phase of Kareerand Project.			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 70
Severity	Significant (3)	The unauthorised release of contaminated water that contains radionuclides to the environment can be significant and slightly harmful	
Spatial Scale	Local (3)	The unauthorised of contaminated water that contains radionuclides to the environment can be beyond the mining rights area into the immediate surroundings	
Duration	Immediate (1)	The unauthorised of contaminated water that contains radionuclides to the environment has to be reported as an Incident with the NNR. It t is unlikely that the duration will be beyond 1 month	
Frequency of activity	Improbable (1)	The unauthorised of contaminated water that contains radionuclides to the environment is unlikely to occur more than once a year	
Frequency of impact	Very Seldom (2)	Even if the activity occurs, it is very seldom that it will lead to a public radiation exposure condition	
Legal Issues	Fully covered by legislation (5)	The release of contaminated water that contains radionuclides to the environment covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	The unauthorised of contaminated water that contains radionuclides can be observed without much effort.	
Post-Mitigation / Management			
Nature	Negative		Low Risk (negative) – 48
Severity	Small (2)	With the implementation of a management programme, the impact of the activity can be small	
Spatial Scale	Local (3)	The unauthorised of contaminated water that contains radionuclides to the environment can be beyond the mining rights area into the immediate surroundings	
Duration	Immediate (1)	The unauthorised of contaminated water that contains radionuclides to the environment has to be reported as an Incident with the NNR. It t is unlikely that the duration will be beyond 1 month	
Frequency of activity	Improbable (1)	The unauthorised of contaminated water that contains radionuclides to the environment is unlikely to occur more than once a year	
Frequency of impact	Almost never (1)	With the implementation of a management programme, the impact will occur almost never	
Legal Issues	Fully covered by legislation (5)	The release of contaminated water that contains radionuclides to the environment covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Immediately (1)	With the implementation of a management programme, the activity will be detected almost immediately.	

Table 6.5 Summary of the activities and the impact of the activities during the post-closure phase.

Interaction	Impact
Implementation of the decommissioning plan	The execution of the decommissioning plan involves a site-wide plan to demolish, decontaminate and remove all the surface infrastructure that may contain or that are contaminated with radionuclides. These areas will be rehabilitated and cleaned for clearance by the NNR. Implement final rehabilitation and mitigation measures at the TSF.
Exhalation of radon gas and particulate matter from the remaining TSFs to the atmosphere	Radon gas generated in the tailings material due to the presence of Ra-226 will be exhaled to the atmosphere. Inhalation of the radon gas contributes to the total effective dose. Wind erosion at the TSF will cause particulate matter containing radionuclides to be emitted to the atmosphere. The airborne dust (PM_{10}) and deposited dust (TPS) contribute to the total effective dose through inhalation, ingestion and external radiation exposure routes.
Leaching and migration of radionuclides from the TSFs	Radionuclides will leach from the TSF into the underlying aquifer, after which it will migrate in the general groundwater flow direction. Abstraction and use of the contaminated water contribute to the total effective dose through the ingestion and possible external radiation exposure routes.

6.4.3.2 Impact Rating

Table 6.6 presents the impact significant rating for the implementation of the decommissioning plan for Kareerand Project.

6.4.4 Exhalation of Radon Gas and Particulate Matter from TSFs

6.4.4.1 Impact Description

During the post-closure phase, the Kareerand TSF will remain at the surface. Under worst-case conditions, the TSF will serve as a source of windblown dust (i.e., wind erosion) to the atmosphere during the post-closure period. During the same period, radon gas generated in the tailings material due to the presence of Ra-226 will be exhaled from the TSF.

The emission and subsequent dispersion of the particulate matter into the atmosphere results in an airborne radionuclides concentration associated with the PM_{10}, and a soil radionuclides concentration following the deposition of the TSP. Through secondary pathways, the radionuclides in the soil may be transferred to crops and animal products. Contributions to the total effective dose to receptors identified for the Kareerand Project include inhalation of the airborne dust, ingestion of contaminated soil, crops and animal products, and external gamma radiation through cloudshine and groundshine.

Table 6.6 Impact significant rating for the implementation of the decommissioning plan for Kareerand Project.

Dimension	Rating	Motivation	Significance
Impact Description: Implementation of the NNR approved decommissioning plan for Kareerand Project.			
Prior to Mitigation / Management			
Nature	Positive		Moderate Risk (Positive) – 128
Severity	Small (2)	The effective implementation of the decommissioning plan will have a small impact on radiation exposure to members of the public	
Spatial Scale	Area-specific (1)	The effective implementation of the decommissioning plan will be limited to the specific areas	
Duration	Beyond the life of the activity (5)	The effective implementation of the decommissioning plan will have a permanent impact on members of the public	
Frequency of activity	Definite (5)	Within the NNR nuclear authorisation structures, the probability that the impact will occur is likely	
Frequency of impact	Almost never (5)	The impact of the effective implementation of the decommissioning plan will be experienced daily	
Legal Issues	Fully covered by legislation (5)	The effective implementation of the decommissioning plan is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Immediately (1)	The effective implementation of the decommissioning plan will be detected almost immediately.	

Following the exhalation and subsequent dispersion of the radon gas into the atmosphere, inhalation of the airborne gas contributes to the total effective dose to receptors identified for the Kareerand Project.

6.4.4.2 Management/Mitigation Measures

The management objective would be to first ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint), and secondly to optimise the radiation protection by applying the ALARA principle.

The total effective dose as a contribution from the windblown dust and radon gas released from the Kareerand TSF is below the regulatory compliance criteria, except near the TSF. This means that from a compliance perspective no additional management or mitigation measures are required. From a dose optimisation perspective, the following mitigation measures that are in line with the measures proposed by the air quality impact assessment can be applied for the post-closure phase:

- The vegetation of exposed area of the Kareerand TSF to reduce wind erosion; and
- Covering layer over the exposed area of the TSF to reduce wind erosion and radon exhalation.

6.4.4.3 Impact Rating

Table 6.7 presents the impact significant rating for the exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of Kareerand Project.

6.4.5 Leaching and Migration of Contaminants from the Kareerand TSF

6.4.5.1 Impact Description

From the commissioning of a TSF, radionuclides contained in the tailings material leach from the TSF to the underlying strata. The rate of leaching is controlled by complex geochemical and hydrological processes but generally are a very slow process. Once in the underlying strata, migration of these radionuclides is equally slow along the groundwater flow path.

The abstraction of groundwater for personal or agricultural purposes may result in a radiological impact to receptors identified for the Kareerand Project through direct ingestion of water or the ingestion of crops and animal products as secondary pathways. The radiological impact along the groundwater pathway only manifest itself during the post-closure period after hundreds to thousands of years after closure.

6.4.5.2 Management/Mitigation Measures

The management objective would be to first ensure that radiation exposure is below the regulatory compliance criteria (i.e., the dose constraint), and secondly to optimise the radiation protection by applying the ALARA principle.

The total effective dose from the ingestion of groundwater as a contribution from the Kareerand TSF was hypothetically illustrated to be below the regulatory compliance criteria, which means that from a compliance perspective no additional management or mitigation measures are required. However, from an optimisation of radiation protection perspective for the post-closure period, the following management/mitigation measures can be implemented if it is assumed that the facility remains at the surface:

- Implementation of a passive groundwater remediation system downstream of the Kareerand TSF to capture the contaminant plume.

Note that active remediation systems, such as cut-off trenches or a pump and treat system, might also be effective in the short to medium term. However, the timescales of concern are beyond what can be considered as active institutional control periods.

Table 6.8 presents the impact significant rating for the leaching and migration of radionuclides from the Kareerand TSF during the post-closure phase of the Kareerand Project.

Table 6.7 Impact significant rating for the exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of the Kareerand Project.

Dimension	Rating	Motivation	Significance
Impact Description: Exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of Kareerand Project			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 135
Severity	Insignificant (1)	The potential impact of the radon gas and dust dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	The dispersion of radon gas and dust are beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the post-closure phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas and dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near the TSF to be affected by the calculated effective dose above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of radon and dust and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Dispersion of radon and dust is only partly visible and require environmental measurements to detect an increase in the airborne radon concentration	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the radon gas and dust dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	The dispersion of radon gas and dust are beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas and dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by the calculated effective dose above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of radon and dust and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Dispersion of radon and dust is only partly visible and require environmental measurements to detect an increase in the airborne radon concentration	

Table 6.8 Impact significant rating for the leaching and migration of radionuclides from the TSFs the post-closure phase of Kareerand Project.

Dimension	Rating	Motivation	Significance
Impact Description: Leaching and migration of radionuclides from the Kareerand TSF during the post-closure phase of the Kareerand Project			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 135
Severity	Insignificant (1)	The severity of the impact is insignificant since the calculated total effective dose is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	The impact extends beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the post-closure phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, the frequency of the activity is definite	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will use borehole water a few hundreds of meters away from the TSF as its only source of water	
Legal Issues	Fully covered by legislation (5)	The leach and migration of contaminated water from the TSF is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	The migration of contaminated groundwater is a very slow process and it is only after laboratory analysis that one would know the water is contaminated	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 120
Severity	Insignificant (1)	The severity of the impact is insignificant since the calculated total effective dose is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (2)	The impact extent will be limited to the site	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the post-closure phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, the frequency of the activity is definite	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will use borehole water a few hundreds of meters away from the TSF as its only source of water	
Legal Issues	Fully covered by legislation (5)	The leach and migration of contaminated water from the TSF is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	The migration of contaminated groundwater is a very slow process and it is only after laboratory analysis that one would know the water is contaminated	

6.5 Cumulative Impact

6.5.1 Regional

Section 2.3.4.3 noted that a cumulative radiological impact to members of the public is possible in the areas, with possible contributions from the broader AngloGold Ashanti Vaal River Operations as well as the other mining operations in the area.

The scope of the assessment was limited to the Kareerand Project and did not make provision for a regional assessment to evaluate cumulative effects (see Section 2.3.4.3). Also, the application of the dose constraint as regulatory compliance criteria opposed to the dose limit of 1 mSv.year^{-1} (or 1,000 µSv.year^{-1}), as defined in Section 2.2.3, is to allow for the cumulative impact from more than one operation in an area. In other words, by constraining Kareerand Project in terms Regulation 388 to 250 µSv.year^{-1}, provision is made for a cumulative impact while still in compliance with the public dose limit of 1,000 µSv.year^{-1}.

6.5.2 Local

Figure 6.1 shows the impact of the radon inhalation dose, as the main contributor to the total effective dose for the existing Kareerand TSF footprint, while Figure 6.2 shows the cumulative impact of both the existing and extension TSF footprint. It is clear that the existing footprint has an impact to the south and south-east, with a slight impact to the north of the existing site. No impact is registered towards the west onto the extended footprint area.

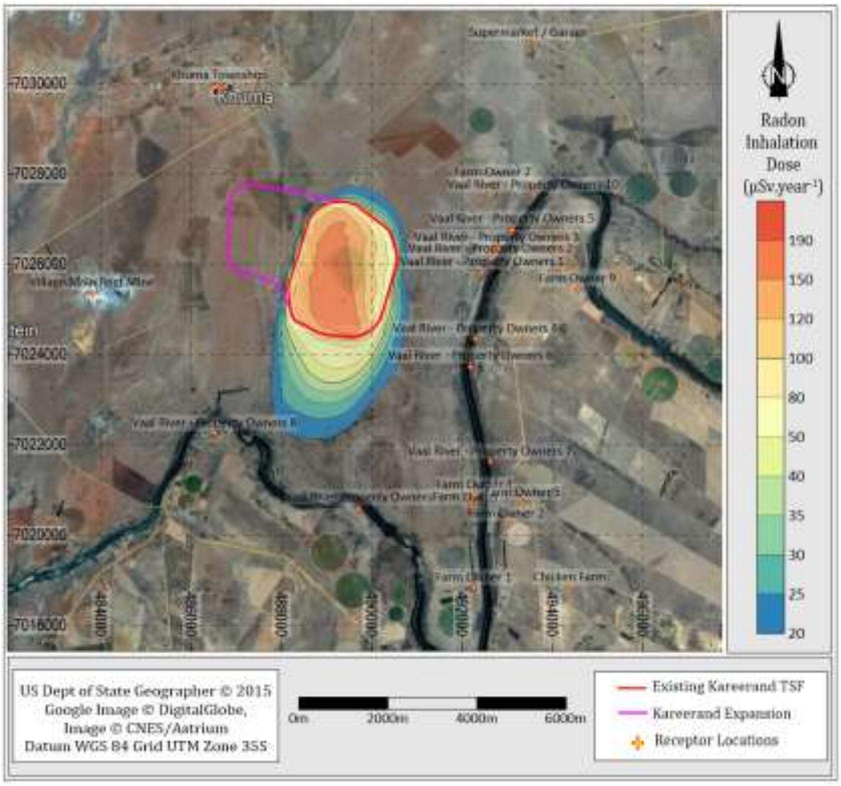


Figure 6.1 **The radon inhalation dose induced by the existing TSF footprint associated with Kareerand Project.**

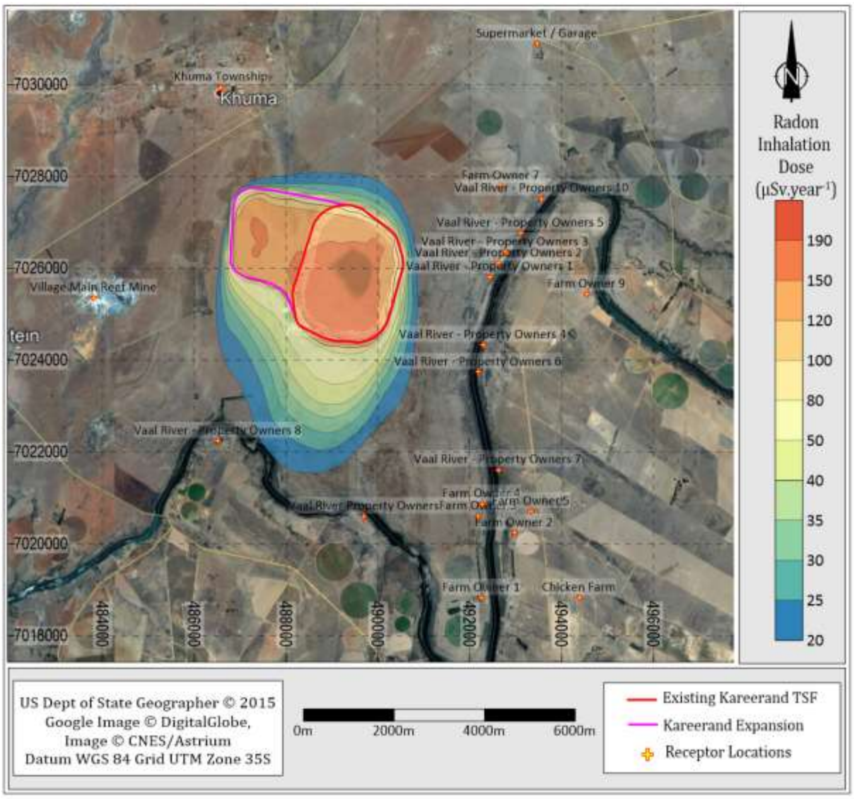


Figure 6.2 The cumulative radon inhalation dose induced by the existing and extension TSF footprint associated with Kareerand Project.

Figure 6.2 shows that the cumulative impact includes an additional component over the extended footprint area, as well as a component to the south of the extension area. The cumulative impact towards the south of the existing footprint area is slightly higher than the plume shown in Figure 6.1.

7 Radiological Monitoring Plan

7.1 General

The NNR regulatory process requires CoR holders to submit a public Radiation Protection Programme (RPP) for approval by the NNR. The basis for the definition of the public RPP is the outcome of the comprehensive radiological public safety assessment and includes a monitoring programme, a surveillance programme and a control programme.

The purpose of this section is to define a radiological monitoring plan for the Kareerand Project. The basis for the definition of the monitoring plan presented here is the outcome of the radiological impact assessment presented in this report, taken into consideration the radiological information available at present (see Section 3.7).

The section is structured as follows. Section 7.2 discusses the characterisation of the baseline conditions associated with Kareerand Project. Section 7.3 presents the proposed monitoring programme for Kareerand Project, while Section 7.4 presents the proposed monitoring locations.

7.2 Baseline Characterisation

Some baseline site characterisation studies have been performed for the Kareerand Project (see Section 3.7.4). This included a gamma radiation and dose rate survey of the Extension area, full-spectrum radioanalysis of soil samples collected at four locations within the Extension area, and an environmental radon survey at the same four locations. No surface water bodies or boreholes are available in the impacted area that could be sampled for full spectrum analysis.

The human behavioural and land use conditions associated with the area is well characterised since the Extension area falls within the Scope of the CoR. No additional studies were performed for the Kareerand Project.

7.3 Monitoring Programme

Table 7.1 summarises the proposed monitoring programme for the Kareerand Project aimed at public radiation protection. The responsibility for the implementation and execution of the monitoring programme lies with the Radiation Protection Function (RP Function) that include legally appointed persons consisting of a Radiation Protection Monitor(s) (RPM), a Radiation Protection Officer (RPO), and a Radiation Protection Specialist (RPS).

A full-spectrum analysis is suitable for detailed dose analysis but is an expensive procedure with long lead times to perform the analysis, which is why less frequent intervals are proposed. The total uranium and thorium analysis, as well as the Ra-226 analysis, are relatively inexpensive with fast turnaround times. These results will monitor variations in activity concentration over the monitoring period.

Table 7.1 Summary of the environmental monitoring programme proposed for the Kareerand Project aimed at public radiation protection.

Monitoring Element	Comment	Frequency
Surface water	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Biannually
	Total Uranium and Thorium, and Ra-226	Quarterly
Sediments	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Annually
	Total Uranium and Thorium, and Ra-226	Biannually
Groundwater	Full-spectrum analysis (U-238, U-235, Th-232 and progeny)	Once every two years
	Total Uranium and Thorium, and Ra-226	Biannually
Radon gas	Environmental radon using Radon Gas Monitors (RGMs)	Quarterly for a period of 2 to 3 month
Dust fallout	Total Uranium and Thorium, and Ra-226	Quarterly

Large variations in the activity concentration over a short period are not expected in groundwater, oppose to surface water, for example. Therefore, a less frequent sampling schedule is proposed for groundwater. The same principle applies to the sediment samples at the same locations as the surface water sample.

The RGMs to monitor the variation in radon gas works in monitoring periods of 2 to 3 month, after which the RGMs is replaced with new RGMs for the next monitoring period.

7.4 Proposed Monitoring Points

Most of the monitoring points proposed to be part of the monitoring programme coincide with the monitoring programme for the environmental pathways. The following can be noted:

- The surface water monitoring locations should coincide with the monitoring points proposed as part of the surface water impact assessment. The principle to be applied is that the monitoring locations should be upstream and downstream of the Kareerand Project in potentially affected surface water streams, as well as upstream and downstream of specific discharge points.
- The sediment monitoring locations should coincide with the surface water monitoring points, applying the same principles.
- The groundwater monitoring points should coincide with the monitoring points proposed in the groundwater impact assessment. The principle to be applied is that the monitoring locations should be upstream and downstream of the Kareerand Project, as well as upstream and downstream of specific surface facilities. The exact location will be determined by the availability of water-bearing boreholes in the specific area.
- The environmental radon monitoring locations do not have to coincide with specific locations. The principle to apply is that it should be widespread over the mining rights area, in the dominant wind direction where receptors are located, complemented with monitoring

locations in what can be considered as background. The exact location is often influenced by whether a secured location is available to improve the recovery rate of the RGMs.

- The dust fallout monitoring locations should coincide with the monitoring points (dust buckets) proposed in the air quality impact assessment.

8 Conclusions and Recommendations

8.1 General

The purpose of the radiological impact assessment was defined as to demonstrate that members of the public living near the Kareerand Project will not be exposed to levels of ionizing radiation above the regulatory compliance criteria for public protection and to assess the radiological impact on members of the public living near the Kareerand Project as input into the EIA process. A systematic approach was followed that included the definition of the regulatory framework and technical basis of the assessment, a system description, the systematic definition of public exposure conditions, the consequence analysis of the exposure conditions and the radiological impact assessment.

Presented here is some general conclusions in Section 8.2 derived from the radiological impact assessment results and recommendations in Section 8.3 for the improvement of the radiological impact assessment.

8.2 Conclusions

Following a systematic approach, only one public exposure condition was derived to be representative for the area, namely a Commercial Agricultural Exposure Condition. The atmospheric and the groundwater pathway was included as contributing pathways for the Commercial Agricultural Exposure Condition.

The following was concluded from the total effective dose assessment results:

- The contribution from the groundwater pathway is only visible in thousands of years at maximum total effective doses less than 100 µSv.year^{-1}, which means that it cannot be considered as a contributing pathway for the Commercial Agricultural Exposure Condition during the operational phase of the Kareerand Project;
- Conservatively it was assumed that commercial farmers are 100% dependent on the farm system to supply in their annual need for crops, fruit, vegetables and animal products as part of the Commercial Agricultural Exposure Condition. The potential total effective dose in these areas during the operational period is not expected to be higher than 100 µSv.year^{-1} during the operational phase of the Kareerand Project.

It can, therefore, be concluded with a reasonable level of assurance that members of the public that can associate themselves with one of the exposure conditions will not be subject to a total effective dose more than the public dose constraint of 250 µSv.year^{-1}.

These total effective dose assessment results were used to derive the radiological impact rating during the different phases of the Kareerand Project. Table 8.1 summarises the radiological impact significant rating for the operational phase of Kareerand Project, while Table 8.2 summarises the radiological impact significant rating for the post-closure phase of the Kareerand Project.

Table 8.1 Summary of the radiological impact significant rating for the operational phase of the Kareerand Project.

Dimension	**Rating**	**Motivation**	**Significance**
Impact Description: Exhalation and dispersion of radon gas to the atmosphere during the operational phase of Kareerand Project			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 135
Severity	Insignificant (1)	The potential impact of the radon exhalation and subsequent dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of airborne radon gas exhaled from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near the TSF to be affected by radon inhalation above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Exhalation and dispersion of radon and the subsequent contribution to a radon inhalation dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Exhalation and dispersion of radon gas is not visible and require environmental measurements to detect an increase in the airborne radon concentration	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the radon exhalation and subsequent dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of airborne radon gas exhaled from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas will be exhaled and dispersed for as long as the TSF remain at the surface	

Dimension	**Rating**	**Motivation**	**Significance**
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by radon inhalation above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Exhalation and dispersion of radon and the subsequent contribution to a radon inhalation dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Exhalation and dispersion of radon gas is not visible and require environmental measurements to detect an increase in the airborne radon concentration	
Impact Description: Emission and dispersion of particulate matter that contains radionuclides to the atmosphere during the operational phase of Kareerand Project.			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the dispersion of dust that contains radionuclides beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of dust emitted from the TSF is beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near the TSF to be affected by dust dispersed into the environment above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of dust that contains radionuclides and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	Dispersion of dust is visible and can be observed without much effort. Note that the annual averages are used.	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 117
Severity	Insignificant (1)	The potential impact of the dispersion of dust that contains radionuclides beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	Dispersion of dust emitted from the TSF is beyond the mining rights area into the immediate surroundings	

Dimension	Rating	Motivation	Significance
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by dust dispersed into the environment above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of dust that contains radionuclides and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	Dispersion of dust is visible and can be observed without much effort. Note that the annual averages are used.	
Impact Description: Release of contaminated water that contains radionuclides into the environment during the operational phase of Kareerand Project.			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 70
Severity	Significant (3)	The unauthorised release of contaminated water that contains radionuclides to the environment can be significant and slightly harmful	
Spatial Scale	Local (3)	The unauthorised of contaminated water that contains radionuclides to the environment can be beyond the mining rights area into the immediate surroundings	
Duration	Immediate (1)	The unauthorised of contaminated water that contains radionuclides to the environment has to be reported as an Incident with the NNR. It t is unlikely that the duration will be beyond 1 month	
Frequency of activity	Improbable (1)	The unauthorised of contaminated water that contains radionuclides to the environment is unlikely to occur more than once a year	
Frequency of impact	Very Seldom (2)	Even if the activity occurs, it is very seldom that it will lead to a public radiation exposure condition	
Legal Issues	Fully covered by legislation (5)	The release of contaminated water that contains radionuclides to the environment covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Without much effort (2)	The unauthorised of contaminated water that contains radionuclides can be observed without much effort.	
Post-Mitigation / Management			
Nature	Negative		Low Risk (negative)

Dimension	Rating	Motivation	Significance
Severity	Small (2)	With the implementation of a management programme, the impact of the activity can be small	– 48
Spatial Scale	Local (3)	The unauthorised of contaminated water that contains radionuclides to the environment can be beyond the mining rights area into the immediate surroundings	
Duration	Immediate (1)	The unauthorised of contaminated water that contains radionuclides to the environment has to be reported as an Incident with the NNR. It t is unlikely that the duration will be beyond 1 month	
Frequency of activity	Improbable (1)	The unauthorised of contaminated water that contains radionuclides to the environment is unlikely to occur more than once a year	
Frequency of impact	Almost never (1)	With the implementation of a management programme, the impact will occur almost never	
Legal Issues	Fully covered by legislation (5)	The release of contaminated water that contains radionuclides to the environment covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Immediately (1)	With the implementation of a management programme, the activity will be detected almost immediately.	

Table 8.2 Summary of the radiological impact significant rating for the post-closure phase of the Kareerand Project.

Dimension	Rating	Motivation	Significance
Impact Description: Implementation of the NNR approved decommissioning plan for Kareerand Project.			
Prior to Mitigation / Management			
Nature	Positive		Moderate Risk (Positive) −128
Severity	Small (2)	The effective implementation of the decommissioning plan will have a small impact on radiation exposure to members of the public	
Spatial Scale	Area-specific (1)	The effective implementation of the decommissioning plan will be limited to the specific areas	
Duration	Beyond the life of the activity (5)	The effective implementation of the decommissioning plan will have a permanent impact on members of the public	
Frequency of activity	Definite (5)	Within the NNR nuclear authorisation structures, the probability that the impact will occur is likely	
Frequency of impact	Almost never (5)	The impact of the effective implementation of the decommissioning plan will be experienced daily	
Legal Issues	Fully covered by legislation (5)	The effective implementation of the decommissioning plan is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Immediately (1)	The effective implementation of the decommissioning plan will be detected almost immediately.	
Impact Description: Exhalation, emission and dispersion of radon gas and particulate matter that contains radionuclides during the post-closure phase of Kareerand Project			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 135
Severity	Insignificant (1)	The potential impact of the radon gas and dust dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	The dispersion of radon gas and dust are beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the post-closure phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas and dust will be exhaled and dispersed for as long as the TSF remain at the surface	

Dimension	**Rating**	**Motivation**	**Significance**
Frequency of impact	Very seldom (2)	It is very unlikely that a person will spend a whole year near the TSF to be affected by the calculated effective dose above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of radon and dust and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Dispersion of radon and dust is only partly visible and require environmental measurements to detect an increase in the airborne radon concentration	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 126
Severity	Insignificant (1)	The potential impact of the radon gas and dust dispersion beyond the TSF boundaries is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	The dispersion of radon gas and dust are beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the operational phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, radon gas and dust will be exhaled and dispersed for as long as the TSF remain at the surface	
Frequency of impact	Almost never (1)	With mitigation measures implemented, a person will almost never spend a whole year near the TSF to be affected by the calculated effective dose above the dose constraint.	
Legal Issues	Fully covered by legislation (5)	Dispersion of radon and dust and the subsequent contribution to the total effective dose is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	Dispersion of radon and dust is only partly visible and require environmental measurements to detect an increase in the airborne radon concentration	
Impact Description: Leaching and migration of radionuclides from the Kareerand TSF during the post-closure phase of the Kareerand Project			
Prior to Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 135
Severity	Insignificant (1)	The severity of the impact is insignificant since the calculated total effective dose is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (3)	The impact extends beyond the mining rights area into the immediate surroundings	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the post-closure phase	

Dimension	Rating	Motivation	Significance
Frequency of activity	Definite (5)	Given the nature of the TSF, the frequency of the activity is definite	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will use borehole water a few hundreds of meters away from the TSF as its only source of water	
Legal Issues	Fully covered by legislation (5)	The leach and migration of contaminated water from the TSF is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	The migration of contaminated groundwater is a very slow process and it is only after laboratory analysis that one would know the water is contaminated	
Post-Mitigation / Management			
Nature	Negative		Moderate Risk (negative) – 120
Severity	Insignificant (1)	The severity of the impact is insignificant since the calculated total effective dose is below the dose constraint and significantly less than the dose limit	
Spatial Scale	Local (2)	The impact extent will be limited to the site	
Duration	Beyond the life of the activity (5)	The impact will occur for the duration of the post-closure phase	
Frequency of activity	Definite (5)	Given the nature of the TSF, the frequency of the activity is definite	
Frequency of impact	Very seldom (2)	It is very unlikely that a person will use borehole water a few hundreds of meters away from the TSF as its only source of water	
Legal Issues	Fully covered by legislation (5)	The leach and migration of contaminated water from the TSF is covered by the National Nuclear Regulator Act (NNR Process)	
Detection	Need some effort (3)	The migration of contaminated groundwater is a very slow process and it is only after laboratory analysis that one would know the water is contaminated	

8.3 Recommendations

The radiological impact assessment made extensively use of assumptions for conditions and parameter values required for the dose assessment, which is not ideal. To improve this situation and to facilitate a more detailed assessment of the potential radiological impact that is consistent with the requirements for the NNR, it is recommended that the baseline characterisation, as well as the radiological monitoring programme defined in Section 7.3 be implemented at the locations defined in Section 7.3.

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Appendix A:
Radionuclide and Element Dependent Data

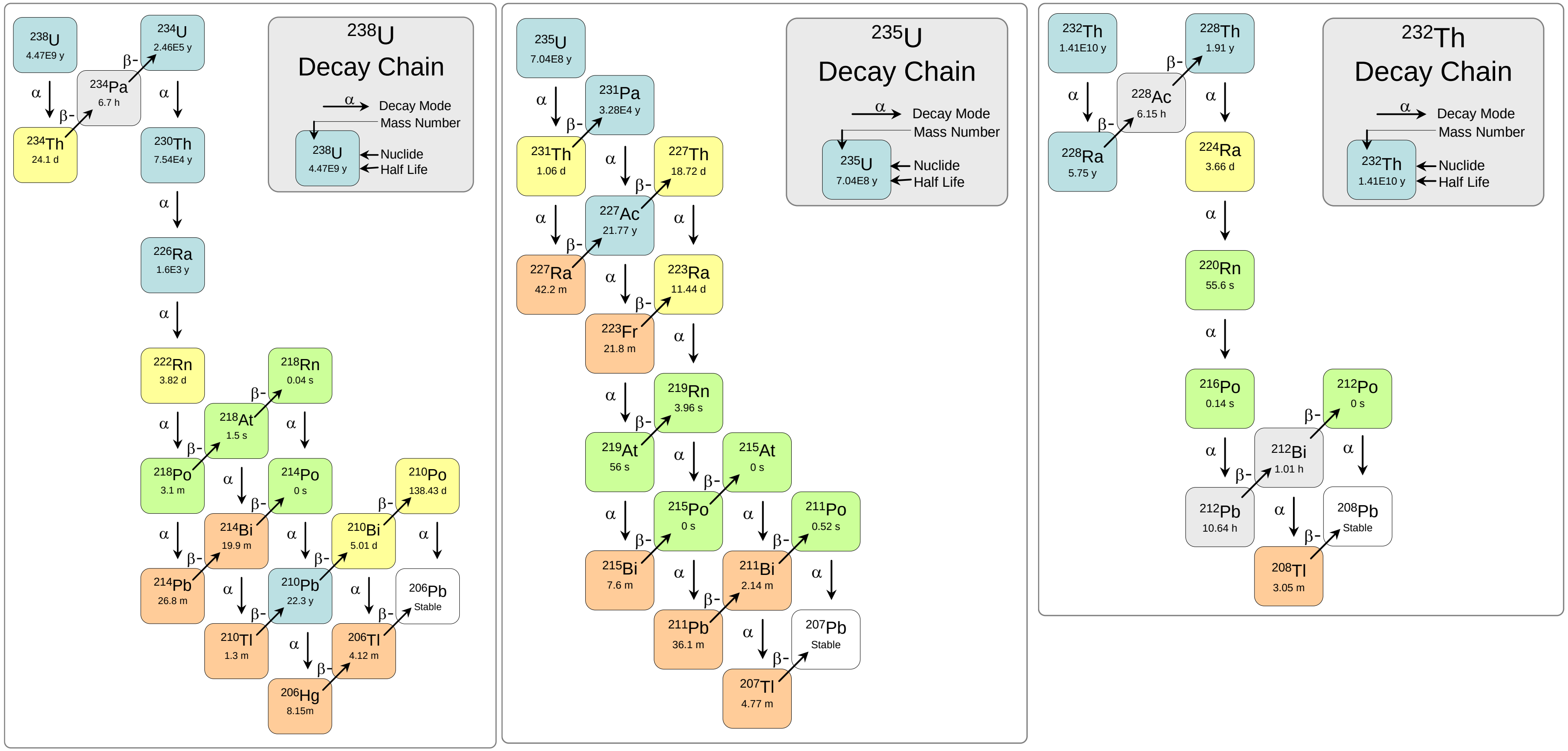

Figure A 1 Schematic illustrations of the U-238, U-235, and Th-232 decay chains.

Table A 1 Radiological properties for the Uranium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Units	Decay Constant	Half-Life (years)	Decay Constant (years)	Atomic Mass	Specific Activity (Bg.kg^{-1})
Uranium	U-238	α	4.468E+09	y	1.551359E-10	4.468000E+09	1.551359E-10	238.05	1.243803E+07
Thorium	Th-234	β	2.410E+01	d	2.876129E-02	6.598220E-02	1.050506E+01	234.04	8.566645E+17
Protactinium	Pa-234m	β	1.170E+00	m	5.924335E-01	2.224504E-06	3.115963E+05	234.04	2.541002E+22
Uranium	U-234	α	2.445E+05	y	2.834958E-06	2.445000E+05	2.834958E-06	234.04	2.311871E+11
Thorium	Th-230	α	7.700E+04	y	9.001911E-06	7.700000E+04	9.001911E-06	230.03	7.468842E+11
Radium	Ra-226	α	1.600E+03	y	4.332170E-04	1.600000E+03	4.332170E-04	226.03	3.658113E+13
Radon	Rn-222	α	3.824E+00	d	1.812860E-01	1.046817E-02	6.621473E+01	222.02	5.692148E+18
Polonium	Po-218	α	3.050E+00	m	2.272614E-01	5.798920E-06	1.195304E+05	218.01	1.046437E+22
Lead	Pb-214	β	2.680E+01	m	2.586370E-02	5.095445E-05	1.360327E+04	214.00	1.213218E+21
Bismuth	Bi-214	β	1.990E+01	m	3.483152E-02	3.783558E-05	1.831998E+04	214.00	1.633890E+21
Polonium	Po-214	α	1.643E+02	us	4.218790E-03	5.206353E-12	1.331349E+11	214.00	1.187399E+28
Lead	Pb-210	β	2.230E+01	y	3.108283E-02	2.230000E+01	3.108283E-02	209.98	2.825159E+15
Bismuth	Bi-210	β	5.012E+00	d	1.382975E-01	1.372211E-02	5.051317E+01	209.98	4.591209E+18
Polonium	Po-210	α	1.384E+02	d	5.009013E-03	3.788638E-01	1.829542E+00	209.98	1.662905E+17

Table A 2 Radiological properties for the Actinium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Units	Decay Constant	Half-Life (years)	Decay Constant (years)	Atomic Mass	Specific Activity (Bg.kg^{-1})
Uranium	U-235	α	7.038E+08	y	9.848639E-10	7.038000E+08	9.848639E-10	235.04	7.997165E+07
Thorium	Th-231	β	2.552E+01	h	2.716094E-02	2.911248E-03	2.380928E+02	231.04	1.966867E+19
Protactinium	Pa-231	α	3.276E+04	y	2.115834E-05	3.276000E+04	2.115834E-05	231.04	1.747878E+12
Actinium	Ac-227	β	2.177E+01	y	3.183517E-02	2.177300E+01	3.183517E-02	227.03	2.676315E+15
Thorium	Th-227	α	1.872E+01	d	3.703105E-02	5.124709E-02	1.352559E+01	227.03	1.137068E+18
Radium	Ra-223	α	1.143E+01	d	6.062158E-02	3.130459E-02	2.214203E+01	223.02	1.894897E+18
Radon	Rn-219	α	3.960E+00	s	1.750372E-01	1.254848E-07	5.523753E+06	219.01	4.813713E+23
Polonium	Po-215	α	1.780E-03	s	3.894085E+02	5.640480E-11	1.228880E+10	215.00	1.090890E+27
Lead	Pb-211	β	3.610E+01	m	1.920075E-02	6.863640E-05	1.009883E+04	210.99	9.135254E+20
Bismuth	Bi-211	α	2.140E+00	m	3.239006E-01	4.068750E-06	1.703587E+05	210.99	1.541051E+22
Thallium	Tl-207	β	4.770E+00	m	1.453139E-01	9.069131E-06	7.642929E+04	206.98	7.047673E+21

Table A 3 Radiological properties for the Thorium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Units	Decay Constant	Half-Life (years)	Decay Constant (years)	Atomic Mass	Specific Activity (Bg.kg^{-1})
Thorium	Th-232	α	1.405E+10	y	4.933432E-11	1.405000E+10	4.933432E-11	232.04	4.057876E+06
Radium	Ra-228	β	5.750E+00	y	1.205473E-01	5.750000E+00	1.205473E-01	228.03	1.008957E+16
Actinium	Ac-228	α	6.130E+00	h	1.130746E-01	6.992927E-04	9.912118E+02	228.03	8.296243E+19
Radium	Ra-224	α	3.660E+00	d	1.893845E-01	1.002053E-02	6.917268E+01	224.02	5.893270E+18
Radon	Rn-220	α	5.560E+01	s	1.246668E-02	1.761858E-06	3.934184E+05	220.01	3.412859E+22
Polonium	Po-216	α	1.500E-01	s	4.620981E+00	4.753213E-09	1.458271E+08	216.00	1.288515E+25
Lead	Pb-212	β	1.064E+01	h	6.514541E-02	1.213781E-03	5.710647E+02	211.99	5.141324E+19
Bismuth	Bi-212	β	6.055E+01	m	1.144752E-02	1.151228E-04	6.020936E+03	211.99	5.420695E+20
Polonium	Po-212	α	3.050E-01	us	2.272614E+00	9.664867E-15	7.171823E+13	211.99	6.456921E+30

Appendix B:
Methodological Approach to Dose Calculation

Dose Conversion Factors

Radiation dose is a term used to describe the amount of energy that ionizing radiation deposits in a mass of matter, such as human tissue. Types of ionizing radiation differ in the way in which they interact with biological materials. Hence, equal energy amounts deposited in a mass of human tissue do not necessarily have equal biological effects. For example, a dose of one unit of alpha radiation energy is more harmful than 1 unit of energy from beta radiation, since an alpha particle, being slower and more heavily charged, loses its energy more densely along its path.

The radiation dose associated with each radionuclide is calculated using a specific numerical factor, developed taking into account the relative effectiveness of the radiation to cause biological harm and other parameters relating to the likelihood of harm to particular tissues or organs exposed to the radiation (Eckermann *et al.*, 1988). These numerical factors, referred to as 'dose conversion factors', are used to convert radioactivity concentrations members of the public are exposed to, to a total effective dose. The estimation of the **total annual effective radiation dose** that an individual is exposed to is the sum of the internal and external effective doses. Radioactivity that enters the body fluids from inhalation (respiratory tract) and ingestion (gastrointestinal tract) constitute the internal effective doses.

As indicated in Section 2, the most pertinent guidance currently available for conducting prior and operational public safety assessments for NORM facilities is the Regulatory Guide RG-002 (NNR, 2013). This guide summarises dose conversion factors for use in the assessment of inhalation and ingestion exposure to radionuclides, as obtained from the ICRP Publication 72 (ICRP, 1996) and the IAEA Safety Standards Series (IAEA, 2011) documents. The dose conversion factors published in RG-002 make a distinction between different age groups, which represent the ranges of age groups as listed in Table B 1.

Table B 1 Age group ranges applicable to age dependent dose conversion factors as published in RG-002 (NNR, 2013).

Ages specified in RG-002	Applicable Age Range
New-born	From 0 to 1 year of age
1 Year	From 1 year to 2 years
5 Year	More than 2 years to 7 years
10 Year	More than 7 years to 12 years
15 Year	More than 12 years to 17 years
Adult	More than 17 years

Table C 1 and Table C 2 (Appendix C) present the dose conversion factors for the different age groups for inhalation and ingestion, as derived from the values published in RG-002 (NNR, 2013).

In addition to ingestion and inhalation, radioactivity may also enter the body through the skin, which constitutes external radiation exposure. For external exposures, the kinds of radiation of concern are those sufficiently penetrating to traverse the overlying tissues of the body and deposit ionising energy in radiosensitive organs and tissues. Photons and electrons are the most important radiations emitted by radionuclides distributed in the environment that can penetrate the body from outside. This situation contrasts with the intake of radionuclides by inhalation or ingestion, where the radiations are emitted inside the body.

Calculation of the effective dose contribution from external radiation exposure to a contaminated environmental medium (e.g. water, soil or air) requires an indication of the exposure period to a unit volume of the contaminated medium, and an estimate of the effective dose per unit time-integrated exposure to a radionuclide. The effective dose conversion factors for external exposure relate the concentrations of radionuclides in environmental media to the effective radiation doses to organs and tissues of the body.

Effective external dose conversion factors are published in the EPA Federal Guidance Document No. 12 (Eckerman and Ryman, 1993). The dose received through external exposure is a function of the intensity of the radiation and is assumed to constitute nearly uniform irradiation of the body. The estimation of the dose is therefore independent of the age of the person exposed and the conversion factors are therefore age-independent.

Table C 3 in Appendix C presents the external exposure dose conversion factors as specified in RG-002 (NNR, 2013). The values presented are for external soil exposure (ground shine), external water exposure (water immersion) and external air exposure (cloud immersion), respectively.

Inhalation Exposure (LLα and Radon)

The effective dose from the inhalation of dust containing LLα radionuclides ($ED_{Inh_{LL\alpha}}$, in μSv.y^{-1}) is calculated from measured or modelled airborne radionuclide concentrations (in Bq.m^{-3} nuclide specific), multiplied by appropriate inhalation dose coefficients. The equation to calculate the LLα inhalation dose is given by:

Equation 1

$$ED_{Inh_{LL\alpha}} = C_{LL\alpha}\, DC_{inh}\, EP_h\, BR_h$$

where $C_{LL\alpha}$ is the airborne activity concentration for LLα (Bq.g^{-1}), DC_{inh}.is the dose coefficient for inhalation (μSv.Bq^{-1}), EP_h is the human exposure (occupancy) period to the LLα airborne concentration, and BR_h is the human air-breathing rate. The inhalation dose is directly linear to the breathing rate and exposure period. Breathing rates for different age groups as specified in RG-002 are listed in Table C 4 in Appendix C.

The dose received through the inhalation of airborne radon (ED_{Inh_Rn}, μSv.y^{-1}) can be calculated using the following equation:

Equation 2

$$ED_{Inh\_Rn} = C_{Rn}\, DC_{Rn}$$

where C_{Rn} is the airborne radon concentration (Bq.m^{-3}), and DC_{Rn} is the annual radon inhalation dose coefficient [(mSv.h^{-1}) per (Bq.m^{-3})] (see Table B 2).

Table B 2 Values recommended for calculation of dose from the exposure of inhaled radon (IAEA BSS, ICRP 65; UNSCEAR).

Parameter	Indoors	Outdoors	At Work	Unit
Conversion Coefficient[1]	5.56E-06			(mJ.m^{-3}) per (Bq.m^{-3})
Radon progeny conversion	3.54			(mJ.h.m^{-3}) per (WLM)
Effective dose per unit exposure to radon	4.0	4.0	5.0	mSv per WLM
Dose conversion for effective dose per unit exposure	1.1	1.1	1.4	(mSv.h^{-1}) per (mJ.m^{-3})
Exposure period	7 000	1 760	2 000	[h]
Equilibrium factor	0.4	0.8	0.4	[-]
Annual exposure per unit radon concentration[2]	1.56E-02	7.83E-03	4.45E-03	(mJ.h.m^{-3}) per (Bq.m^{-3})
	2.22E-06	4.45E-06	2.23E-06	(mJ.m^{-3}) per (Bq.m^{-3})
Annual dose conversion factor[3]	1.76E-02	8.85E-03	6.23E-03	(mSv) per (Bq.m^{-3})
	2.51E-06	5.03E-06	3.14E-06	(mSv.h^{-1}) per (Bq.m^{-3})
Dose Coefficient (UNSCEAR)[4]	9.00E-06			(mSv.h^{-1}) per (Bq.m^{-3})

1 Conversion Coefficient = Ratio of PAEC (Potential Alpha Energy Concentration) and EEC (Equilibrium Equivalent Concentration) of Radon

2 Annual exposure per unit radon concentration = 5.56E-06 x 0.4 x 7,000

3 Annual dose conversion factor = 1.56E-02 x 1.1

4 EEC of Radon

Ingestion Exposure

Ingestion Rates

Table C 5 lists prescribed (RG-002) ingestion rates for adult members of the public compared to ranges of ingestion rates published in the literature. The comparison shows that the values prescribed in RG-002 largely fall within the range of literature values and are appropriately scaled to the South African population to be applicable for use in the assessment.

Table C 6 lists the ingestion rates for the different age groups as derived from the adult values prescribed in RG-002. The values for the other age groups are taken as a percentage of the annual ingestion rate for adults, according to the values listed in the first row of Table C 5. Where values for specific agricultural products are not available from RG-002, the values listed under the 'Average' column in Table C 5 are used.

Water Ingestion

The effective dose rate from the ingestion of contaminated water ($ED_{ing,water}$, in µSv.y^{-1}) is calculated from measured ^{or} modelled radionuclide concentrations of the water, multiplied with appropriate ingestion dose coefficients and water consumption rates, and is given by:

Equation 3

$$ED_{ing,water} = C_{water}\, DC_{ing}\, CR_{water}$$

where C_{water} is the radionuclide concentration in the water (Bq.m^{-3}), DC_{ing}.is the dose coefficient for ingestion (µSv.Bq^{-1}), and CR_{water} is the water consumption rate (m^3.y^{-1}) per age group.

Inadvertent Ingestion of Contaminated Soil

The effective dose rate from the ingestion of contaminated soil ($ED_{ing,soil}$, in µSv.y^{-1}) is calculated from measured or modelled radionuclide concentrations in the soil, multiplied with appropriate ingestion dose coefficients and soil consumption rates and is given by:

Equation 4

$$ED_{ing,soil} = C_{soil}\, DC_{ing}\, CR_{soil}$$

where C_{soil} is the radionuclide concentration in the soil (Bq.kg^{-1}), DC_{ing}.is the dose coefficient for ingestion (µSv.Bq^{-1}), and CR_{soil} is the individual soil consumption rate (kg.y^{-1}).

The activity concentration in the soil can increase over time through continued deposition of airborne radionuclides. The approach used for estimating activity concentrations in soil (C_{soil}) is presented in Appendix D. The rate at which different age groups inadvertently consume soil on an annual basis is obtained from values published in RG-002.

Ingestion of Contaminated Crops

The soil contaminated with radionuclides could contaminate crops that are grown in it. The effective dose rate from the ingestion of contaminated secondary crops ($ED_{ing,crop}$, in µSv.y^{-1}) (e.g. fruit, cereals, leafy or root vegetables) is calculated as a summation of measured or modelled radionuclide concentrations of the secondary crop, multiplied with appropriate ingestion dose coefficients and crop consumption rates, and is given by:

Equation 5

$$ED_{ing,crop} = \sum\nolimits_{crop} (C_{crop}\, CR_{crops}\ \ DC_{ing})$$

where C_{crop} is the radionuclide concentration in the crop (Bq.kg^{-1}), DC_{ing}.is the dose coefficient for ingestion (µSv.Bq^{-1}), and CR_{crop} is the individual crop consumption rate (kg.y^{-1}). The age group-specific consumption rates for individual crop types are listed in Table C 6. The activity concentration in the crop (C_{crop}, in Bq.kg^{-1}) can be calculated using the following equation:

Equation 6

$$\begin{aligned} C_{crop} = {} & C_{soil}\left(CF_{crop} + \left(1 - f_{prep}\right)S_{crop}\right) \\ & + Int_{crop}\, f_{growth}\left(C_{water}\, I_{rate} + Dep_{rate}\right)\left(\frac{\left(1 - f_{prep}\right) + f_{trans}}{Y_c\, \lambda_{\mathrm{w}}}\right) \end{aligned}$$

where C_{water} is the radionuclide concentration in the water (Bq.m^{-3}), C_{soil} is the radionuclide concentration in the soil (Bq.kg^{-1}), CF_{crop} is the soil to crop concentration factor (Bq.kg^{-1} fresh weight per Bq.kg^{-1} dry soil), S_{crop} is the soil contamination on the crop (kg.kg^{-1}). f_{growth} is the crop growth day per days of the year (unitless), Int_{crop} is the interception fraction (irrigation water and deposition) on the crop (unitless), I_{rate} is the annual depth of irrigation applied to the crop (m.y^{-1}), Dep_{rate} is the deposition rate of airborne contaminants (Bq.m^{-2}.y^{-1}). Y_c is the crop yield (kg.m^{-2}, fresh weight of crop), λ_w is the removal rate of contaminants on the crop (through irrigation or deposition) by weathering processes (y^{-1}), f_{trans} is the fraction of activity transferred from external to internal plant surfaces (unitless), and f_{prep}.is the fraction of activity removed from the crop surfaces after food preparation.

The concentration factor (CF_{crop}) defines the transfer of activity from the soil to the crops consumed by humans. Equation 6 makes provision for crops to become contaminated in the following ways:

- Internal intake of contaminants from the soil surface into the crop *via* the roots as well as the soil contamination on the crops itself, which is represented by the term, $C_{soil}(CF_{crop} + (1 - f_{prep})\, S_{crop})$;
- External contamination of the crop due to deposition of airborne dust, represented by the term $Int_{crop}\, f_{growth}\, Dep_{rate}$; and
- External contamination of the crop due to irrigation of the crops, represented by the term $Int_{crop}\, f_{growth} C_{water}\, I_{rate}$.

A concentration factor (CF_{crop}) defines the transfer of activity from contaminated soil to crops planted in the soil and consumed by humans or animals. The concentration factor reflects only the uptake of radionuclides from the soil via roots and excludes the effects of deposition of radionuclides onto the plant surfaces by re-suspension, deposition, and fallout. Concentration factors prescribed in RG-002 (NNR, 2013) are presented for different soil groups. The RG-002 values are listed in Table C 7 in Appendix C, where it is listed alongside values from other literature sources. Where data for a specific nuclide are not available from RG-002, the values from Staven *et al.* (2003) will be used. Values for the other parameters given in Equation 6 are listed in Appendix C

Ingestion of Contaminated Animal Products

The effective dose from the ingestion of contaminated animal products ($ED_{ing,Anm}$, in µSv.y^{-1}) (e.g. beef, mutton, pork, poultry milk, and eggs) is calculated from measured or modelled (using Equation 6) radionuclide concentrations of the secondary animal product, by multiplication with appropriate ingestion dose coefficients and animal product ingestion rates, and is given by:

Equation 7

$$ED_{ing,Anm} = \sum_{Anm} (C_{Anm}\ CR_{Anm}\ DC_{ing})$$

where C_{Anm} is the radionuclide concentration in the animal product (Bq.kg^{-1} fresh weight of products), CR_{Anm} is the individual consumption rate of the animal products (kg.y^{-1} fresh weight of the product), and DC_{ing}.is the dose coefficient for ingestion (µSv.Bq^{-1}). Similarly, the effective dose from the ingestion of milk ($ED_{ing,milk}$, in µSv.y^{-1}) can be calculated using the following equation:

Equation 8

$$ED_{ing,milk} = C_{milk}\, CR_{milk}\, DC_{ing}$$

where C_{milk} is the radionuclide concentration in the animal product (Bq.L^{-1}), CR_{milk} is the individual consumption rate of the animal products (L.y^{-1}), and DC_{ing}.is the dose coefficient for ingestion (µSv.Bq^{-1}). The age-specific annual ingestion rate for different animal products are listed in Table C 6 in Appendix C. The concentration in the animal product (C_{Anm}) can be calculated using the following equation:

Equation 9

$$C_{Anm} = CF_{Anm}\left[C_{past}\, CR_{Ap} + C_{water}\, CR_{Aw} + C_{soil}\, CR_{Asoil} + C_{sed} CR_{Ased}\right]$$

where CF_{Anm} is the concentration factor for the animal product (d.kg^{-1} fresh weight of the product), C_{past} is the pasture radionuclide concentration (Bq.kg^{-1} fresh weight of the pasture), CR_{past} is the animal pasture consumption rate (kg.d^{-1} fresh weight of the pasture). Animals may obtain radionuclides via drinking water. This is expressed using C_{water} (Bq.m^{-3}), the radionuclide concentration of water provided for the animals, and CR_{water} is the animal water consumption rate (m.d^{-1}). Ingestion of soil is calculated using C_{soil}, the soil radionuclide concentration (Bq.kg^{-1}). CR_{As} is the animal soil consumption rate (kg.d^{-1} wet weight of soil). Similarly, sediment is calculated using $C_{sed,wet}$, the radionuclide concentration in the wet sediment (Bq.kg^{-1}). CR_{Ased} is the animal sediment consumption rate (kg.d^{-1} wet weight of sediment). Similarly, the concentration in animal milk from (C_{milk}) can be calculated using the following equation:

Equation 10

$$C_{milk} = CF_{milk}\left[C_{past}\, CR_{Ap} + C_{water}\, CR_{Aw} + C_{soil}\, CR_{Asoil} + C_{sed} CR_{Ased}\right]$$

where CF_{milk} is the concentration factor for the animal milk (d.L^{-1}), and the remainder of the parameters are listed above. Values for the consumption rates of water, soil and fodder for beef, sheep/goat/pig and poultry respectively, are summarised in Table C 8 in Appendix C.

The transfer of radionuclides from animal feed (CF_{Anm}] to animal products such as milk and meat is described by using a transfer coefficient. The transfer coefficients obtained from RG-002, are listed in Table C 10 in Appendix C. The transfer coefficients for milk taken from RG-002, applies to cow milk only, but the values from other references (also listed in Table C 10) may be applied to cow, goat and sheep milk. The coefficients listed for the transfer of radionuclides from animal feed (pasture, grass, forage) to meat may be applied to all types of beef products, as well as pigs, goats, horses and game animals. The poultry values may be applied to all types of poultry. The values from RG-002 will be used in the analysis. Where transfer coefficients for specific elements or animal products were not available from RG-002, values from Staven *et al.* (2003) will be used.

The concentration in the pasture is calculated using an equation similar to Equation 6, but without the food preparation loss term. The activity concentration in pasture (C_{past}, in Bq.kg^{-1}) can be calculated using the following equation:

Equation 11

$$C_{past} = CF_{past}\, C_{soil}\, S_{crop} + \; Int_{crop}\; f_{growth}(C_{water}\, I_{rate} + Dep_{rate})\left(\frac{f_{trans}}{Y_c\, \lambda_{\mathrm{w}}}\right)$$

where C_{water} is the radionuclide concentration in the water (Bq.m^{-3}), C_{soil} is the radionuclide concentration in the soil (Bq.kg^{-1}), CF_{past} is the soil to pasture concentration factor (Bq.kg^{-1} fresh weight per Bq.kg^{-1} dry soil), and Int_{past} is the interception fraction (irrigation water and deposition) on pasture (unitless). I_{rate} is the annual depth of irrigation applied to the pasture (m.y^{-1}) and Dep_{rate} is the deposition rate of airborne contaminants (Bq.m^{-2}.y^{-1}). Y_{past} is the pasture yield (kg.m^{-2}, fresh weight of pasture), λ_{w} is the removal rate of contaminants on the pasture (through irrigation or deposition) by weathering processes (y^{-1}), and $\mathrm{Ing}_{\mathrm{past}}$ is the consumption rate of pasture by the animals (kg.d^{-1} fresh weight of pasture).

External Gamma Irradiation: Air

The effective dose from external exposure to contaminated air (ED_{Ext_a}, in µSv.y^{-1}) is calculated from measured or simulated radionuclide concentration of the air, multiplied with appropriate dose coefficients and the period exposed to the air. The external (cloud immersion) dose can be calculated using the following equation:

Equation 12

$$ED_{ext\_air} = C_{air}\, DC_{ext\_a}\, EP_a$$

where C_{air} is the radionuclide concentration in the air (Bq.m^{-3}), DC_{ext_w}.is the dose coefficient for external exposure to air (µSv.h^{-1} per Bq.m^{-3}), and EP_w is the annual human exposure period to contaminated air (h.y^{-1}). Exposure is age group-specific and the values used in this assessment, as obtained from RG-002, is summarised in Table C 10 in Appendix C.

External Gamma Irradiation: Soil

The effective dose from external exposure to the contaminated soil of various extents (ED_{Ext_s}, in µSv.y^{-1}) is calculated from measured or simulated radionuclide concentration of the soil, multiplied with appropriate dose coefficients and the period exposed to the soil. The external (ground shine) dose can be calculated using the following equation:

Equation 13

$$ED_{ext\_soil} = C_{soil}\, DC_{ext\_s}\, EP_s$$

where C_{soil} is the radionuclide concentration in the soil (Bq.kg^{-1}), DC_{ext_s}.is the dose coefficient for external exposure to soil (µSv.h^{-1} per Bq.kg^{-1}), and EP_s is the annual human exposure period to contaminated air (h.y^{-1}). Duration of exposure for different age groups is presented in Table C 11 in Appendix C.

External Gamma Irradiation: Water

The effective dose from external exposure to contaminated water (ED_{Ext_w}, in µSv.y^{-1}) is calculated from measured or simulated radionuclide concentration of the water, multiplied with appropriate dose conversion coefficients and the period exposed to the water. The external (water immersion) dose can be calculated using the following equation:

Equation 14

$$ED_{Ext\_w} = C_{water}\, DC_{ext\_w}\, EP_w$$

where C_{water} is the radionuclide concentration in the water (Bq.m^{-3}), DC_{ext_w}.is the dose coefficient for external exposure to water (µSv.h^{-1} per Bq.m^{-3}), and EP_w is the annual human exposure period to contaminated water (h.y^{-1}). Duration of exposure for different age groups is presented in Table C 11 in Appendix C.

Time-Dependent Soil Concentration

The radionuclide concentration of in the topsoil layer (rooting zone) of previously uncontaminated soil can increase in two ways: the deposition of dispersed airborne radionuclides onto the surface, and the transfer of radionuclides in water to the soil during irrigation. Some of the radionuclides in the rooting zone will leach to greater depths (deeper zone), while root systems will take some of the radionuclides up into plants and crops. Some of the radionuclides will be adsorbed to soil particles, while bioturbation processes may transfer radionuclide between soil layers. The net effect is a change in soil radionuclide concentration in the rooting zone with time.

The radionuclide concentration in the soil can be calculated using the following equation:

Equation 15

$$C_{soil} = \frac{Soil_{RZ}}{(h_{RZ} * \rho_{RZ} * Area)}$$

where C_{soil} (Bq.kg^{-1}) is the radionuclide concentration in the soil rooting zone, $Soil_{RZ}$ (Bq) is the radionuclide inventory in the soil rooting zone, $Area$ (m^2) is the area of the soil layer, h_{RZ} (m) is the depth of the soil rooting zone and ρ_{RZ} (kg.m^{-3}) is the density of the soil rooting zone. The change in the radionuclide inventory ($Soil_{RZ}$) in an area is given by the differential equation:

Equation 16

$$\frac{dSoil_{RZ}}{dt} = (\lambda * Soil_{RZ}) + (Soil_{DZ} * \lambda_{Eros,DZ}) + (Soil_{DZ} * \lambda_{BioT,DZ}) + (Dep_{air} + I_{rrig}) - (Soil_{RZ} * \lambda_{Leach,RZ}) - (Soil_{RZ} * \lambda_{Eros,RZ}) - (Soil_{RZ} * \lambda_{BioT,RZ}) - (Soil_{RZ} * \lambda_{RootU,RZ})$$

where λ (y^{-1}) is a radionuclide specific decay/ingrowth function that together with the $Soil_{RZ}$ is an expression for decay and ingrowth of radionuclides, $\lambda_{Eros,DZ}$ (y^{-1}) is the apparent transfer of radionuclides from the deep soil to the rooting zone, $\lambda_{BioT,DZ}$ (y^{-1}) is the transport of radionuclides from the deep soil to the rooting zone due to bioturbation, $Soil_{DZ}$ (Bq) is the radionuclide inventory in the deep zone of the soil, due to erosion processes, Dep_{air} (Bq.y^{-1}) is the total deposition of radionuclides from the atmosphere on the area, I_{rrig} (Bq.y^{-1}) is the transfer of radionuclides from water to soil due to irrigation, $\lambda_{Leach,RZ}$ (y^{-1}) is the transport of radionuclides from the soil rooting zone to deeper parts of the soil by leaching, $\lambda_{Eros,RZ}$ (y^{-1}) is the transport of radionuclides from the rooting zone due to erosion processes, $\lambda_{BioT,RZ}$ (y^{-1}) is the transfer of radionuclides from the rooting zone to the deep soil due to bioturbation, and $\lambda_{RootU,RZ}$.(y^{-1}) is the transfer of radionuclides from the rooting zone to plants through root uptake.

Dep_{air} (Bq.y^{-1}) is calculated by:

Equation 17

$$Dep_{air} = Rate_{dep} * Area,$$

where $Rate_{dep}$ (Bq.m^{-2}.y^{-1}) is the deposition rate on the soil layer and $Area$ (m^2) is the area of the soil layer. I_{rrig} (Bq.y^{-1}) is calculated by:

Equation 18

$$I_{rrig} = C_{water,irr} * Rate_{irr} * Area,$$

where $C_{water,irr}$ (Bq.m^{-3}) is the radionuclide concentration in nearby irrigation water and $Rate_{irr}$ (m^3.m^{-2}.y^{-1}) is the irrigation rate for the area. $\lambda_{Eros,DZ}$ (y^{-1}) is calculated by:

Equation 19

$$\lambda_{Eros,DZ} = \frac{Rate_{eros}}{\left(h_{soil,DZ} * \rho_{soil,DZ}\right)},$$

where $Rate_{eros}$ (kg. m^{-2}.y^{-1}) is the erosion rate of soils in the area, $h_{soil,DZ}$ (m) is the depth of the deep soil zone and $\rho_{soil,DZ}$ (kg. m^{-3}) is the density of the deep zone soil. Similarly, $\lambda_{Eros,RZ}$ (y^{-1}) is calculated by:

Equation 20

$$\lambda_{Eros,RZ} = \frac{Rate_{eros}}{\left(h_{soil,RZ} * \rho_{soil,RZ}\right)},$$

where $h_{soil,RZ}$ (m) is the depth of the root zone and $\rho_{soil,RZ}$ (kg. m^{-3}) is the density of the root zone. $\lambda_{BioT,DZ}$ (y^{-1}) is calculated by:

Equation 21

$$\lambda_{BioT,DZ} = \frac{BioT}{\left(h_{soil,DZ} * \rho_{soil,DZ}\right)},$$

where $BioT$ (kg. m^{-2}.y^{-1}) is the bioturbation in the soil. Similarly, $\lambda_{BioT,RZ}$ (y^{-1}) is calculated by:

Equation 22

$$\lambda_{BioT,RZ} = \frac{BioT}{\left(h_{soil,RZ} * \rho_{soil,RZ}\right)}.$$

$\lambda_{Leach,RZ}$ (y^{-1}) is calculated by:

Equation 23

$$\lambda_{Leach,RZ} \ = \frac{I_{nfil}}{\left(h_{soil,RZ} * \varepsilon_{soil,RZ} * Ret_{RZ}\right)},$$

where I_{nfil} ($m^3.m^{-2}.y^{-1}$) is the infiltration rate into the soils, normally defined by the difference between the local precipitation rate and the evapotranspiration rate, $\varepsilon_{soil,RZ}$ ($m^3.m^{-3}$) is the porosity of the soil rooting zone and Ret_{RZ} (-) is the retardation factor for the soil rooting zone that can be calculated by:

Equation 24

$$Ret_{RZ} \ = \ 1 + \frac{\rho_{soil,RZ} * K_{d\ soil,RZ}}{\varepsilon_{soil,RZ}},$$

where $K_{d\ soil,RZ}$ ($m^3.kg^{-1}$) is the distribution coefficient for the soil rooting zone. Similarly, $\lambda_{Leach,DZ}$ (y^{-1}) is calculated by:

Equation 25

$$\lambda_{Leach,DZ} \ = \frac{I_{nfil}}{\left(h_{soil,DZ} * \varepsilon_{soil,DZ} * Ret_{DZ}\right)}$$

where $\varepsilon_{soil,DZ}$ ($m^3.m^{-3}$) is the porosity of the soil-rooting zone and $RetD_{DZ}$ (-) is the retardation factor for the deep soil zone that can be calculated by:

Equation 26

$$Ret_{DZ} \ = \ 1 + \frac{\rho_{soil,DZ} * K_{d\ soil,DZ}}{\varepsilon_{soil,DZ}},$$

where $K_{d\ soil,DZ}$ ($m^3.kg^{-1}$) is the distribution coefficient for the deep soil zone. The transfer of radionuclides from the root zone through root uptake is calculated by:

Equation 27

$$RootU_{RZ} = \frac{Y_{crop} \ * Num_{crop} * CF_{crop}}{\left(h_{soil,RZ} * \rho_{soil,RZ}\right)}$$

where Y_{crop} is the annual crop yield ($kg.m^{-2}$), Num_{crop} is the number of crops harvested annually (y^{-1}), CF_{crop} is the soil to crop concentration factor for the crop (Bq.kg^{-1} fresh weight / Bq.kg^{-1} dry soil).

Similarly, the radionuclide inventory $Soil_{DZ}$ (Bq) in an area is calculated using the differential equation:

Equation 28

$$\frac{dSoil_{DZ}}{dt} = (\lambda * Soil_{DZ}) + (Soil_{RZ} * \lambda_{Leach,RZ}) + (Soil_{RZ} * \lambda_{BioT,RZ}) + (Soil_{RZ} * \lambda_{RootU,RZ}) - (Soil_{DZ} * \lambda_{Leach,DZ}) - (Soil_{DZ} * \lambda_{Eros,DZ}) - (Soil_{DZ} * \lambda_{BioT,DZ})$$

Calculation of the Airborne radon Concentration

Radon release from a mineralised stockpile facility to the environment involves two mechanisms. The first is the liberation from the particle in which the radon is formed, which is characterised by the radon emanation coefficient. The second is the transport of radon through the bulk medium to the atmosphere, which is characterised by the diffusion coefficient in the bulk medium.

The release to the environment will also be affected by the presence of covering layers and the prevailing meteorological conditions. The flux from an uncovered stockpile facility is also directly related to the Ra-226 activity concentration, the emanation coefficient and the bulk density. If any of these variables increases, then the surface radon flux increases proportionally. The flux also increases as the diffusion coefficient increases. It has been shown that the thickness has no effect beyond about 2 to 4 m (IAEA, 1992).

The radon flux at the surface of stockpiles material $Flux_t$, (Bq.y^{-1}) with a surface area (m^2), uniform density ρ_b (kg.m^{-3}) and Ra-226 concentration C_{Ra} (Bq.g^{-1}) is presented by (IAEA, 2013):

Equation 29

$$Flux_t = Area \cdot C_{Ra} \cdot \rho_b \cdot E \cdot L_r \cdot \lambda \cdot \tanh \frac{z_r}{L_r}$$

where E is the emanation coefficient of the material (unitless) assumed to be 0.2, λ is the decay constant for Rn-222 (2.06E-06 s^{-1}), and z_r is the thickness of the facility (m). The parameter L_r is defined as the radon diffusion length, which is a function of the material-specific radon diffusion coefficient (D) and the decay constant for radon and is given by (IAEA, 2013):

Equation 30

$$L_r = \sqrt{\frac{D}{\lambda}}$$

The radon diffusion coefficient (D) is specific to the material and a function of its physical parameters. The effective radon diffusion coefficient in the open air is estimated at 1.10E-05 m^2.s^{-1}. Inside a material, it is proportional to the porosity and moisture saturation of the material. In different materials, the radon diffusion length can vary from low numbers (~ 0.2) to a maximum of approximately 1.4 m for high porosity materials that contain no moisture. The material-specific radon diffusion coefficient is estimated using the following empirical correlation derived from a database of measured effective diffusion coefficients (Rogers and Nielson, 1991):

Equation 31

$$D = D_0 n\, exp(-6Sn - 6S^{14n})$$

where D_0 denotes the radon diffusion coefficient in air, n denotes the porosity of the material and S is the saturation of the material. The thickness of the facility (z_r) is a parameter that is required for the radon flux calculation. However, the value of the term in Equation 29 that requires this parameter ($\tanh\frac{z_r}{L_r}$), changes very little over a layer thickness of 0.1 m to 4 m, where it is at its maximum value. Any thickness beyond 4 m results in a value approaching 1. To simplify the calculation, it is therefore conservatively assumed that the facility will be 5 meters or more. A thinner layer will only have the effect of reducing the radon exhalation rate. Alternatively, a much thicker layer (>10 m) will not significantly increase the radon exhalation rate calculated with an assumed 5 m thickness.

Placing a cover (e.g., a layer of sand or crushed rock) over a source of radon gas will reduce the rate at which radon is emitted to the atmosphere. The effect of a mine tailings cover or similar layer on the flux of radon from the facility is given by (IAEA, 2013):

Equation 32

$$F_c = \frac{2F_r \cdot e^{\left(\frac{-Z_c}{L_c}\right)}}{\left[1 + \frac{n_r L_r}{n_c L_c}\tanh\frac{z_r}{L_r}\right] + \left[1 - \frac{n_r L_r}{n_c L_c}\tanh\frac{z_r}{L_r}\right] e^{\left[-2\frac{z_c}{L_c}\right]}}$$

where the radon flux at the surface of the cover material F_c (Bq.m^{-2}.s^{-1}) is a function of the radon flux F_r (Bq.m^{-2}.s^{-1}) from the *uncovered* source material. F_c, is adjusted with the thickness of the cover material and rejects (z_c and z_r in meter), the radon diffusion lengths of the cover and rejects (L_c, and L_r in m), and the porosity of the cover and reject materials (n_c and n_r).

The associated airborne radon concentration at the surface of the stacked mineralogical material ($C_{Rn,air}$, Bq.m^{-3}) can be approximated by the following equation (Yu *et al.*, 2001):

Equation 33

$$C_{Rn,air} = \frac{F_c}{\lambda h}\left[1 - e^{-\frac{\lambda W}{2u}}\right]$$

Here, F_c is the radon flux at the surface of the tailings or cover (Bq.m^{-2}.s^{-1}), whichever applies, W is the width of the source perpendicular to the wind direction (m), u is the mean wind speed (m.s^{-1}), and h is the height for vertical mixing (taken as 2 m).

Appendix C:
Calculation Parameter Values

Table C 1 Dose conversion factors ($Sv.Bq^{-1}$) for inhalation exposure to various radionuclides, taken from RG-002 (NNR, 2013).

Radionuclide	0 to 1 year	1 to 2 years	2 to 7 years	7 to 12 years	12 to 17 years	Adult
Th-232	8.30E-05	8.10E-05	6.30E-05	5.00E-05	4.70E-05	4.50E-05
Ra-228	4.90E-05	4.80E-05	3.20E-05	2.00E-05	1.60E-05	1.60E-05
Th-228	1.80E-04	1.50E-04	8.30E-05	5.20E-05	3.60E-05	2.90E-05
Ra-224	1.20E-05	9.20E-06	5.90E-06	4.40E-06	4.20E-06	3.40E-06
U-238	2.90E-05	2.50E-05	1.60E-05	1.00E-05	8.70E-06	8.00E-06
U-234	3.30E-05	2.90E-05	1.90E-05	1.20E-05	1.00E-05	9.40E-06
Th-230	2.10E-04	2.00E-04	1.40E-04	1.10E-04	9.90E-05	1.00E-04
Ra-226	3.40E-05	2.90E-05	1.90E-05	1.20E-05	1.00E-05	9.50E-06
Pb-210	1.80E-05	1.80E-05	1.10E-05	7.20E-06	5.90E-06	5.60E-06
Po-210	1.80E-05	1.40E-05	8.60E-06	5.90E-06	5.10E-06	4.30E-06
U-235	3.00E-05	2.60E-05	1.70E-05	1.10E-05	9.20E-06	8.50E-06
Pa-231	2.20E-04	2.30E-04	1.90E-04	1.50E-04	1.50E-04	1.40E-04
Ac-227	1.70E-03	1.60E-03	1.00E-03	7.20E-04	5.60E-04	5.50E-04
Ra-223	3.20E-05	2.40E-05	1.50E-05	1.10E-05	1.10E-05	8.70E-06

Table C 2 Dose conversion factors ($Sv.Bq^{-1}$) for ingestion exposure to various radionuclides taken from RG-002 (NNR, 2013).

Radionuclide	0 to 1 year	1 to 2 years	2 to 7 years	7 to 12 years	12 to 17 years	Adult
Th-232	4.60E-06	4.50E-07	3.50E-07	2.90E-07	2.50E-07	2.30E-07
Ra-228	3.00E-05	5.70E-06	3.40E-06	3.90E-06	5.30E-06	6.90E-06
Th-228	3.70E-06	3.70E-07	2.20E-07	1.50E-07	9.40E-08	7.20E-08
Ra-224	2.70E-06	6.60E-07	3.50E-07	2.60E-07	2.00E-07	6.50E-08
U-238	3.40E-07	1.20E-07	8.00E-08	6.80E-08	6.70E-08	4.50E-08
U-234	3.70E-07	1.30E-07	8.80E-08	7.40E-08	7.40E-08	4.90E-08
Th-230	4.10E-06	4.10E-07	3.10E-07	2.40E-07	2.20E-07	2.10E-07
Ra-226	4.70E-06	9.60E-07	6.20E-07	8.00E-07	1.50E-06	2.80E-07
Pb-210	8.40E-06	3.60E-06	2.20E-06	1.90E-06	1.90E-06	6.90E-07
Po-210	2.60E-05	8.80E-06	4.40E-06	2.60E-06	1.60E-06	1.20E-06
U-235	3.50E-07	1.30E-07	8.50E-08	7.10E-08	7.00E-08	4.70E-08
Pa-231	1.30E-05	1.30E-06	1.10E-06	9.20E-07	8.00E-07	7.10E-07
Ac-227	3.30E-05	3.10E-06	2.20E-06	1.50E-06	1.20E-06	1.10E-06
Ra-223	5.30E-06	1.10E-06	5.71E-07	4.50E-07	3.70E-07	1.00E-07

Table C 3 External irradiation dose conversion factors for various radionuclides, taken from RG-002 (NNR, 2013).

Nuclide	Water Immersion	Air Submersion	Exposure to contaminated soil		
			Surface contamination	Contaminated to 15 cm deep	Contaminated to infinite depth
	$Sv.m^3.Bq^{-1}.s^{-1}$	$Sv.m^3.Bq^{-1}.s^{-1}$	$Sv.m^2.Bq^{-1}.s^{-1}$	$Sv.m^3.Bq^{-1}.s^{-1}$	$Sv.m^3.Bq^{-1}.s^{-1}$
Th-232	1.99E-20	8.72E-18	5.51E-19	2.78E-21	2.79E-21
Ra-228	-	-	-	-	-
Th-228	2.05E-19	9.20E-17	2.35E-18	4.17E-20	4.25E-20
Ra-224	1.03E-18	4.71E-16	9.57E-18	2.62E-19	2.74E-19
U-238	7.95E-21	3.41E-18	5.51E-19	5.52E-22	5.52E-22
U-234	1.75E-20	7.63E-18	7.48E-19	2.14E-21	2.15E-21
Th-230	3.94E-20	1.74E-17	7.50E-19	6.39E-21	6.47E-21
Ra-226	6.59E-19	3.15E-16	6.44E-18	1.65E-19	1.70E-19
Pb-210	1.31E-19	5.64E-17	2.13E-18	1.31E-20	1.31E-20
Po-210	9.03E-22	4.16E-19	8.29E-21	2.45E-22	2.80E-22
U-235	1.59E-17	7.20E-15	1.48E-16	3.75E-18	3.86E-18
Pa-231	-	-	-	-	-
Ac-227	1.30E-20	5.82E-18	1.57E-19	2.62E-21	2.65E-21
Ra-223	1.35E-17	6.09E-15	1.28E-16	3.10E-18	3.23E-18

Table C 4 Summary of daily inhaled volumes for different age groups as taken from RG-002 (NNR, 2013).

Age Group	Inhalation Rate ($m^3.day^{-1}$)
0 to 2 years	5.28
2 to 7 years	8.88
7 to 12 years	15.36
12 to 17 years	20.16
Adults	22.08

Table C 5 Ingestion rates for adult members of the public as proposed in RG-002 (NNR, 2013), compared to ranges of literature values.

Ingestion Pathway	Unit	RG-002	NUREG-5512 Vol. 4		
			Average	Minimum	Maximum
Water	$L.y^{-1}$	6.00E+02	4.78E+02	8.44E+01	1.84E+03
Milk		1.20E+02	2.33E+02	9.51E-01	1.21E+03
Soil	$kg.y^{-1}$	3.70E-02	1.83E-02	9.31E-04	3.58E-02
Grain		2.50E+02	1.44E+01	1.62E-01	9.70E+01
Fruit		-	5.28E+01	1.24E-01	6.53E+02
Leafy Vegetables		-	2.14E+01	3.58E-02	2.13E+02
Root Vegetables		-	4.46E+01	3.41E-01	3.79E+02
Meat (beef)		3.00E+01	3.98E+01	1.20E-01	2.22E+02
Meat (mutton)		2.50E+01	-	-	-
Meat (pork)		2.00E+01	-	-	-
Poultry		5.00E+01	2.53E+01	5.77E-01	7.29E+01
Eggs		1.50E+01	1.91E+01	2.62E-01	1.21E+02

Table C 6 Ingestion rates for different age groups as defined from the adult ingestion rates.

Ingestion Pathway	Unit	Ingestion Rates for Different Age Groups				
		0 - 2 Years	2 - 7 Years	7 - 12 Years	12 – 17 Years	Adult
% of Adult Rate	-	40	50	60	85	100
Water	L.y^{-1}	2.40E+02	3.00E+02	3.60E+02	5.10E+02	6.00E+02
Milk		4.80E+01	6.00E+01	7.20E+01	1.02E+02	1.20E+02
Soil	kg.y^{-1}	1.48E-02	1.85E-02	2.22E-02	3.15E-02	3.70E-02
Grain		1.00E+01	1.25E+01	1.50E+01	2.130E+01	2.50E+01
Fruit		2.11E+01	2.64E+01	3.17E+01	4.49E+01	5.28E+01
Leafy Vegetables		8.56E+00	1.07E+01	1.28E+01	1.82E+01	2.14E+01
Root Vegetables		1.78E+01	2.23E+01	2.68E+01	3.79E+01	4.46E+01
Meat (beef)		1.20E+01	1.50E+01	1.80E+01	2.55E+01	3.00E+01
Meat (mutton)		1.00E+01	1.25E+01	1.50E+01	2.13E+01	2.50E+01
Meat (pork)		8.00E+00	1.00E+01	1.20E+01	1.70E+01	2.00E+01
Poultry		2.00E+01	2.50E+01	3.00E+01	4.25E+01	5.00E+01
Eggs		6.00E+00	7.50E+00	9.00E+00	1.28E+01	1.50E+01

Table C 7 Parameters used in describing radionuclide uptake in plants and crops.

Parameter	Unit	Root	Leafy	Fruit	Cereal	Forage	Grain	Hay
Crop Yield	kg.m^{-2}	2.4E+00	2.9E+00	2.4E+00	3.9E-01	1.9E+00	6.6E-01	1.9E+00
Growing Period	Days	9.0E+01	4.5E+01	9.0E+01	9.0E+01	3.E+01	9.0E+01	4.5E+01
Translocation Factor	-	1.0E-01	1.0E+00	1.0E-01	1.0E-01	1.0E+00	1.0E-01	1.0E+00
Food processing	-	9.0E-01	9.0E-01	9.0E-01	9.0E-01	0.0E+00	0.0E+00	0.0E+00
Weathering rates	y^{-1}	1.8E+01	1.8E+01	1.8E+01	1.8E+01	1.8E+01	1.8E+01	1.8E+01
Crop Interception Factor	-	3.0E-01	3.0E-01	3.0E-01	3.0E-01	3.0E-01	3.0E-01	3.0E-01
Soil contamination of crop	-	2.0E-03	1.2E-03	4.0E-03	3.4E-03	1.0E-03	1.0E-03	1.0E-03
Mass Interception Factor	m^{-2}.kg^{-1}	3.0E-01	3.0E-01	3.0E-01	3.0+00	3.0+00	3.0+00	3.0+00

Table C 8 Annual water, soil and fodder consumption rates by animals (beef, sheep, goats, pigs, and poultry) compiled from various sources.

Water	Fodder	Soil	Reference
Beef Water (L.d^{-1}), Soil and Fodder (kg.d^{-1}) Consumption Rates			
75	16	1.25	RG-002
60	55 (wet)	0.6-	(IAEA, 2003)
80	10	0.6	(Kozak and Stenhouse, 2002)
20 to 200	9 to 300	0.1 to 2.2	(Kozak and Stenhouse, 2002)
35.6	33	1.5	(Penfold *et al.*, 1999)
20 to 100	10 to 25	-	(IAEA, 1994a)
50 to 60	25	0.5	(IAEA, 2003)
Sheep/Pig Water (L.d^{-1}), Soil and Fodder (kg.d^{-1}) Consumption Rates			Reference
15	1.5	0.8	RG-002
3 to 10	0.5 to 3.5	-	(IAEA, 1994a)
Poultry Water (L.d^{-1}), Soil and Fodder (kg.d^{-1}) Consumption Rates			Reference
0.3	0.15	-	RG-002
0.1 to 0.3	0.05 to 0.15	-	(IAEA, 1994a)
0.3	0.15	0.01	

Table C 9 Soil to secondary crop concentration factors (Bq.kg^{-1} crop per Bq.kg^{-1} dry soil) compiled from various sources.

U	Th	Ra	Pb	Po	Pa	Ac	Reference
Leafy Vegetables							
2.0E-02	1.2E-03	9.1E-02	8.0E-02	7.4E-03	-	-	RG-002[1]
1.0E-03	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(IAEA, 2003)
8.3E-04	1.8E-04	4.9E-03	1.0E-03	1.1E-05	1.1E-04	1.1E-04	(De Beer, *et al.*, 2002)
3.0E-04	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(Kozak and Stenhouse, 2002)
1.0E-03	5.0E-04	4.0E-02	1.0E-02	2.0E-04	2.1E-02	3.2E-04	(Penfold *et al.*, 1999)
1.7E-03	3.6E-04	9.8E-03	2.0E-03	2.4E-04	9.4E-05	9.4E-05	(Staven *et al.*, 2003)
Root Vegetables							Reference
8.4E-03	8.0E-04	7.0E-02	1.5E-02	5.8E-03	-	-	RG-002[1]
1.0E-03	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(IAEA, 2003)
2.2E-03	4.8E-05	7.8E-03	1.6E-03	1.8E-05	1.8E-04	1.8E-04	(De Beer, *et al.*, 2002)
3.0E-04	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(Kozak and Stenhouse, 2002)
1.0E-03	5.0E-04	3.0E-01	6.0E-02	2.0E-04	2.0E-02	6.0E-04	(Penfold *et al.*, 1999)
3.0E-03	8.5E-05	5.0E-04	1.5E-03	1.8E-03	8.8E-05	8.5E-05	(Staven *et al.*, 2003)
Fruit							Reference
1.5E-02	7.8E-04	1.7E-02	1.5E-02	1.9E-04	-	-	RG-002[2]
2.2E-03	4.8E-05	7.8E-03	1.6E-03	1.8E-05	1.8E-04	1.8E-04	(De Beer, *et al.*, 2002)
7.2E-04	4.5E-05	1.1E-03	1.8E-03	2.2E-04	4.5E-05	4.5E-05	(Staven *et al.*, 2003)
Cereal							Reference
1.5E-02	6.4E-05	2.4E-03	1.2E-03	2.4E-04	-	-	RG-002[1,3]
1.0E-04	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(IAEA, 2003)
1.1E-03	2.9E-05	1.0E-03	4.0E-03	4.4E-04	4.4E-04	4.4E-04	(De Beer, *et al.*, 2002)
1.0E-04	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(Kozak and Stenhouse, 2002)
1.0E-04	1.0E-03	4.0E-02	1.0E-02	2.0E-04	1.3E-02	1.9E-04	(Penfold *et al.*, 1999)
1.2E-03	3.1E-05	1.1E-03	4.3E-03	2.1E-03	2.0E-05	2.0E-05	(Staven *et al.*, 2003)
Grain (Animal Feed)							Reference
7.8E-03	1.8E-03	1.8E-02	2.8E-03	2.4E-04	-	-	RG-002[1,4]
1.2E-03	3.1E-05	1.1E-03	4.3E-03	2.1E-03	2.0E-05	2.0E-05	(Staven *et al.*, 2003)
Forage, Hay (Animal Feed)							Reference
4.6E-02	9.9E-02	7.1E-02	9.2E-02	1.2E-01	-	-	RG-002[1]
1.0E-03	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(IAEA, 2003)
2.3E-02	1.1E-02	8.0E-02	1.1E-03	2.0E-02	2.0E-02	2.0E-02	(De Beer, *et al.*, 2002)
8.0E-03	5.0E-04	4.0E-02	1.0E-02	2.0E-04	4.0E-02	1.0E-03	(Kozak and Stenhouse, 2002)
5.0E-04	5.0E-04	4.0E-02	1.0E-02	2.0E-04	3.2E-02	4.8E-04	(Penfold *et al.*, 1999)
8.3E-03	1.8E-03	4.9E-02	1.0E-02	1.2E-03	4.7E-04	4.7E-04	(Staven *et al.*, 2003)
Average Crop Concentration Factors							Reference
2.7E-03	3.9E-04	1.0E-02	4.0E-03	1.3E-03	1.2E-04	1.2E-04	(Staven *et al.*, 2003)

(1) Concentration factors from RG-002 are given on basis of dry weight concentration in the plant to the dry weight concentration in the soil, (2) RG-002 values for fruit given as wet weight concentration in fruit per dry weight concentration in soil. (3) Values for grain from RG-002 are specifically for maize. (4) The animal feed from grain is for maize stalks and roots, which are commonly used as animal feed.

Table C 10 Transfer coefficients from the animal feed to animal products in d.kg^{-1} and d.L^{-1} compiled from various sources.

U	Th	Ra	Pb	Po	Pa	Ac	Reference
Transfer Coefficients for Meat (d.kg^{-1})							
3.9E-04	2.3E-04	1.7E-03	7.0E-04	5.0E-03	-	-	RG-002 (Beef)
3.0E-02	5.0E-03	5.0E-03	7.1E-03	5.0E-03	-	-	RG-002 (Mutton)
3.0E-04	2.7E-03	9.0E-04	4.0E-04	5.0E-03	5.0E-05	1.6E-04	(IAEA, 2003)
3.4E-04	9.0E-04	9.4E-04	4.0E-04	5.0E-03	5.0E-03	5.0E-03	(De Beer, *et al.*, 2002)
6.0E-04	2.7E-03	1.3E-03	1.0E-02	4.0E-03	5.0E-05	1.6E-04	(Kozak and Stenhouse, 2002)
3.0E-04	2.7E-03	9.0E-04	4.0E-04	5.0E-03	2.6E-05	1.6E-04	(Penfold *et al.*, 1999)
3.0E-04	4.0E-05	9.0E-04	4.0E-04	5.0E-03	4.0E-05	4.0E-04	(Staven *et al.*, 2003)
Transfer Coefficients for Milk (d.L^{-1})							Reference
1.8E-03	5.0E-06	3.8E-04	1.9E-04	2.1E-04	-	-	RG-002
4.0E-04	5.0E-06	1.3E-03	3.0E-04	3.4E-04	5.0E-06	4.0E-07	(IAEA, 2003)
4.0E-04	1.7E-06	1.3E-03	2.0E-04	1.0E-03	1.0E-03	1.0E-03	(De Beer, *et al.*, 2002)
3.7E-04	5.0E-06	1.3E-03	3.0E-04	3.0E-04	5.0E-06	4.0E-07	(Kozak and Stenhouse, 2002)
4.0E-04	5.0E-06	1.3E-03	2.7E-04	3.4E-04	5.0E-06	4.0E-07	(Penfold *et al.*, 1999)
4.0E-04	5.0E-06	1.3E-03	2.6E-04	3.4E-04	5.0E-06	2.0E-05	(Staven *et al.*, 2003)
Transfer Coefficients for Poultry (d.kg^{-1})							Reference
7.5E-01	4.0E-03	9.9E-04	2.0E-03	2.4E+00	-	-	RG-002
3.0E-04	9.0E-04	9.0E-04	4.0E-04	5.0E-03	5.0E-03	5.0E-03	(De Beer, *et al.*, 2002)
1.0E+00	6.0E-03	3.0E-02	8.0E-01	2.3E+00	6.0E-03	6.0E-03	(Staven *et al.*, 2003)
Transfer Coefficients for Eggs (d.kg^{-1})							Reference
1.1E+00	2.0E-03	2.0E-05	2.0E-03	3.1E+00	-	-	RG-002
1.0E+00	2.0E-03	2.0E-05	2.0E-03	1.8E-02	1.8E-02	1.8E-02	(De Beer *et al.*, 2002)
1.0E+00	4.0E-03	3.1E-01	1.0E+00	7.0E+00	4.0E-03	4.0E-03	(Staven *et al.*, 2003)

Table C 11 Occupancy factors taken from RG-002 (NNR, 2013).

Activity	0 – 2 Years	2 – 7 Years	7 – 12 Years	12 – 17 Years	Adult
Time spent indoors	7 914	7 775	7 568	7 665	7 050
Time spent outdoors	846	985	1 192	1 092	1 710
Working on contaminated sediments and land	0	0	0	0	2 000
Playing on contaminated sediments and land	200	383	383	300	0
Swimming	19.2	27.4	30.2	27.8	9
Boating	0	78	76	110	170
Fishing	0	78	76	110	170

Appendix D:
Conceptual Representation of the Groundwater Model in Ecolego

The *System Level* model that was used to evaluate the contribution of the groundwater pathway was implemented in Ecolego® Version 6 (http://ecolego.facilia.se/ecolego/show/HomePage). A conceptual representation of the different compartments of the *System Level* Model is presented in Figure D 1 to Figure D 5.

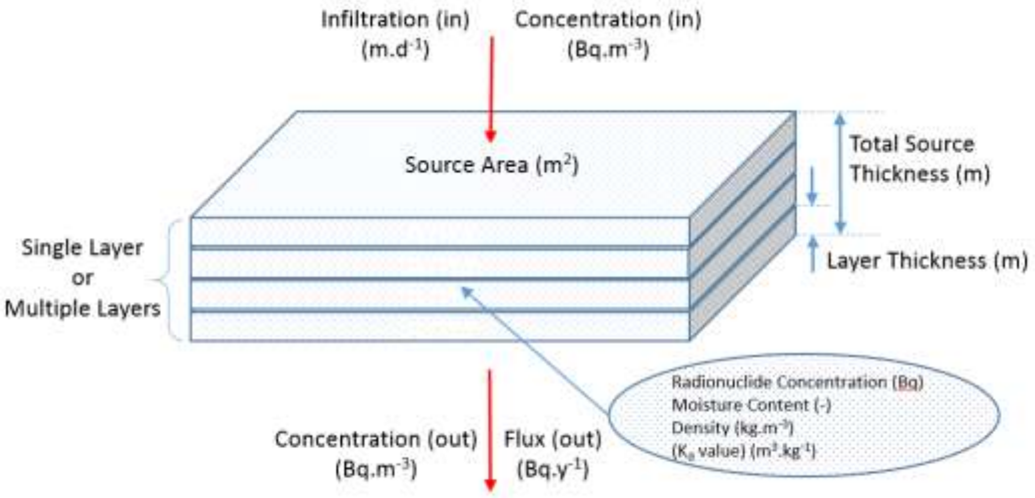

Figure D 1 Conceptual representation and associated parameters values for the source term model.

Figure D 1 shows that the source term model is a function of the radionuclide specific activity concentration (Bq), the volumetric moisture content ($m^3.m^{-3}$), the dry bulk density of the source material ($kg.m^{-3}$), and the radio element-specific distribution coefficient or K_d-value ($m^3.kg^{-1}$). The advective transfer coefficient that represents the loss of radionuclides from the total source, or from one layer to the next, is given by the model described in IAEA (2004b) and Baes and Sharp (1983):

Equation 34

$$\lambda_w = \frac{I_w}{\theta_w H_w R_w}$$

where I_w is the infiltration rate to the source layer ($m.y^{-1}$), θ_w is the soil moisture content in the source (unitless) and H_w is the thickness of source (m) R_w is the retardation coefficient in the source (unitless):

Equation 35

$$R_w = 1 + \frac{\rho_w K_{dw}}{\theta_w}$$

where, ρ_w is the soil bulk density in the source ($kg.m^{-3}$) and $K_{d,w}$ is the sorption distribution coefficient in the source ($m^3.kg^{-1}$). For multiple layers with different properties, the transfer coefficient is defined for each layer with its associated parameters values. Figure D 1 shows that the output from the source term model is the radionuclide concentration ($Bq.m^{-3}$) or flux ($Bq.y^{-1}$) leaving the compartment.

The transfer coefficient accounting for the effect of dispersion in transport from compartment *i* to compartment *j* ($\lambda_{D,ij}$, y^{-1}) is calculated using the following equation (IAEA, 2004b):

Equation 36

$$\lambda_{D,ij} = \frac{\alpha_L}{H_i} \cdot \lambda_{w,ij}$$

where α_L *i*s the longitudinal dispersivity (m) and H_i is the compartment thickness. Note that the transfer coefficient in Equation 36 represents the dispersion of radionuclides between the compartments in both directions.

Figure D 2 shows that the unsaturated zone model is a function of the volumetric moisture content ($m^3.m^{-3}$) and the dry bulk density of the unsaturated zone ($kg.m^{-3}$), the radioelement specific distribution coefficient or K_d-value ($m^3.kg^{-1}$) for the unsaturated soils, as well as the dispersivity (m). The advective and dispersive transfer coefficients that represent the transfer and loss of radionuclides from the unsaturated zone to the saturated zone (aquifer) is similar to those presented in Equation 34 to Equation 36, except that it is for the unsaturated zone parameter values.

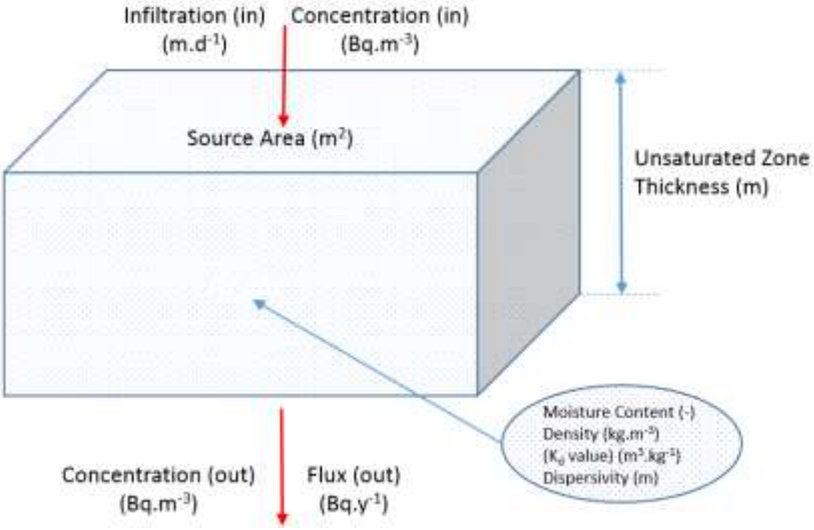

Figure D 2 Conceptual representation and associated parameters values for the unsaturated zone model.

Figure D 3 is a simplified representation of the aquifer mixing zone and the most important parameters. The infiltration rate ($m.y^{-1}$) is assumed constant (i.e. steady-state conditions) and equal to the infiltration rate to the unsaturated zone. The radionuclide concentration ($Bq.m^{-3}$) of water (moisture) entering the mixing zone is equal to the concentration flowing from the unsaturated zone. It is assumed that the mixing zone is represented as one compartment of known thickness. The area is the same as that of the source, while the depth is equal to the aquifer thickness.

The water entering the mixing zone may contain a radionuclide concentration, but it is assumed that the radionuclide concentration ($Bq.m^{-3}$) of the water is zero. The Darcy velocity ($m.y^{-1}$)

defines the flow rate entering the mixing zone and that flow rate through the zone. The output after mixing defines the concentration (Bq.m^{-3}) and flux (Bq.y^{-1}) into the flow tube (aquifer).

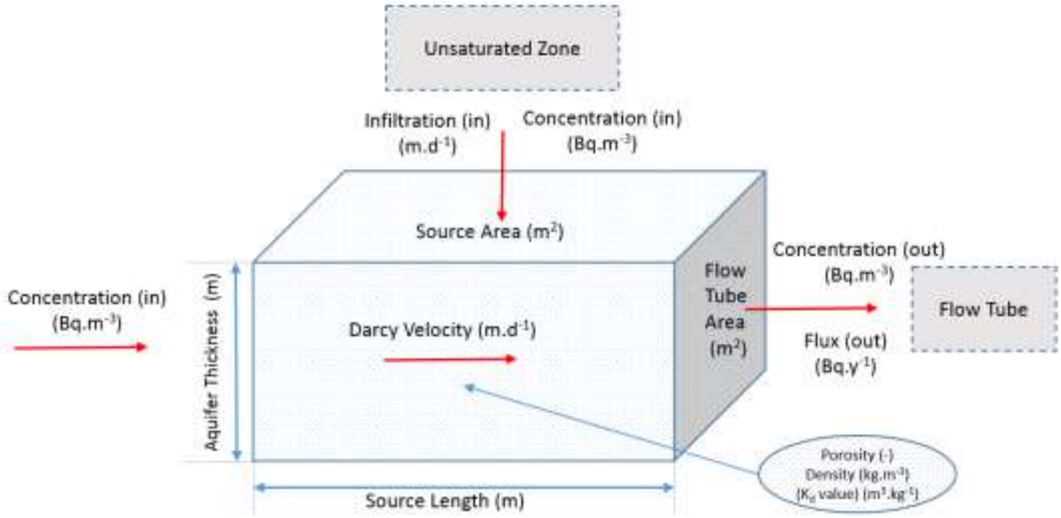

Figure D 3 Conceptual representation and associated parameters values for the aquifer mixing zone model.

Figure D 3 shows that the aquifer mixing zone model is a function of the Darcy velocity (m.y^{-1}), the dry bulk density of the aquifer (kg.m^{-3}), and the radio element-specific distribution coefficient or K_d-value (m^3.kg^{-1}) for the aquifer.

The radionuclide concentration (Bq.m^{-3}) of water entering the aquifer compartment is equal to the outflow concentration from the aquifer mixing zone. The Darcy velocity (m.y^{-1}) in the aquifer is assumed to be constant with time. The output at the receptor point defines the concentration (Bq.m^{-3}) and flux (Bq.y^{-1}) at the borehole.

Figure D 3 shows that the aquifer model is a function of the Darcy velocity (m.y^{-1}), the aquifer porosity, the dry bulk density of the aquifer (kg.m^{-3}), the radioelement specific distribution coefficient or K_d-value (m^3.kg^{-1}) for the aquifer, and the dispersivity (m). The advective and dispersive transfer coefficients that represent the transfer and loss of radionuclides from the aquifer is similar to those presented in Equation 34 to Equation 36, except that it is for the aquifer parameter values.

The concentration of the water abstracted from the borehole is simplistically taken as the sum of the flow tube concentration (Bq.m^{-3}) multiplied by the fraction of the borehole intersect the plume, and the background concentration (Bq.m^{-3}) multiplied with the fraction intersect the uncontaminated water. As a conservative assumption, it is assumed that the whole screen intersection the contaminant plume.

Figure D 5 is a simplified representation of the borehole abstraction module and the most important parameters.

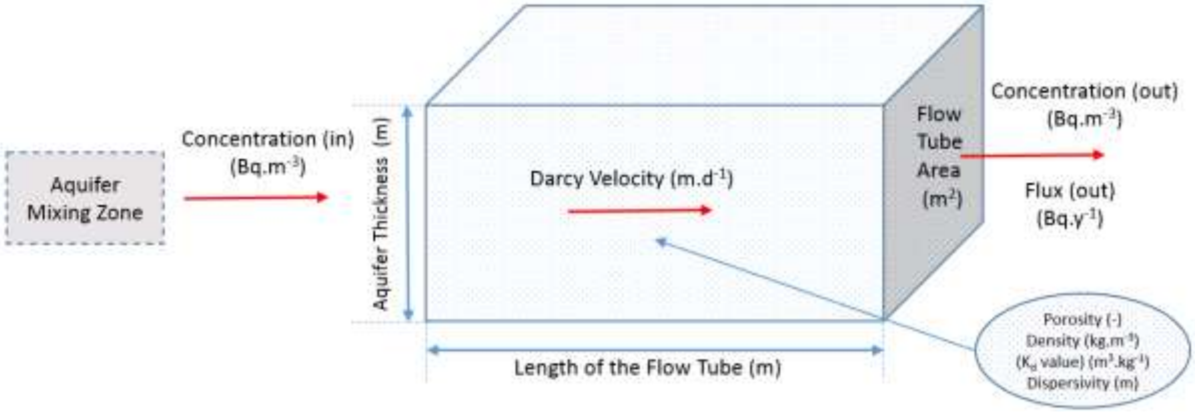

Figure D 4 Conceptual representation and associated parameters values for the aquifer (saturated zone) model.

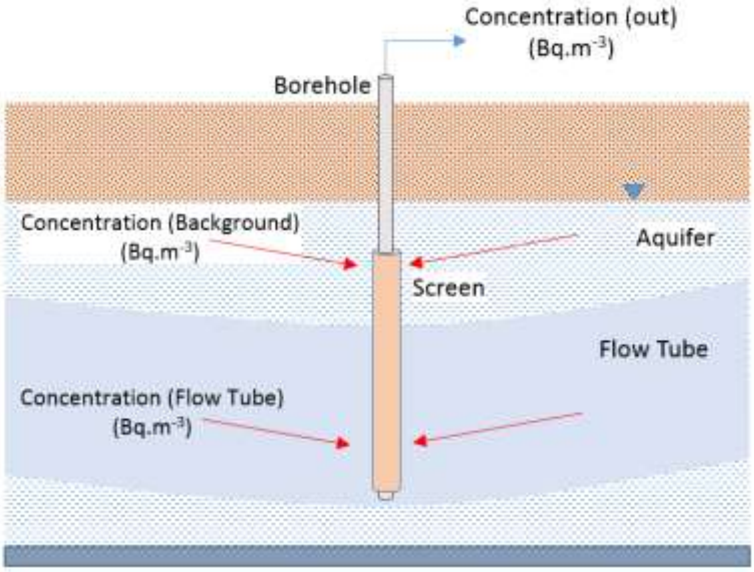

Figure D 5 Conceptual representation and associated parameters values for the borehole abstraction model.

Appendix E:
Gamma Radiation Survey Results

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
2726	0.30	1.70	20.93	3.60	14.62	27.60	-26.872857	26.884523
2727	0.50	0.10	1.23	8.70	35.32	36.70	-26.872857	26.884525
2728	0.40	1.90	23.40	4.90	19.89	34.40	-26.872855	26.88453
2729	0.50	1.10	13.54	4.70	19.08	30.30	-26.872855	26.884532
2730	0.50	2.00	24.63	4.60	18.68	35.70	-26.872965	26.884472
2731	0.40	1.30	16.01	4.70	19.08	30.40	-26.873145	26.884308
2732	0.30	2.30	28.32	6.20	25.17	40.50	-26.87324	26.884177
2733	0.30	2.80	34.48	3.00	12.18	32.80	-26.873327	26.884102
2734	0.20	1.90	23.40	6.80	27.61	38.20	-26.873442	26.883967
2735	0.40	2.00	24.63	6.00	24.36	38.60	-26.873583	26.883802
2736	0.20	1.50	18.47	5.70	23.14	32.40	-26.87374	26.883658
2737	0.30	0.70	8.62	5.50	22.33	26.80	-26.87384	26.883447
2738	0.20	3.30	40.63	4.90	19.89	39.90	-26.873965	26.883132
2739	0.40	2.40	29.55	4.10	16.65	35.20	-26.874013	26.882793
2740	0.60	1.50	18.47	7.00	28.42	42.40	-26.87402	26.882562
2741	0.40	1.90	23.40	4.40	17.86	32.80	-26.874022	26.882315
2742	0.40	0.90	11.08	7.90	32.07	38.20	-26.874023	26.882002
2743	0.40	2.10	25.86	4.90	19.89	35.50	-26.874032	26.881785
2744	0.20	2.30	28.32	7.00	28.42	41.30	-26.874043	26.881612
2745	0.50	0.40	4.93	7.90	32.07	35.90	-26.87404	26.881425
2746	0.40	0.90	11.08	4.90	19.89	28.40	-26.874025	26.88118
2747	0.10	2.40	29.55	4.90	19.89	33.70	-26.874068	26.88094
2748	0.40	1.80	22.16	4.90	19.89	33.10	-26.874063	26.880625
2749	0.50	1.20	14.78	7.10	28.83	38.50	-26.874085	26.880315
2750	0.60	0.80	9.85	5.20	21.11	30.80	-26.87409	26.88003
2751	0.50	1.40	17.24	3.30	13.40	27.90	-26.874128	26.879703
2752	0.30	1.30	16.01	8.40	34.10	41.80	-26.874188	26.87942
2753	0.30	2.80	34.48	5.90	23.95	42.50	-26.874242	26.879257
2754	0.40	1.60	19.70	6.50	26.39	37.40	-26.874303	26.878902
2755	0.40	2.00	24.63	5.70	23.14	37.50	-26.874352	26.878587
2756	0.40	2.20	27.09	4.30	17.46	34.90	-26.874248	26.87845
2757	0.50	1.10	13.54	3.80	15.43	28.00	-26.87426	26.878422
2758	0.40	0.70	8.62	6.80	27.61	32.80	-26.874232	26.878108
2759	0.30	0.50	6.16	5.50	22.33	26.30	-26.874068	26.877868
2760	0.30	1.80	22.16	4.10	16.65	30.30	-26.873873	26.877582
2761	0.50	1.90	23.40	3.00	12.18	30.10	-26.873728	26.87721
2762	0.50	1.40	17.24	3.80	15.43	30.20	-26.873565	26.876845
2763	0.50	1.30	16.01	4.60	18.68	32.20	-26.873452	26.87656
2764	0.30	2.30	28.32	3.30	13.40	30.90	-26.873283	26.876172
2765	0.40	1.30	16.01	2.20	8.93	23.10	-26.873162	26.875843
2766	0.30	1.80	22.16	3.00	12.18	26.40	-26.873055	26.875623
2767	0.40	1.40	17.24	3.60	14.62	27.00	-26.872905	26.875397
2768	0.40	1.40	17.24	3.60	14.62	27.20	-26.87271	26.87518
2769	0.40	0.70	8.62	3.10	12.59	21.40	-26.87248	26.874973
2770	0.20	2.10	25.86	3.80	15.43	29.20	-26.872302	26.874818
2771	0.50	1.10	13.54	1.40	5.68	20.60	-26.872135	26.874617
2772	0.30	1.70	20.93	3.00	12.18	25.90	-26.871943	26.874383
2773	0.60	1.80	22.16	4.10	16.65	34.30	-26.870793	26.87164
2774	0.40	1.50	18.47	3.80	15.43	29.10	-26.870795	26.87135
2775	0.30	3.60	44.33	3.20	12.99	38.60	-26.870873	26.870995
2776	0.40	2.00	24.63	4.40	17.86	33.90	-26.870928	26.870658
2777	0.30	1.50	18.47	2.80	11.37	23.00	-26.87098	26.870362
2778	0.60	2.60	32.01	3.50	14.21	37.50	-26.871045	26.869997
2779	0.50	0.50	6.16	3.10	12.59	21.20	-26.871105	26.869727
2780	0.20	1.90	23.40	6.00	24.36	35.00	-26.871097	26.869412
2781	0.50	1.60	19.70	5.70	23.14	37.20	-26.871118	26.869123
2782	0.40	1.40	17.24	5.50	22.33	33.50	-26.87117	26.868783

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
2783	0.70	1.20	14.78	6.80	27.61	40.50	-26.8712	26.868387
2784	0.40	1.30	16.01	4.70	19.08	29.70	-26.871282	26.86802
2785	0.50	1.10	13.54	5.70	23.14	33.90	-26.87128	26.867778
2786	0.40	1.70	20.93	5.20	21.11	34.50	-26.871278	26.86756
2787	0.70	0.80	9.85	4.70	19.08	31.30	-26.871272	26.867245
2788	0.40	2.70	33.25	3.80	15.43	36.00	-26.871272	26.866937
2789	0.50	1.60	19.70	7.60	30.86	44.00	-26.87125	26.866643
2790	0.50	0.30	3.69	5.80	23.55	29.40	-26.871137	26.866447
2791	0.40	2.00	24.63	8.60	34.92	48.20	-26.871043	26.866212
2792	0.60	2.00	24.63	6.20	25.17	43.00	-26.870902	26.865985
2793	0.50	3.20	39.40	7.30	29.64	51.70	-26.870812	26.86581
2794	0.60	2.10	25.86	7.30	29.64	47.90	-26.870675	26.86559
2795	0.40	1.70	20.93	6.00	24.36	37.10	-26.870563	26.865422
2796	0.50	1.70	20.93	6.00	24.36	38.00	-26.870488	26.865283
2797	0.50	1.70	20.93	4.40	17.86	34.30	-26.870375	26.865102
2798	0.70	2.70	33.25	6.40	25.98	50.10	-26.870242	26.864915
2799	0.60	1.80	22.16	3.80	15.43	34.40	-26.87014	26.864733
2800	0.50	2.10	25.86	5.70	23.14	40.60	-26.870033	26.864557
2801	0.60	1.80	22.16	4.60	18.68	36.80	-26.869868	26.864363
2802	0.50	2.60	32.01	4.10	16.65	38.00	-26.869698	26.864143
2803	0.40	2.20	27.09	5.40	21.92	38.70	-26.869627	26.864052
2804	0.60	2.10	25.86	4.30	17.46	38.00	-26.86951	26.863858
2805	1.00	1.30	16.01	8.40	34.10	52.20	-26.869385	26.863688
2806	1.00	1.00	12.31	7.90	32.07	47.80	-26.869353	26.86366
2807	0.90	1.20	14.78	9.50	38.57	52.60	-26.869353	26.86366
2808	1.00	2.60	32.01	6.40	25.98	54.30	-26.869353	26.863658
2809	0.80	2.60	32.01	9.70	39.38	61.00	-26.869343	26.863573
2810	0.70	2.00	24.63	3.00	12.18	33.40	-26.870227	26.863253
2811	0.80	2.60	32.01	4.30	17.46	43.70	-26.870378	26.863413
2812	0.40	2.50	30.78	3.80	15.43	34.80	-26.870422	26.86351
2813	0.40	3.10	38.17	4.00	16.24	39.80	-26.8705	26.863688
2814	0.40	3.20	39.40	5.90	23.95	46.90	-26.870583	26.863847
2815	1.00	2.50	30.78	4.00	16.24	44.60	-26.87067	26.864062
2816	0.50	2.60	32.01	7.00	28.42	48.40	-26.870798	26.86429
2817	0.40	1.20	14.78	7.10	28.83	37.90	-26.87095	26.864547
2818	0.70	2.50	30.78	4.80	19.49	43.60	-26.871083	26.864727
2819	0.70	1.50	18.47	5.20	21.11	37.30	-26.871195	26.864908
2820	0.80	1.40	17.24	6.20	25.17	42.60	-26.871197	26.864923
2821	0.40	2.00	24.63	8.70	35.32	47.60	-26.871312	26.8651
2822	0.70	1.20	14.78	7.30	29.64	42.70	-26.871407	26.865265
2823	0.60	2.00	24.63	6.80	27.61	44.40	-26.871548	26.865537
2824	0.30	2.60	32.01	7.00	28.42	44.30	-26.871735	26.865843
2825	0.50	2.90	35.71	3.20	12.99	36.70	-26.871937	26.866225
2826	0.40	1.60	19.70	4.10	16.65	30.80	-26.872122	26.86657
2827	0.30	3.50	43.10	4.80	19.49	43.10	-26.872273	26.866867
2828	0.70	1.70	20.93	7.80	31.67	47.60	-26.8732	26.868258
2829	0.60	0.80	9.85	5.50	22.33	33.10	-26.873317	26.868493
2830	0.50	2.00	24.63	6.00	24.36	40.80	-26.87344	26.868787
2831	0.60	1.90	23.40	7.30	29.64	45.80	-26.873572	26.869053
2832	0.50	1.70	20.93	7.00	28.42	42.10	-26.873662	26.869283
2833	0.50	1.30	16.01	8.10	32.89	42.50	-26.873758	26.869493
2834	0.60	0.80	9.85	8.20	33.29	41.00	-26.873805	26.86964
2835	0.50	2.40	29.55	7.30	29.64	47.40	-26.873912	26.869818
2836	0.40	1.60	19.70	7.60	30.86	41.60	-26.874058	26.870023
2837	0.60	1.70	20.93	4.10	16.65	33.20	-26.874152	26.870183
2838	0.50	2.00	24.63	4.30	17.46	35.40	-26.874232	26.870307
2839	0.60	0.20	2.46	6.60	26.80	31.80	-26.874335	26.870452

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
2840	0.40	2.00	24.63	4.90	19.89	35.00	-26.87446	26.870638
2841	0.40	1.80	22.16	5.70	23.14	36.90	-26.874605	26.870863
2842	0.60	1.00	12.31	5.50	22.33	34.20	-26.874678	26.871015
2843	0.40	1.70	20.93	2.80	11.37	26.10	-26.87476	26.871125
2844	0.40	1.50	18.47	4.70	19.08	30.50	-26.874878	26.871318
2845	0.30	2.20	27.09	8.40	34.10	46.50	-26.874978	26.871515
2846	0.50	1.70	20.93	7.30	29.64	43.20	-26.875105	26.871723
2847	0.30	1.80	22.16	3.60	14.62	28.80	-26.875258	26.871992
2848	0.40	1.50	18.47	5.40	21.92	34.90	-26.875348	26.8722
2849	0.50	0.90	11.08	5.20	21.11	30.40	-26.875457	26.872515
2850	0.50	1.70	20.93	6.00	24.36	38.10	-26.875505	26.872672
2851	0.40	1.40	17.24	8.90	36.13	45.10	-26.875542	26.872833
2852	0.30	1.20	14.78	3.60	14.62	24.50	-26.87562	26.873035
2853	0.50	2.40	29.55	5.10	20.71	40.40	-26.875683	26.873252
2854	0.40	2.50	30.78	4.60	18.68	37.10	-26.875722	26.87338
2855	0.40	2.80	34.48	4.00	16.24	38.20	-26.8758	26.87364
2856	0.50	0.80	9.85	5.20	21.11	29.50	-26.875877	26.873867
2857	0.30	1.90	23.40	6.00	24.36	37.20	-26.87597	26.874128
2858	0.40	1.40	17.24	7.10	28.83	38.50	-26.876045	26.87434
2859	0.40	2.60	32.01	3.00	12.18	32.80	-26.876138	26.874612
2860	0.10	2.50	30.78	3.50	14.21	30.10	-26.876238	26.874837
2861	0.20	2.20	27.09	4.10	16.65	31.00	-26.876288	26.875028
2862	0.30	1.50	18.47	5.50	22.33	33.40	-26.876352	26.875207
2863	0.40	1.20	14.78	5.50	22.33	32.60	-26.876435	26.875455
2864	0.40	1.60	19.70	2.80	11.37	26.50	-26.876532	26.875677
2865	0.30	1.60	19.70	3.30	13.40	25.90	-26.877107	26.877292
2866	0.30	1.30	16.01	6.00	24.36	33.50	-26.877228	26.877522
2867	0.30	1.60	19.70	4.70	19.08	29.80	-26.8773	26.877722
2868	0.30	3.00	36.94	3.50	14.21	35.40	-26.877425	26.877985
2869	0.50	0.80	9.85	4.70	19.08	28.30	-26.877533	26.878257
2870	0.40	1.20	14.78	5.50	22.33	31.30	-26.877613	26.87845
2871	0.40	0.80	9.85	6.60	26.80	33.10	-26.87767	26.878563
2872	0.50	1.20	14.78	4.40	17.86	29.60	-26.877738	26.878828
2873	0.50	1.30	16.01	3.80	15.43	29.10	-26.87789	26.879155
2874	0.30	2.60	32.01	4.60	18.68	37.00	-26.878023	26.879472
2875	0.20	2.10	25.86	2.50	10.15	25.70	-26.878098	26.879692
2876	0.40	1.50	18.47	5.70	23.14	34.80	-26.878207	26.879907
2877	0.30	0.60	7.39	5.80	23.55	27.60	-26.878392	26.880195
2878	0.30	1.40	17.24	3.00	12.18	24.40	-26.87854	26.880428
2879	0.30	1.80	22.16	7.60	30.86	41.70	-26.878625	26.880662
2880	0.40	2.00	24.63	5.40	21.92	36.80	-26.878798	26.880898
2881	0.60	1.50	18.47	5.70	23.14	37.40	-26.878962	26.881175
2882	0.70	1.00	12.31	6.50	26.39	39.00	-26.879137	26.881453
2883	0.40	1.50	18.47	7.30	29.64	41.00	-26.879295	26.881703
2884	0.50	2.10	25.86	5.70	23.14	39.60	-26.879362	26.881827
2885	0.40	1.70	20.93	5.70	23.14	36.10	-26.879313	26.881827
2886	0.50	1.70	20.93	7.60	30.86	43.80	-26.879312	26.881828
2887	0.30	2.00	24.63	8.40	34.10	46.10	-26.879308	26.881832
2888	0.30	2.10	25.86	6.20	25.17	38.60	-26.879307	26.881832
2889	0.30	1.60	19.70	8.40	34.10	42.20	-26.879305	26.881833
2890	0.50	1.90	23.40	4.40	17.86	34.60	-26.879305	26.881835
2891	0.40	0.90	11.08	4.90	19.89	28.20	-26.879435	26.881822
2892	0.30	2.60	32.01	4.90	19.89	38.20	-26.879733	26.881732
2893	0.40	1.30	16.01	4.90	19.89	30.20	-26.880048	26.88163
2894	0.40	2.30	28.32	3.00	12.18	31.70	-26.880283	26.881522
2895	0.10	2.40	29.55	7.90	32.07	43.40	-26.880287	26.88152
2896	0.30	1.70	20.93	5.20	21.11	33.50	-26.880445	26.881343

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
2897	0.40	2.20	27.09	7.60	30.86	45.50	-26.88042	26.881198
2898	0.50	2.00	24.63	4.10	16.65	33.80	-26.880392	26.88107
2899	0.50	1.70	20.93	4.10	16.65	31.70	-26.880365	26.880943
2900	0.40	2.20	27.09	4.60	18.68	35.30	-26.880305	26.88071
2901	0.40	1.50	18.47	6.50	26.39	37.30	-26.88024	26.88046
2902	0.30	1.10	13.54	5.20	21.11	28.80	-26.88017	26.88026
2903	0.50	1.20	14.78	4.40	17.86	29.10	-26.880095	26.880013
2904	0.60	1.60	19.70	4.10	16.65	32.70	-26.880035	26.879828
2905	0.30	1.70	20.93	5.50	22.33	33.20	-26.879968	26.879647
2906	0.50	1.30	16.01	7.90	32.07	42.30	-26.879863	26.879405
2907	0.60	2.00	24.63	4.90	19.89	37.80	-26.879773	26.879163
2908	0.50	0.50	6.16	8.40	34.10	38.50	-26.879635	26.878882
2909	0.70	1.10	13.54	6.00	24.36	37.40	-26.879533	26.878642
2910	0.30	1.70	20.93	7.60	30.86	40.80	-26.879433	26.878407
2911	0.30	1.90	23.40	5.20	21.11	35.00	-26.879332	26.878163
2912	0.40	1.70	20.93	5.20	21.11	34.80	-26.879268	26.877985
2913	0.40	2.60	32.01	4.90	19.89	38.40	-26.879203	26.877783
2914	0.40	1.30	16.01	7.60	30.86	38.70	-26.879115	26.877532
2915	0.30	1.70	20.93	7.30	29.64	39.00	-26.879052	26.87733
2916	0.60	1.70	20.93	5.20	21.11	37.00	-26.879003	26.877143
2917	0.30	3.20	39.40	5.70	23.14	44.00	-26.878953	26.876932
2918	0.20	2.10	25.86	6.00	24.36	37.40	-26.878873	26.876662
2919	0.50	0.90	11.08	4.90	19.89	30.90	-26.878762	26.876468
2920	0.40	1.90	23.40	6.20	25.17	39.40	-26.87888	26.87629
2921	0.40	2.10	25.86	3.50	14.21	32.60	-26.878908	26.87604
2922	0.50	1.40	17.24	6.80	27.61	38.90	-26.878597	26.873787
2923	0.30	2.00	24.63	3.80	15.43	30.70	-26.87851	26.873417
2924	0.70	1.40	17.24	4.90	19.89	36.10	-26.878388	26.872958
2925	0.50	1.90	23.40	2.70	10.96	29.10	-26.87824	26.87249
2926	0.30	1.00	12.31	5.20	21.11	28.70	-26.878058	26.87208
2927	0.50	2.00	24.63	6.00	24.36	40.50	-26.877895	26.871708
2928	0.60	2.30	28.32	5.10	20.71	41.70	-26.87777	26.87147
2929	0.50	1.60	19.70	3.30	13.40	29.80	-26.877598	26.871145
2930	0.50	2.30	28.32	6.20	25.17	43.00	-26.877398	26.870818
2931	0.40	2.70	33.25	4.10	16.65	36.80	-26.877237	26.87055
2932	0.40	2.00	24.63	6.50	26.39	40.80	-26.877098	26.870267
2933	0.40	1.40	17.24	5.20	21.11	32.50	-26.876985	26.869983
2934	0.50	2.00	24.63	4.90	19.89	36.30	-26.876872	26.869727
2935	0.50	1.40	17.24	5.40	21.92	35.10	-26.876755	26.869472
2936	0.30	1.80	22.16	5.70	23.14	35.60	-26.87665	26.86925
2937	0.40	2.90	35.71	4.80	19.49	41.90	-26.876573	26.869012
2938	0.80	1.60	19.70	5.70	23.14	42.20	-26.876462	26.868755
2939	0.50	0.60	7.39	8.20	33.29	38.70	-26.876378	26.868473
2940	0.70	1.20	14.78	6.20	25.17	39.00	-26.876275	26.868158
2941	0.70	1.50	18.47	6.50	26.39	42.20	-26.876172	26.867835
2942	0.60	1.30	16.01	6.80	27.61	40.00	-26.876048	26.867525
2943	0.40	1.40	17.24	8.10	32.89	42.10	-26.875958	26.867298
2944	0.40	1.10	13.54	6.80	27.61	36.30	-26.875823	26.867002
2945	0.50	2.80	34.48	5.90	23.95	46.40	-26.875688	26.866688
2946	0.40	1.50	18.47	5.50	22.33	34.40	-26.875563	26.86644
2947	0.30	0.60	7.39	8.50	34.51	37.10	-26.87545	26.866185
2948	0.40	2.00	24.63	6.00	24.36	38.50	-26.87537	26.865978
2949	0.40	3.10	38.17	3.80	15.43	39.80	-26.875297	26.86581
2950	0.70	2.70	33.25	4.00	16.24	41.80	-26.875233	26.865645
2951	0.40	2.40	29.55	7.80	31.67	47.10	-26.875183	26.865502
2952	0.40	4.40	54.18	5.90	23.95	53.40	-26.875143	26.865342
2953	0.40	1.70	20.93	8.10	32.89	44.40	-26.87505	26.865092

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
2954	0.30	2.30	28.32	5.20	21.11	37.20	-26.874948	26.86483
2955	0.70	1.50	18.47	8.40	34.10	47.70	-26.87486	26.864587
2956	0.70	1.90	23.40	4.60	18.68	38.70	-26.874773	26.864377
2957	0.50	1.40	17.24	7.30	29.64	41.20	-26.874677	26.864148
2958	0.60	2.10	25.86	5.90	23.95	43.40	-26.874603	26.863983
2959	0.80	2.90	35.71	5.90	23.95	50.60	-26.874517	26.863732
2960	0.50	3.30	40.63	7.80	31.67	55.20	-26.874407	26.86343
2961	0.40	2.70	33.25	2.70	10.96	33.00	-26.874305	26.863192
2962	0.60	0.50	6.16	6.80	27.61	35.10	-26.87422	26.862937
2963	0.50	3.00	36.94	4.00	16.24	40.50	-26.874167	26.862827
2964	0.40	1.10	13.54	5.20	21.11	30.30	-26.874167	26.862825
2965	0.60	2.10	25.86	4.90	19.89	39.80	-26.874207	26.862715
2966	0.60	2.80	34.48	3.80	15.43	40.40	-26.87442	26.86264
2967	0.70	1.40	17.24	4.10	16.65	34.30	-26.874613	26.862588
2968	0.20	2.50	30.78	4.90	19.89	35.80	-26.874813	26.862518
2969	0.60	2.10	25.86	3.00	12.18	32.80	-26.87508	26.862432
2970	0.50	1.40	17.24	6.00	24.36	37.40	-26.875273	26.862377
2971	0.30	2.30	28.32	4.30	17.46	33.90	-26.875387	26.862348
2972	0.10	1.50	18.47	5.70	23.14	30.80	-26.875418	26.862562
2973	0.70	1.20	14.78	6.20	25.17	39.60	-26.87551	26.862842
2974	0.90	2.00	24.63	5.40	21.92	44.50	-26.875587	26.863077
2975	0.50	1.70	20.93	7.00	28.42	42.40	-26.875642	26.863318
2976	0.70	1.40	17.24	8.10	32.89	47.20	-26.875707	26.86356
2977	0.70	1.30	16.01	6.50	26.39	40.60	-26.875805	26.86376
2978	0.50	1.90	23.40	7.30	29.64	44.20	-26.875948	26.864007
2979	0.60	2.50	30.78	4.60	18.68	40.80	-26.876047	26.86421
2980	0.40	2.40	29.55	5.10	20.71	38.50	-26.87616	26.864403
2981	0.70	1.30	16.01	5.70	23.14	37.20	-26.876258	26.864643
2982	0.60	3.10	38.17	7.50	30.45	54.50	-26.876363	26.864833
2983	0.60	2.30	28.32	5.70	23.14	43.50	-26.876517	26.865037
2984	0.30	1.30	16.01	7.90	32.07	39.30	-26.876647	26.865273
2985	0.40	2.50	30.78	5.40	21.92	39.70	-26.876807	26.865487
2986	1.00	1.00	12.31	7.00	28.42	44.80	-26.876935	26.86567
2987	0.90	0.80	9.85	8.10	32.89	45.40	-26.877113	26.865902
2988	0.40	1.90	23.40	7.30	29.64	43.00	-26.877298	26.866098
2989	0.50	1.20	14.78	8.70	35.32	43.30	-26.877492	26.866352
2990	0.80	1.70	20.93	4.10	16.65	37.20	-26.877668	26.866577
2991	0.50	0.10	1.23	4.70	19.08	24.20	-26.877858	26.866805
2992	0.50	1.50	18.47	3.80	15.43	30.60	-26.878072	26.867082
2993	0.40	1.20	14.78	5.20	21.11	31.40	-26.878313	26.867393
2994	0.60	0.60	7.39	6.80	27.61	34.90	-26.87847	26.867712
2995	0.60	1.40	17.24	5.40	21.92	36.30	-26.878605	26.867968
2996	0.50	1.40	17.24	5.20	21.11	34.30	-26.878735	26.868195
2997	0.50	1.30	16.01	5.70	23.14	35.00	-26.87881	26.86833
2998	0.50	2.40	29.55	5.40	21.92	40.40	-26.878925	26.868515
2999	0.40	1.90	23.40	5.20	21.11	36.00	-26.879062	26.86874
3000	0.30	2.10	25.86	9.70	39.38	50.60	-26.879175	26.868968
3001	0.50	2.20	27.09	6.80	27.61	44.20	-26.879303	26.869197
3002	0.40	1.30	16.01	6.30	25.58	34.90	-26.87941	26.869397
3003	0.70	0.50	6.16	6.00	24.36	33.20	-26.879577	26.86966
3004	0.30	2.40	29.55	5.10	20.71	37.30	-26.879698	26.869945
3005	0.40	1.90	23.40	7.30	29.64	43.20	-26.879832	26.870207
3006	0.50	1.40	17.24	6.80	27.61	39.10	-26.879965	26.870457
3007	0.60	1.30	16.01	4.60	18.68	33.30	-26.880093	26.870725
3008	0.50	3.20	39.40	6.40	25.98	50.00	-26.8803	26.871107
3009	0.80	1.00	12.31	4.40	17.86	33.00	-26.8804	26.871292
3010	0.40	1.80	22.16	4.60	18.68	33.40	-26.880617	26.871593

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
3011	0.40	2.30	28.32	4.60	18.68	36.90	-26.88073	26.871733
3012	0.50	1.70	20.93	5.40	21.92	36.00	-26.880875	26.871932
3013	0.80	1.20	14.78	5.20	21.11	36.90	-26.881037	26.872172
3014	0.60	1.40	17.24	6.00	24.36	39.10	-26.881202	26.872418
3015	0.50	1.10	13.54	3.90	15.83	27.80	-26.88133	26.872607
3016	0.40	2.10	25.86	3.00	12.18	29.80	-26.881485	26.872853
3017	0.50	2.10	25.86	3.80	15.43	33.50	-26.881667	26.873115
3018	0.10	2.80	34.48	6.20	25.17	40.70	-26.88184	26.873395
3019	0.50	1.80	22.16	5.70	23.14	38.60	-26.882025	26.87369
3020	0.10	2.90	35.71	4.90	19.89	37.20	-26.882197	26.873943
3021	0.60	1.30	16.01	4.40	17.86	32.40	-26.882355	26.874207
3022	0.40	1.50	18.47	4.90	19.89	32.30	-26.882468	26.874407
3023	0.40	3.20	39.40	3.80	15.43	40.20	-26.882513	26.874438
3024	0.40	1.30	16.01	6.80	27.61	36.30	-26.882497	26.874477
3025	0.70	1.40	17.24	5.70	23.14	38.60	-26.882508	26.874565
3026	0.50	2.40	29.55	6.50	26.39	44.60	-26.88263	26.874775
3027	0.60	1.40	17.24	5.20	21.11	35.70	-26.882753	26.87502
3028	0.50	1.30	16.01	4.90	19.89	32.50	-26.882867	26.875207
3029	0.30	1.60	19.70	3.80	15.43	28.10	-26.882853	26.875178
3030	0.40	1.60	19.70	4.60	18.68	32.20	-26.882852	26.875178
3031	0.60	1.40	17.24	4.40	17.86	32.50	-26.882853	26.875177
3032	0.30	1.20	14.78	4.70	19.08	27.40	-26.882853	26.875177
3033	0.40	1.50	18.47	7.10	28.83	39.20	-26.882853	26.875177
3034	0.30	2.20	27.09	5.40	21.92	37.50	-26.882853	26.875177
3035	0.40	1.80	22.16	4.90	19.89	33.30	-26.882855	26.875177
3036	0.40	2.70	33.25	4.30	17.46	38.50	-26.882855	26.875175
3037	0.40	2.10	25.86	5.40	21.92	38.40	-26.882855	26.875175
3038	0.50	1.60	19.70	5.20	21.11	34.90	-26.882857	26.875173
3039	0.40	2.40	29.55	4.10	16.65	36.00	-26.882858	26.875173
3040	0.30	2.70	33.25	4.30	17.46	36.00	-26.882858	26.875172
3041	0.30	1.80	22.16	5.40	21.92	34.00	-26.882858	26.875172
3042	0.20	2.80	34.48	4.60	18.68	35.60	-26.882858	26.875172
3043	0.20	1.90	23.40	7.10	28.83	38.80	-26.882858	26.875172
3044	0.50	1.30	16.01	4.60	18.68	32.50	-26.88286	26.875172
3045	0.50	2.60	32.01	4.60	18.68	40.20	-26.882858	26.875172
3046	0.40	1.60	19.70	4.10	16.65	30.30	-26.882858	26.875172
3047	0.30	2.50	30.78	5.40	21.92	38.70	-26.882858	26.875172
3048	0.40	0.30	3.69	6.30	25.58	29.20	-26.882858	26.875172
3049	0.50	1.40	17.24	5.40	21.92	34.80	-26.882858	26.875172
3050	0.50	0.40	4.93	6.00	24.36	29.70	-26.882858	26.875172
3051	0.20	2.10	25.86	4.90	19.89	33.00	-26.882858	26.875173
3052	0.40	1.80	22.16	5.70	23.14	36.60	-26.882858	26.875173
3053	0.30	2.20	27.09	4.40	17.86	33.60	-26.88286	26.875175
3054	0.30	2.00	24.63	3.80	15.43	30.60	-26.88286	26.875175
3055	0.40	1.30	16.01	4.40	17.86	29.60	-26.88286	26.875175
3056	0.30	2.00	24.63	5.40	21.92	35.20	-26.88286	26.875175
3057	0.50	0.30	3.69	6.00	24.36	28.90	-26.88286	26.875175
3058	0.40	1.70	20.93	6.50	26.39	39.50	-26.882862	26.875175
3059	0.20	1.70	20.93	8.40	34.10	42.30	-26.882862	26.875175
3060	0.50	1.80	22.16	4.60	18.68	34.80	-26.882862	26.875173
3061	0.30	2.40	29.55	5.20	21.11	36.80	-26.882863	26.875173
3062	0.40	1.70	20.93	4.40	17.86	31.50	-26.882863	26.875173
3063	0.60	1.50	18.47	4.90	19.89	35.40	-26.882863	26.875173
3064	0.20	2.60	32.01	7.80	31.67	45.60	-26.88284	26.875158
3065	0.30	1.90	23.40	5.20	21.11	34.20	-26.882887	26.875128
3066	0.20	3.20	39.40	5.10	20.71	41.40	-26.882892	26.875127
3067	0.30	2.00	24.63	6.00	24.36	37.10	-26.882893	26.875127

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
3068	0.50	0.70	8.62	5.80	23.55	30.70	-26.882892	26.87513
3069	0.50	1.80	22.16	4.10	16.65	33.30	-26.883015	26.875147
3070	0.40	0.40	4.93	5.20	21.11	26.20	-26.883098	26.875173
3071	0.10	1.50	18.47	3.30	13.40	22.80	-26.883102	26.875282
3072	0.40	1.60	19.70	7.10	28.83	40.20	-26.882933	26.875463
3073	0.40	1.10	13.54	6.00	24.36	33.00	-26.882973	26.875773
3074	0.40	1.70	20.93	7.10	28.83	40.60	-26.883087	26.876137
3075	0.20	2.90	35.71	4.60	18.68	37.70	-26.883212	26.876437
3076	0.50	2.40	29.55	4.30	17.46	38.10	-26.88332	26.876703
3077	0.50	2.60	32.01	5.90	23.95	44.00	-26.88344	26.876968
3078	0.40	2.20	27.09	5.40	21.92	39.00	-26.883608	26.877325
3079	0.70	0.50	6.16	6.00	24.36	33.70	-26.883828	26.877795
3080	0.40	1.10	13.54	3.30	13.40	25.30	-26.884023	26.878175
3081	0.40	2.70	33.25	4.10	16.65	37.30	-26.884237	26.878542
3082	0.40	1.50	18.47	5.70	23.14	35.10	-26.88443	26.878838
3083	0.60	0.60	7.39	6.60	26.80	34.70	-26.884663	26.879205
3084	0.30	1.10	13.54	7.40	30.04	36.30	-26.884903	26.879557
3085	0.40	0.80	9.85	4.90	19.89	28.30	-26.884927	26.879597
3086	0.60	1.50	18.47	4.90	19.89	35.40	-26.884925	26.879597
3087	0.60	1.70	20.93	3.30	13.40	32.00	-26.88504	26.879552
3088	0.50	1.40	17.24	4.90	19.89	33.60	-26.885473	26.879412
3089	0.40	2.00	24.63	3.80	15.43	32.20	-26.885895	26.879223
3090	0.40	1.30	16.01	3.60	14.62	26.90	-26.8862	26.879203
3091	0.50	2.60	32.01	5.10	20.71	41.30	-26.886155	26.879057
3092	0.20	1.80	22.16	2.80	11.37	24.30	-26.886065	26.878805
3093	0.40	1.60	19.70	2.50	10.15	25.90	-26.885963	26.878472
3094	0.30	1.00	12.31	6.30	25.58	31.90	-26.885853	26.878175
3095	0.40	1.70	20.93	4.40	17.86	31.70	-26.885775	26.877937
3096	0.50	0.60	7.39	6.30	25.58	32.90	-26.885678	26.87768
3097	0.40	1.30	16.01	6.80	27.61	37.70	-26.885595	26.877507
3098	0.50	2.50	30.78	5.90	23.95	43.50	-26.88547	26.87724
3099	0.30	2.10	25.86	8.10	32.89	44.40	-26.88535	26.876945
3100	0.40	1.70	20.93	4.40	17.86	32.20	-26.88524	26.876697
3101	0.70	1.20	14.78	9.20	37.35	48.80	-26.885203	26.876598
3102	0.40	2.70	33.25	6.50	26.39	45.40	-26.8852	26.87654
3103	0.50	2.20	27.09	6.50	26.39	43.70	-26.885088	26.876313
3104	0.40	2.20	27.09	3.30	13.40	30.60	-26.884923	26.876073
3105	0.30	2.60	32.01	7.30	29.64	46.10	-26.884702	26.875757
3106	0.30	1.10	13.54	6.60	26.80	32.90	-26.884547	26.875497
3107	0.50	1.70	20.93	3.30	13.40	29.50	-26.884433	26.875358
3108	0.40	2.00	24.63	3.50	14.21	30.70	-26.884432	26.875357
3109	0.30	1.80	22.16	3.30	13.40	26.80	-26.88441	26.875307
3110	0.20	2.00	24.63	4.10	16.65	29.20	-26.884377	26.875233
3111	0.10	2.80	34.48	4.90	19.89	36.80	-26.884357	26.8752
3112	0.60	1.80	22.16	3.80	15.43	33.80	-26.884323	26.875143
3113	0.50	1.90	23.40	6.80	27.61	42.30	-26.884255	26.874935
3114	0.30	1.70	20.93	6.50	26.39	37.80	-26.884235	26.87476
3115	0.40	3.10	38.17	6.50	26.39	47.70	-26.884082	26.8747
3116	0.40	1.50	18.47	5.70	23.14	35.40	-26.884093	26.874693
3117	0.40	2.00	24.63	8.10	32.89	45.60	-26.884037	26.874547
3118	0.50	1.90	23.40	7.30	29.64	43.70	-26.884042	26.874253
3119	0.40	2.60	32.01	11.60	47.10	61.50	-26.883992	26.87395
3120	0.40	1.50	18.47	7.10	28.83	39.40	-26.883877	26.873537
3121	0.30	2.20	27.09	4.60	18.68	34.10	-26.883747	26.873057
3122	0.60	1.30	16.01	5.70	23.14	35.90	-26.88357	26.87256
3123	0.30	1.40	17.24	6.80	27.61	36.60	-26.883435	26.872082
3124	0.30	0.80	9.85	4.40	17.86	24.20	-26.883288	26.871577

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
3125	0.50	3.00	36.94	3.00	12.18	37.70	-26.883158	26.871097
3126	0.60	1.80	22.16	5.70	23.14	39.70	-26.88295	26.87058
3127	0.60	2.20	27.09	5.40	21.92	42.50	-26.882728	26.870088
3128	0.60	2.20	27.09	5.10	20.71	41.20	-26.882588	26.869803
3129	0.60	1.80	22.16	6.00	24.36	40.10	-26.882413	26.869502
3130	0.40	2.80	34.48	6.20	25.17	45.40	-26.882245	26.869255
3131	0.50	1.60	19.70	8.90	36.13	47.60	-26.881987	26.868852
3132	0.50	2.90	35.71	6.50	26.39	47.70	-26.881803	26.868532
3133	0.60	0.80	9.85	9.20	37.35	44.50	-26.881635	26.868272
3134	0.40	1.90	23.40	6.00	24.36	37.70	-26.881443	26.867995
3135	0.50	1.90	23.40	6.80	27.61	42.70	-26.88121	26.867668
3136	0.50	2.40	29.55	6.50	26.39	44.90	-26.881007	26.867335
3137	0.50	3.20	39.40	4.80	19.49	44.20	-26.880767	26.867018
3138	0.60	2.80	34.48	4.30	17.46	41.40	-26.880498	26.86665
3139	0.70	1.80	22.16	6.00	24.36	41.60	-26.88023	26.866232
3140	0.50	1.60	19.70	7.90	32.07	44.00	-26.879928	26.865892
3141	0.70	2.50	30.78	3.80	15.43	40.40	-26.879628	26.865533
3142	0.40	3.30	40.63	5.40	21.92	45.50	-26.879277	26.865192
3143	0.50	1.90	23.40	5.20	21.11	36.90	-26.878948	26.864885
3144	0.40	2.90	35.71	6.50	26.39	46.70	-26.878665	26.864595
3145	1.00	3.10	38.17	9.90	40.19	68.50	-26.87838	26.864325
3146	0.60	1.70	20.93	8.40	34.10	48.30	-26.878247	26.864173
3147	0.50	2.20	27.09	4.90	19.89	39.00	-26.877928	26.863875
3148	0.40	0.70	8.62	9.00	36.54	40.30	-26.8779	26.863845
3149	0.20	3.00	36.94	6.70	27.20	45.80	-26.877867	26.863832
3150	0.50	1.10	13.54	7.60	30.86	40.40	-26.877988	26.863695
3151	0.40	3.20	39.40	5.90	23.95	47.30	-26.878287	26.863637
3152	0.40	2.50	30.78	7.30	29.64	46.00	-26.878697	26.863468
3153	0.40	2.90	35.71	7.30	29.64	49.10	-26.879142	26.863292
3154	0.60	1.40	17.24	8.70	35.32	47.20	-26.879258	26.86327
3155	0.50	1.90	23.40	7.80	31.67	46.60	-26.879395	26.863467
3156	0.70	2.50	30.78	6.50	26.39	48.70	-26.879543	26.863668
3157	0.40	2.40	29.55	6.50	26.39	42.80	-26.879665	26.863887
3158	0.50	2.40	29.55	7.80	31.67	48.90	-26.879853	26.864217
3159	0.50	3.40	41.86	5.60	22.74	49.10	-26.879977	26.864462
3160	0.60	2.40	29.55	6.20	25.17	45.70	-26.880115	26.864725
3161	0.50	3.10	38.17	8.30	33.70	56.00	-26.880265	26.864982
3162	0.60	1.60	19.70	6.00	24.36	39.40	-26.880468	26.86517
3163	0.60	2.20	27.09	6.20	25.17	44.20	-26.88066	26.865378
3164	0.50	1.90	23.40	8.40	34.10	47.90	-26.880875	26.865622
3165	0.40	1.90	23.40	7.00	28.42	42.80	-26.881112	26.865868
3166	0.40	2.00	24.63	5.40	21.92	36.80	-26.881322	26.866108
3167	0.50	1.70	20.93	7.00	28.42	42.60	-26.88155	26.866378
3168	0.40	2.80	34.48	6.20	25.17	44.60	-26.881758	26.866615
3169	0.40	2.50	30.78	5.90	23.95	42.70	-26.881943	26.866882
3170	0.50	2.20	27.09	7.00	28.42	44.70	-26.882123	26.867157
3171	0.40	4.10	50.48	7.70	31.26	58.80	-26.882345	26.867463
3172	0.70	1.80	22.16	3.50	14.21	33.80	-26.883435	26.868998
3173	0.30	1.40	17.24	4.40	17.86	29.00	-26.883748	26.869365
3174	0.40	1.80	22.16	5.20	21.11	35.40	-26.883977	26.869673
3175	0.40	2.10	25.86	5.40	21.92	37.40	-26.88422	26.869962
3176	0.40	1.90	23.40	4.40	17.86	32.30	-26.884442	26.870242
3177	0.40	1.90	23.40	3.60	14.62	30.40	-26.884672	26.870508
3178	0.40	1.00	12.31	6.60	26.80	34.00	-26.884933	26.870843
3179	0.50	1.40	17.24	6.80	27.61	39.60	-26.885162	26.871215
3180	0.60	0.40	4.93	9.30	37.76	41.60	-26.885345	26.871503
3181	0.30	2.80	34.48	3.80	15.43	35.30	-26.885507	26.871833

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
3182	0.40	1.50	18.47	7.30	29.64	40.00	-26.885638	26.872108
3183	0.30	2.50	30.78	4.90	19.89	37.40	-26.885752	26.872357
3184	0.30	2.80	34.48	9.40	38.16	54.20	-26.885818	26.872665
3185	0.30	3.00	36.94	5.70	23.14	42.60	-26.885895	26.873053
3186	0.30	2.20	27.09	6.50	26.39	39.90	-26.885938	26.873262
3187	0.40	1.40	17.24	7.10	28.83	38.00	-26.88598	26.87355
3188	0.50	2.00	24.63	4.90	19.89	37.30	-26.88606	26.87384
3189	0.70	1.70	20.93	2.50	10.15	30.80	-26.886118	26.874177
3190	0.20	2.40	29.55	3.50	14.21	30.20	-26.886143	26.874397
3191	0.50	0.30	3.69	7.10	28.83	32.70	-26.886112	26.874443
3192	0.40	1.50	18.47	10.30	41.82	49.20	-26.886102	26.874658
3193	0.30	2.50	30.78	6.80	27.61	43.60	-26.886088	26.874792
3194	0.40	1.10	13.54	7.40	30.04	37.90	-26.886142	26.875028
3195	0.20	1.20	14.78	7.10	28.83	35.00	-26.886217	26.87533
3196	0.40	1.60	19.70	6.00	24.36	35.90	-26.886327	26.87566
3197	0.40	2.70	33.25	7.50	30.45	48.80	-26.88643	26.87588
3198	0.60	3.10	38.17	4.00	16.24	43.30	-26.886552	26.876102
3199	0.50	2.60	32.01	6.50	26.39	46.80	-26.88668	26.876327
3200	0.20	1.80	22.16	9.80	39.79	47.50	-26.886797	26.876585
3201	0.40	1.20	14.78	7.10	28.83	37.70	-26.886987	26.876895
3202	0.60	1.90	23.40	6.20	25.17	42.00	-26.887117	26.877122
3203	0.40	2.60	32.01	7.00	28.42	46.40	-26.8873	26.87736
3204	0.40	1.00	12.31	6.00	24.36	32.20	-26.887465	26.877597
3205	0.50	1.90	23.40	6.20	25.17	40.00	-26.887675	26.87782
3206	0.50	2.70	33.25	4.90	19.89	41.50	-26.887882	26.87812
3207	0.70	1.30	16.01	3.60	14.62	30.90	-26.888083	26.87832
3208	0.50	0.90	11.08	6.30	25.58	34.90	-26.888142	26.878377
3209	0.60	1.00	12.31	7.30	29.64	39.50	-26.888417	26.878257
3210	0.70	0.50	6.16	7.40	30.04	37.90	-26.888807	26.87807
3211	0.50	0.70	8.62	6.30	25.58	32.50	-26.889172	26.877983
3212	0.50	0.70	8.62	6.00	24.36	31.80	-26.889412	26.877872
3213	0.50	2.70	33.25	4.60	18.68	40.10	-26.889432	26.877783
3214	0.40	2.00	24.63	4.10	16.65	33.30	-26.88936	26.877492
3215	0.40	1.60	19.70	7.90	32.07	41.80	-26.88928	26.877248
3216	0.50	0.70	8.62	6.80	27.61	35.30	-26.889232	26.87699
3217	0.40	2.50	30.78	4.90	19.89	38.40	-26.889125	26.876695
3218	0.80	1.30	16.01	6.00	24.36	40.10	-26.889043	26.87643
3219	0.50	1.30	16.01	6.30	25.58	37.30	-26.888977	26.876195
3220	0.50	0.70	8.62	7.10	28.83	36.00	-26.888885	26.875883
3221	0.50	2.10	25.86	5.70	23.14	39.90	-26.888822	26.875657
3222	0.30	2.80	34.48	5.70	23.14	41.10	-26.888752	26.875403
3223	0.30	1.40	17.24	6.00	24.36	34.10	-26.888682	26.875148
3224	0.30	1.30	16.01	7.60	30.86	37.20	-26.8886	26.87496
3225	0.60	1.90	23.40	5.40	21.92	39.20	-26.888577	26.874725
3226	0.40	1.30	16.01	6.80	27.61	36.70	-26.888543	26.874657
3227	0.60	1.00	12.31	5.70	23.14	35.20	-26.888408	26.874397
3228	0.30	1.90	23.40	3.60	14.62	28.30	-26.888255	26.874113
3229	0.40	1.40	17.24	4.90	19.89	31.60	-26.88806	26.873925
3230	0.10	1.80	22.16	5.50	22.33	31.00	-26.888005	26.873815
3231	0.60	0.80	9.85	6.80	27.61	36.60	-26.88797	26.873665
3232	0.50	1.50	18.47	3.60	14.62	29.80	-26.888012	26.873277
3233	0.40	1.70	20.93	4.40	17.86	32.50	-26.88799	26.873065
3234	0.30	2.30	28.32	4.10	16.65	33.60	-26.887897	26.872773
3235	0.10	1.90	23.40	7.30	29.64	38.70	-26.887768	26.87245
3236	0.50	2.10	25.86	4.90	19.89	37.80	-26.887637	26.872147
3237	0.50	1.90	23.40	4.40	17.86	33.80	-26.8875	26.87185
3238	0.40	1.20	14.78	6.30	25.58	35.10	-26.887345	26.87152

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
3239	0.50	1.70	20.93	5.20	21.11	35.50	-26.887272	26.87131
3240	0.50	1.30	16.01	8.40	34.10	43.80	-26.887148	26.87105
3241	0.60	1.70	20.93	5.40	21.92	38.00	-26.886987	26.87068
3242	0.50	2.10	25.86	5.40	21.92	39.30	-26.886825	26.870308
3243	0.50	1.60	19.70	6.00	24.36	37.20	-26.88667	26.869967
3244	0.60	0.60	7.39	7.40	30.04	38.00	-26.886455	26.869582
3245	0.50	1.00	12.31	6.00	24.36	33.70	-26.886288	26.869255
3246	0.50	2.50	30.78	4.90	19.89	40.60	-26.886183	26.868898
3247	0.60	2.30	28.32	4.60	18.68	39.20	-26.886118	26.868612
3248	0.50	0.90	11.08	5.70	23.14	32.80	-26.886062	26.868313
3249	0.50	2.60	32.01	5.10	20.71	42.20	-26.886002	26.868008
3250	0.50	2.00	24.63	3.50	14.21	32.70	-26.885953	26.86773
3251	0.40	1.40	17.24	8.10	32.89	41.70	-26.885933	26.86739
3252	0.40	1.30	16.01	9.20	37.35	44.80	-26.885865	26.866917
3253	0.40	1.70	20.93	8.40	34.10	44.60	-26.885777	26.86654
3254	0.40	1.60	19.70	6.30	25.58	37.70	-26.885792	26.866242
3255	0.50	2.40	29.55	5.70	23.14	41.60	-26.885743	26.865773
3256	0.30	2.30	28.32	6.80	27.61	42.90	-26.885718	26.865632
3257	0.60	1.00	12.31	7.60	30.86	40.30	-26.885647	26.86524
3258	0.30	0.90	11.08	9.00	36.54	40.70	-26.88558	26.864778
3259	0.80	1.70	20.93	6.20	25.17	43.60	-26.885533	26.864357
3260	0.70	0.80	9.85	10.00	40.60	49.60	-26.885477	26.863948
3261	0.40	3.20	39.40	6.70	27.20	48.50	-26.885433	26.863563
3262	0.30	2.60	32.01	5.10	20.71	39.30	-26.88534	26.863218
3263	0.70	2.50	30.78	5.40	21.92	44.60	-26.885298	26.862883
3264	0.40	1.90	23.40	6.50	26.39	39.80	-26.885303	26.862507
3265	0.60	1.80	22.16	6.50	26.39	42.40	-26.885338	26.862127
3266	0.50	1.50	18.47	5.40	21.92	35.20	-26.885385	26.861633
3267	0.50	1.70	20.93	3.80	15.43	32.20	-26.885463	26.861233
3268	0.50	1.60	19.70	4.40	17.86	32.50	-26.885502	26.860793
3269	0.50	1.90	23.40	6.20	25.17	40.00	-26.885538	26.860348
3270	0.60	2.10	25.86	4.10	16.65	37.40	-26.885577	26.859982
3271	0.50	1.10	13.54	5.20	21.11	31.60	-26.885573	26.859985
3272	0.40	0.60	7.39	10.10	41.01	42.60	-26.885573	26.859983
3273	0.30	1.60	19.70	7.60	30.86	40.60	-26.885573	26.859983
3274	0.50	1.20	14.78	7.90	32.07	40.80	-26.885783	26.859725
3275	0.40	3.20	39.40	5.90	23.95	46.00	-26.886078	26.85958
3276	0.40	1.30	16.01	7.90	32.07	40.60	-26.886438	26.859348
3277	0.30	1.10	13.54	5.70	23.14	30.80	-26.88653	26.859322
3278	0.30	2.70	33.25	5.90	23.95	42.60	-26.886628	26.859522
3279	0.50	1.60	19.70	4.90	19.89	35.20	-26.886833	26.859895
3280	0.50	1.80	22.16	6.50	26.39	41.10	-26.887017	26.86026
3281	0.40	2.70	33.25	6.50	26.39	44.90	-26.887125	26.860602
3282	0.60	2.50	30.78	4.60	18.68	40.20	-26.88724	26.860833
3283	0.60	0.40	4.93	9.00	36.54	41.40	-26.887328	26.861053
3284	0.60	1.60	19.70	6.50	26.39	40.70	-26.887428	26.861335
3285	0.20	1.90	23.40	10.00	40.60	47.80	-26.887482	26.861517
3286	0.50	3.40	41.86	9.90	40.19	62.10	-26.88759	26.861868
3287	0.40	2.50	30.78	6.70	27.20	45.00	-26.888553	26.864427
3288	0.30	3.00	36.94	5.90	23.95	44.00	-26.88872	26.864933
3289	0.40	2.70	33.25	7.50	30.45	48.40	-26.88882	26.865432
3290	0.60	1.80	22.16	7.00	28.42	43.90	-26.888917	26.86594
3291	0.30	1.70	20.93	5.40	21.92	34.20	-26.88903	26.866428
3292	0.50	2.30	28.32	4.90	19.89	39.30	-26.889158	26.866945
3293	0.50	1.00	12.31	7.10	28.83	38.00	-26.889288	26.86746
3294	0.30	1.70	20.93	7.60	30.86	40.90	-26.889395	26.867935
3295	0.30	1.30	16.01	7.60	30.86	38.30	-26.889512	26.868442

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
3296	0.30	1.90	23.40	4.10	16.65	30.10	-26.889637	26.86894
3297	0.30	1.30	16.01	6.30	25.58	33.20	-26.88973	26.869442
3298	0.30	2.70	33.25	4.60	18.68	37.10	-26.889842	26.869962
3299	0.40	2.30	28.32	6.00	24.36	40.30	-26.889953	26.870475
3300	0.00	2.70	33.25	5.40	21.92	36.00	-26.890073	26.870983
3301	0.60	1.80	22.16	8.70	35.32	48.50	-26.890183	26.871493
3302	0.50	3.40	41.86	7.50	30.45	53.70	-26.890315	26.871995
3303	0.40	1.30	16.01	5.50	22.33	33.20	-26.890418	26.872483
3304	0.30	2.70	33.25	6.20	25.17	42.50	-26.890533	26.87297
3305	0.50	0.70	8.62	8.20	33.29	38.70	-26.890668	26.873468
3306	0.30	1.40	17.24	4.40	17.86	28.50	-26.890802	26.874015
3307	0.20	2.40	29.55	5.20	21.11	35.50	-26.890838	26.874227
3308	0.40	1.60	19.70	6.50	26.39	38.70	-26.890908	26.874497
3309	0.40	1.40	17.24	7.60	30.86	40.40	-26.89101	26.874968
3310	0.50	1.90	23.40	5.40	21.92	38.40	-26.89107	26.875275
3311	0.50	2.50	30.78	3.80	15.43	36.60	-26.891295	26.875545
3312	0.20	3.00	36.94	6.50	26.39	44.60	-26.891563	26.875913
3313	0.20	3.30	40.63	6.70	27.20	46.00	-26.891845	26.876225
3314	0.80	3.40	41.86	7.50	30.45	59.20	-26.892022	26.876443
3315	0.90	6.00	73.88	5.50	22.33	71.70	-26.892368	26.876662
13031	0.4	1.6	19.7011	3.8	15.428	29.9	0	0
13032	0.5	1.5	18.4698	5.8	23.548	36	0	0
13033	0.4	1.6	19.7011	4.1	16.646	30.1	0	0
13034	0.3	2.2	27.089	6.2	25.172	39.2	0	0
13035	0.3	1.4	17.2385	7.9	32.074	39.5	0	0
13036	0.30	1.40	17.24	6.00	24.36	33.10	-26.873223	26.88413
13037	0.30	1.10	13.54	4.10	16.65	25.40	-26.873288	26.884123
13038	0.40	1.00	12.31	4.80	19.49	28.60	-26.873385	26.884018
13039	0.40	1.20	14.78	5.10	20.71	30.60	-26.873517	26.883867
13040	0.30	2.40	29.55	3.30	13.40	31.10	-26.873685	26.883687
13041	0.30	2.00	24.63	5.50	22.33	35.30	-26.873782	26.883547
13042	0.40	2.80	34.48	3.70	15.02	37.10	-26.873878	26.883277
13043	0.30	1.00	12.31	6.30	25.58	31.80	-26.87394	26.882943
13044	0.20	0.70	8.62	6.10	24.77	27.20	-26.873977	26.88261
13045	0.30	1.10	13.54	5.80	23.55	31.50	-26.873985	26.882458
13046	0.30	0.30	3.69	6.80	27.61	29.80	-26.873982	26.882163
13047	0.20	1.10	13.54	5.30	21.52	27.80	-26.873983	26.88186
13048	0.30	0.50	6.16	7.80	31.67	33.10	-26.873987	26.881667
13049	0.10	2.70	33.25	5.40	21.92	36.70	-26.873977	26.881492
13050	0.20	2.20	27.09	5.20	21.11	35.40	-26.873967	26.881282
13051	0.30	1.90	23.40	4.00	16.24	31.10	-26.873972	26.881022
13052	0.10	2.00	24.63	5.20	21.11	32.10	-26.874003	26.880742
13053	0.30	0.70	8.62	7.00	28.42	32.30	-26.874015	26.880437
13054	0.10	1.70	20.93	4.80	19.49	28.60	-26.874035	26.880135
13055	0.10	1.80	22.16	4.30	17.46	27.90	-26.874048	26.879855
13056	0.20	1.60	19.70	5.80	23.55	31.40	-26.874078	26.879467
13057	0.40	0.40	4.93	7.30	29.64	32.60	-26.874128	26.87921
13058	0.50	1.50	18.47	4.60	18.68	32.40	-26.874167	26.878983
13059	0.30	1.00	12.31	5.80	23.55	30.60	-26.872878	26.875403
13060	0.20	1.80	22.16	4.80	19.49	30.50	-26.872683	26.875175
13061	0.30	0.40	4.93	3.00	12.18	16.70	-26.872453	26.874973
13062	0.20	1.10	13.54	6.50	26.39	32.10	-26.872242	26.874803
13063	0.30	1.60	19.70	4.10	16.65	29.00	-26.872082	26.87459
13064	0.30	1.80	22.16	4.10	16.65	30.00	-26.871923	26.874372
13065	0.30	0.90	11.08	5.30	21.52	27.50	-26.871752	26.874138
13066	0.10	2.10	25.86	4.50	18.27	30.20	-26.871547	26.873872
13067	0.30	1.90	23.40	5.50	22.33	35.00	-26.871395	26.873662

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13068	0.30	0.60	7.39	4.90	19.89	24.10	-26.871193	26.873328
13069	0.30	1.40	17.24	5.00	20.30	30.10	-26.871057	26.873097
13070	0.30	2.00	24.63	4.50	18.27	32.50	-26.870947	26.872898
13071	0.30	1.40	17.24	4.60	18.68	28.60	-26.870755	26.872813
13072	0.30	1.50	18.47	5.50	22.33	32.00	-26.870742	26.872682
13073	0.30	1.90	23.40	1.90	7.71	23.80	-26.870747	26.872343
13074	0.20	1.30	16.01	6.50	26.39	32.90	-26.870752	26.872052
13075	0.40	0.30	3.69	3.40	13.80	19.20	-26.870758	26.871787
13076	0.30	1.80	22.16	3.10	12.59	26.80	-26.870773	26.871485
13077	0.30	1.10	13.54	4.80	19.49	28.10	-26.870815	26.871205
13078	0.50	0.50	6.16	5.10	20.71	27.40	-26.870895	26.870823
13079	0.50	1.20	14.78	3.10	12.59	26.40	-26.870952	26.870478
13080	0.40	2.00	24.63	6.90	28.01	42.10	-26.871	26.870163
13081	0.30	1.00	12.31	4.60	18.68	26.30	-26.871052	26.869805
13082	0.30	1.70	20.93	4.30	17.46	30.00	-26.871072	26.869545
13083	0.20	1.90	23.40	4.30	17.46	29.60	-26.871078	26.86922
13084	0.50	1.80	22.16	3.10	12.59	29.40	-26.871095	26.868963
13085	0.40	2.50	30.78	5.00	20.30	38.60	-26.871145	26.868555
13086	0.40	0.70	8.62	3.40	13.80	22.60	-26.871207	26.86813
13087	0.30	2.60	32.01	5.20	21.11	38.50	-26.871063	26.86623
13088	0.50	0.70	8.62	5.80	23.55	31.60	-26.870937	26.865982
13089	0.50	1.30	16.01	6.30	25.58	35.90	-26.870845	26.865817
13090	0.40	2.60	32.01	7.40	30.04	47.60	-26.87069	26.865585
13091	0.40	1.10	13.54	4.80	19.49	29.40	-26.870583	26.865412
13092	0.60	0.40	4.93	5.60	22.74	30.00	-26.870498	26.865263
13093	0.40	1.00	12.31	5.80	23.55	31.30	-26.870387	26.865087
13094	0.30	3.20	39.40	3.70	15.02	37.60	-26.87027	26.864915
13095	0.50	2.60	32.01	5.70	23.14	43.40	-26.870147	26.864728
13096	0.50	1.50	18.47	6.70	27.20	39.40	-26.870047	26.864563
13097	0.40	2.00	24.63	4.30	17.46	33.70	-26.869882	26.86435
13098	0.40	0.80	9.85	6.10	24.77	31.60	-26.869725	26.864132
13099	0.30	1.80	22.16	4.10	16.65	30.00	-26.869643	26.864012
13100	0.50	1.70	20.93	4.10	16.65	31.60	-26.869523	26.86384
13101	0.80	0.90	11.08	7.50	30.45	43.00	-26.869397	26.863675
13102	1.00	1.10	13.54	5.80	23.55	42.20	-26.869353	26.863622
13103	0.80	2.20	27.09	4.80	19.49	43.10	-26.869352	26.863628
13104	1.00	1.80	22.16	7.00	28.42	50.30	-26.86935	26.863627
13105	1.00	1.20	14.78	8.70	35.32	52.90	-26.86938	26.863505
13106	0.70	2.20	27.09	6.50	26.39	47.10	-26.869507	26.863462
13107	0.80	2.70	33.25	4.00	16.24	43.50	-26.869658	26.86339
13108	1.00	1.00	12.31	7.50	30.45	46.20	-26.869783	26.863342
13109	1.00	0.60	7.39	8.00	32.48	45.50	-26.869952	26.863278
13110	1.10	0.50	6.16	8.10	32.89	46.10	-26.870122	26.863205
13111	1.00	2.00	24.63	8.40	34.10	55.60	-26.870217	26.863167
13112	0.50	1.10	13.54	7.70	31.26	39.90	-26.870307	26.86321
13113	0.40	1.10	13.54	5.60	22.74	31.30	-26.8704	26.863392
13114	0.30	1.60	19.70	4.80	19.49	30.40	-26.870455	26.863505
13115	0.30	0.80	9.85	5.60	22.74	28.60	-26.871195	26.864855
13116	0.40	2.30	28.32	3.30	13.40	32.60	-26.871273	26.864992
13117	0.40	1.70	20.93	5.80	23.55	36.30	-26.871323	26.865075
13118	0.50	1.40	17.24	5.30	21.52	33.80	-26.871418	26.865252
13119	0.40	1.90	23.40	4.30	17.46	32.20	-26.871543	26.865473
13120	0.30	1.40	17.24	7.00	28.42	37.40	-26.871712	26.865767
13121	0.40	1.50	18.47	4.80	19.49	31.30	-26.87192	26.86612
13122	0.40	1.00	12.31	5.60	22.74	31.00	-26.872103	26.866502
13123	0.20	2.30	28.32	3.00	12.18	28.00	-26.872253	26.866815
13124	0.50	0.80	9.85	5.60	22.74	32.00	-26.872427	26.867092

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13125	0.20	1.70	20.93	4.10	16.65	27.50	-26.872572	26.867317
13126	0.30	1.10	13.54	6.50	26.39	33.00	-26.872708	26.867523
13127	0.30	1.20	14.78	4.10	16.65	26.20	-26.872855	26.867747
13128	0.30	1.10	13.54	5.10	20.71	28.00	-26.87299	26.867938
13129	0.40	1.20	14.78	3.90	15.83	27.60	-26.873108	26.868115
13130	0.30	1.80	22.16	5.00	20.30	32.90	-26.873235	26.86831
13131	0.40	1.70	20.93	4.80	19.49	33.50	-26.873338	26.86857
13132	0.50	0.50	6.16	5.10	20.71	27.70	-26.873487	26.868852
13133	0.30	1.30	16.01	6.00	24.36	32.60	-26.873605	26.869117
13134	0.30	1.80	22.16	5.30	21.52	33.30	-26.873703	26.869338
13135	0.50	0.60	7.39	5.80	23.55	30.30	-26.873803	26.86955
13136	0.60	1.10	13.54	5.10	20.71	33.40	-26.873905	26.869712
13137	0.60	1.00	12.31	6.80	27.61	37.70	-26.873997	26.869867
13138	0.50	1.50	18.47	5.50	22.33	36.20	-26.874135	26.870092
13139	0.30	1.50	18.47	7.20	29.23	38.10	-26.874207	26.87024
13140	0.30	2.00	24.63	3.80	15.43	30.10	-26.874302	26.870363
13141	0.40	1.20	14.78	6.50	26.39	35.30	-26.87441	26.870522
13142	0.30	1.00	12.31	6.30	25.58	31.70	-26.874552	26.870717
13143	0.40	1.20	14.78	7.00	28.42	36.90	-26.875312	26.872147
13144	0.20	1.50	18.47	7.20	29.23	36.30	-26.875417	26.872415
13145	0.30	1.80	22.16	4.30	17.46	31.00	-26.875503	26.872663
13146	0.30	1.90	23.40	2.60	10.56	25.40	-26.875528	26.87276
13147	0.20	0.90	11.08	3.40	13.80	21.00	-26.875593	26.872975
13148	0.30	1.00	12.31	4.80	19.49	26.60	-26.875658	26.873178
13149	0.30	2.70	33.25	5.00	20.30	38.70	-26.875698	26.873307
13150	0.30	2.10	25.86	4.50	18.27	34.00	-26.87577	26.873548
13151	0.30	2.40	29.55	6.20	25.17	40.10	-26.875857	26.873807
13152	0.10	1.10	13.54	5.30	21.52	26.40	-26.875938	26.874052
13153	0.20	0.80	9.85	7.30	29.64	32.10	-26.876022	26.874295
13154	0.30	1.30	16.01	5.80	23.55	32.40	-26.876123	26.874552
13155	0.20	0.90	11.08	5.10	20.71	26.60	-26.876218	26.874777
13156	0.30	2.10	25.86	3.80	15.43	30.40	-26.876287	26.874988
13157	0.30	2.30	28.32	4.70	19.08	35.90	-26.876335	26.875143
13158	0.30	1.20	14.78	5.50	22.33	30.70	-26.876412	26.875375
13159	0.30	1.10	13.54	3.40	13.80	22.20	-26.876493	26.875625
13160	0.20	0.80	9.85	5.30	21.52	26.30	-26.876557	26.875817
13161	0.30	2.30	28.32	5.50	22.33	37.20	-26.876623	26.876033
13162	0.40	1.40	17.24	4.30	17.46	29.40	-26.876698	26.876242
13163	0.30	1.10	13.54	6.80	27.61	34.10	-26.876823	26.87653
13164	0.50	0.30	3.69	6.30	25.58	30.10	-26.876927	26.876778
13165	0.30	0.90	11.08	3.20	12.99	20.90	-26.877027	26.877055
13166	0.30	1.30	16.01	4.10	16.65	27.50	-26.877117	26.877277
13167	0.30	1.70	20.93	5.00	20.30	31.40	-26.877203	26.877467
13168	0.40	2.00	24.63	4.30	17.46	32.80	-26.87728	26.877658
13169	0.20	0.90	11.08	4.80	19.49	23.90	-26.877375	26.877887
13170	0.30	0.80	9.85	5.80	23.55	29.10	-26.877493	26.878173
13171	0.20	2.00	24.63	3.30	13.40	27.00	-26.87757	26.87837
13172	0.50	0.50	6.16	6.30	25.58	32.20	-26.877625	26.878515
13173	0.40	1.40	17.24	4.60	18.68	29.80	-26.877712	26.878742
13174	0.40	1.20	14.78	5.10	20.71	30.00	-26.877868	26.879095
13175	0.30	0.80	9.85	8.00	32.48	36.30	-26.878022	26.879415
13176	0.30	0.80	9.85	4.60	18.68	25.30	-26.87813	26.87966
13177	0.40	0.90	11.08	4.90	19.89	28.30	-26.878258	26.879908
13178	0.60	0.70	8.62	4.60	18.68	28.40	-26.878385	26.880145
13179	0.30	1.10	13.54	5.80	23.55	31.10	-26.878533	26.880392
13180	0.40	2.00	24.63	2.80	11.37	28.00	-26.878672	26.88063
13181	0.30	0.60	7.39	5.60	22.74	27.10	-26.878802	26.880857

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13182	0.30	0.80	9.85	5.10	20.71	26.00	-26.878965	26.881128
13183	0.20	1.60	19.70	8.40	34.10	40.50	-26.879123	26.881387
13184	0.40	1.40	17.24	5.50	22.33	33.60	-26.879283	26.881648
13185	0.30	1.90	23.40	6.20	25.17	36.70	-26.879397	26.881843
13186	0.30	1.50	18.47	6.20	25.17	35.50	-26.879387	26.88182
13187	0.20	1.60	19.70	6.20	25.17	33.80	-26.879387	26.88181
13188	0.40	0.90	11.08	6.50	26.39	33.10	-26.879382	26.881818
13189	0.20	2.10	25.86	5.50	22.33	34.20	-26.879383	26.881825
13190	0.20	1.00	12.31	6.00	24.36	29.40	-26.879383	26.881832
13191	0.30	2.30	28.32	6.90	28.01	41.80	-26.879385	26.881835
13192	0.20	1.60	19.70	5.80	23.55	32.10	-26.879427	26.881827
13193	0.30	2.10	25.86	3.80	15.43	31.40	-26.87977	26.881713
13194	0.30	1.00	12.31	5.30	21.52	29.20	-26.880075	26.88159
13195	0.30	0.50	6.16	6.60	26.80	29.40	-26.880412	26.881462
13196	0.50	1.10	13.54	3.40	13.80	25.90	-26.880412	26.881462
13197	0.50	1.60	19.70	6.20	25.17	38.80	-26.880423	26.881363
13198	0.40	1.60	19.70	4.80	19.49	32.50	-26.880375	26.881177
13199	0.40	1.50	18.47	4.10	16.65	29.20	-26.880347	26.881042
13200	0.40	0.50	6.16	3.90	15.83	21.80	-26.88032	26.880918
13201	0.40	2.10	25.86	4.00	16.24	32.70	-26.88027	26.880722
13202	0.40	0.40	4.93	4.20	17.05	21.60	-26.8802	26.88047
13203	0.40	0.70	8.62	4.60	18.68	25.70	-26.880128	26.880247
13204	0.30	1.30	16.01	2.90	11.77	22.30	-26.880063	26.880043
13205	0.20	1.40	17.24	1.90	7.71	18.80	-26.879997	26.879825
13206	0.40	0.40	4.93	4.70	19.08	24.40	-26.879935	26.879658
13207	0.30	1.40	17.24	3.40	13.80	25.60	-26.879843	26.879405
13208	0.20	1.30	16.01	5.30	21.52	28.20	-26.879747	26.879148
13209	0.20	2.90	35.71	6.40	25.98	43.10	-26.879632	26.878862
13210	0.30	1.40	17.24	4.60	18.68	28.70	-26.879523	26.878622
13211	0.20	0.90	11.08	6.00	24.36	29.60	-26.87943	26.878423
13212	0.30	1.80	22.16	5.00	20.30	33.60	-26.87933	26.878197
13213	0.30	0.90	11.08	6.50	26.39	32.30	-26.879248	26.878
13214	0.20	1.70	20.93	4.80	19.49	29.30	-26.879183	26.8778
13215	0.30	0.80	9.85	4.40	17.86	24.60	-26.879108	26.877555
13216	0.20	2.00	24.63	3.50	14.21	27.40	-26.879032	26.877337
13217	0.20	1.00	12.31	4.80	19.49	25.60	-26.878973	26.877158
13218	0.30	0.40	4.93	5.90	23.95	26.50	-26.878913	26.876938
13219	0.10	1.00	12.31	5.80	23.55	26.60	-26.878848	26.876697
13220	0.30	1.50	18.47	4.80	19.49	30.10	-26.878745	26.876455
13221	0.10	1.40	17.24	5.50	22.33	28.20	-26.878798	26.87627
13222	0.20	0.80	9.85	5.60	22.74	26.00	-26.87879	26.87601
13223	0.50	1.20	14.78	3.10	12.59	25.90	-26.878783	26.875743
13224	0.30	2.10	25.86	4.00	16.24	30.90	-26.878777	26.875497
13225	0.20	0.60	7.39	4.60	18.68	23.10	-26.878768	26.875233
13226	0.20	1.90	23.40	5.20	21.11	32.90	-26.878783	26.875163
13227	0.10	2.20	27.09	2.80	11.37	25.60	-26.878737	26.874925
13228	0.20	1.50	18.47	4.30	17.46	27.40	-26.878695	26.874592
13229	0.50	0.80	9.85	7.80	31.67	39.10	-26.877863	26.871633
13230	0.50	1.20	14.78	5.80	23.55	34.80	-26.877738	26.8714
13231	0.60	0.90	11.08	4.40	17.86	30.30	-26.877547	26.871083
13232	0.30	1.00	12.31	2.90	11.77	21.60	-26.877355	26.87078
13233	0.40	1.10	13.54	4.10	16.65	27.10	-26.877195	26.870498
13234	0.50	1.60	19.70	6.00	24.36	37.80	-26.877062	26.870217
13235	0.20	1.70	20.93	6.50	26.39	35.90	-26.876925	26.869922
13236	0.30	1.70	20.93	6.70	27.20	38.40	-26.876812	26.869653
13237	0.40	1.60	19.70	6.20	25.17	37.00	-26.876695	26.869412
13238	0.50	1.20	14.78	6.80	27.61	37.90	-26.876597	26.869183

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13239	0.60	2.10	25.86	4.50	18.27	38.40	-26.876513	26.868938
13240	0.40	1.30	16.01	7.50	30.45	39.80	-26.876418	26.868672
13241	0.40	2.30	28.32	5.70	23.14	39.50	-26.876337	26.868398
13242	0.60	0.80	9.85	8.20	33.29	40.70	-26.876227	26.868067
13243	0.40	1.50	18.47	5.30	21.52	34.30	-26.876122	26.867742
13244	0.50	2.00	24.63	5.30	21.52	37.60	-26.876012	26.867457
13245	0.40	1.30	16.01	5.50	22.33	32.80	-26.87591	26.867228
13246	0.60	1.70	20.93	7.50	30.45	45.20	-26.875775	26.866928
13247	0.50	2.10	25.86	7.40	30.04	46.20	-26.875615	26.866593
13248	0.40	1.10	13.54	8.20	33.29	40.40	-26.875517	26.866363
13249	0.30	0.80	9.85	7.30	29.64	34.00	-26.875413	26.866118
13250	0.30	2.10	25.86	4.50	18.27	33.70	-26.87533	26.86593
13251	0.30	0.30	3.69	7.80	31.67	32.30	-26.875253	26.865745
13252	0.30	2.10	25.86	5.20	21.11	36.60	-26.875195	26.865583
13253	0.30	2.60	32.01	5.20	21.11	39.10	-26.875137	26.865428
13254	0.50	1.80	22.16	6.00	24.36	39.20	-26.875072	26.865263
13255	0.80	1.10	13.54	3.90	15.83	32.70	-26.874977	26.864998
13256	0.70	1.10	13.54	7.50	30.45	42.30	-26.874898	26.864762
13257	0.50	1.20	14.78	5.30	21.52	32.70	-26.874818	26.864538
13258	0.40	1.90	23.40	5.00	20.30	35.70	-26.874737	26.864337
13259	0.50	0.90	11.08	6.60	26.80	35.60	-26.87464	26.86411
13260	0.40	1.50	18.47	6.30	25.58	36.40	-26.87456	26.863918
13261	0.60	1.20	14.78	6.80	27.61	38.80	-26.874453	26.863663
13262	0.50	1.00	12.31	5.80	23.55	33.60	-26.874347	26.863383
13263	0.40	1.20	14.78	3.90	15.83	26.40	-26.874245	26.863117
13264	0.30	1.20	14.78	5.10	20.71	29.00	-26.874157	26.862875
13265	0.60	2.10	25.86	3.80	15.43	35.60	-26.87414	26.862813
13266	0.40	2.60	32.01	4.70	19.08	39.10	-26.874145	26.862742
13267	0.40	0.90	11.08	6.50	26.39	33.70	-26.874323	26.862673
13268	0.50	1.00	12.31	3.20	12.99	24.20	-26.874547	26.862603
13269	0.50	1.80	22.16	6.00	24.36	38.90	-26.874733	26.862542
13270	0.40	1.80	22.16	4.50	18.27	32.60	-26.874945	26.862467
13271	0.40	1.60	19.70	4.10	16.65	29.70	-26.875203	26.86238
13272	0.40	2.20	27.09	3.10	12.59	31.60	-26.87539	26.862323
13273	0.50	1.00	12.31	7.30	29.64	38.10	-26.875437	26.862348
13274	0.10	1.90	23.40	4.50	18.27	28.20	-26.875532	26.862638
13275	0.40	1.00	12.31	5.60	22.74	30.50	-26.875628	26.862925
13276	0.40	2.30	28.32	5.50	22.33	39.90	-26.875665	26.863157
13277	0.50	1.50	18.47	6.50	26.39	38.70	-26.875733	26.863383
13278	0.40	1.40	17.24	6.50	26.39	36.10	-26.875807	26.863617
13279	0.60	0.80	9.85	6.30	25.58	34.80	-26.87591	26.863882
13280	0.40	2.00	24.63	4.30	17.46	33.40	-26.876022	26.864108
13281	0.50	2.80	34.48	5.00	20.30	42.00	-26.876132	26.864323
13282	0.40	1.50	18.47	4.80	19.49	31.80	-26.876233	26.864515
13283	0.30	1.50	18.47	6.50	26.39	36.40	-26.876353	26.864738
13284	0.40	2.30	28.32	5.00	20.30	36.90	-26.876457	26.864932
13285	0.30	0.80	9.85	7.70	31.26	36.10	-26.876598	26.865142
13286	0.40	1.20	14.78	4.10	16.65	27.60	-26.87811	26.86709
13287	0.50	0.20	2.46	3.70	15.02	20.90	-26.878337	26.867425
13288	0.40	1.70	20.93	5.50	22.33	35.10	-26.878495	26.867717
13289	0.10	2.40	29.55	5.70	23.14	36.50	-26.878625	26.867968
13290	0.40	1.10	13.54	5.80	23.55	32.30	-26.878748	26.868205
13291	0.40	0.70	8.62	4.90	19.89	27.30	-26.878825	26.868347
13292	0.60	1.60	19.70	4.60	18.68	34.90	-26.878922	26.868525
13293	0.60	0.40	4.93	4.90	19.89	28.10	-26.879045	26.868747
13294	0.30	1.40	17.24	7.00	28.42	36.30	-26.879163	26.868953
13295	0.60	0.00	0.00	6.20	25.17	29.50	-26.879297	26.869202

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13296	0.30	1.60	19.70	3.40	13.80	26.60	-26.879413	26.86942
13297	0.50	1.20	14.78	6.80	27.61	38.10	-26.879555	26.869668
13298	0.40	0.90	11.08	4.90	19.89	28.10	-26.879693	26.869943
13299	0.30	1.70	20.93	6.00	24.36	34.50	-26.879835	26.870227
13300	0.40	1.40	17.24	5.30	21.52	32.20	-26.879965	26.870477
13301	0.50	0.80	9.85	4.60	18.68	28.70	-26.880087	26.870723
13302	0.50	2.80	34.48	2.80	11.37	35.90	-26.880287	26.87111
13303	0.50	1.70	20.93	5.30	21.52	35.80	-26.880413	26.871317
13304	0.50	0.80	9.85	7.80	31.67	38.20	-26.88062	26.8716
13305	0.50	1.00	12.31	6.50	26.39	35.70	-26.880747	26.871768
13306	0.40	1.10	13.54	3.40	13.80	23.80	-26.880885	26.871942
13307	0.50	1.10	13.54	4.40	17.86	28.40	-26.88106	26.872197
13308	0.40	1.10	13.54	5.10	20.71	30.30	-26.881223	26.872435
13309	0.30	1.60	19.70	5.30	21.52	32.80	-26.881375	26.872633
13310	0.30	2.20	27.09	4.50	18.27	34.50	-26.88153	26.872875
13311	0.40	1.80	22.16	5.30	21.52	35.40	-26.881698	26.873135
13312	0.30	1.40	17.24	5.30	21.52	31.30	-26.881877	26.873415
13313	0.40	0.70	8.62	9.70	39.38	42.10	-26.882077	26.873688
13314	0.40	2.00	24.63	9.60	38.98	50.10	-26.882238	26.873955
13315	0.40	1.80	22.16	6.20	25.17	37.70	-26.8824	26.874223
13316	0.30	1.70	20.93	4.80	19.49	31.00	-26.882522	26.87445
13317	0.30	2.40	29.55	5.90	23.95	39.10	-26.882533	26.874478
13318	0.20	0.80	9.85	6.30	25.58	28.40	-26.882543	26.874512
13319	0.40	2.10	25.86	6.40	25.98	40.80	-26.88257	26.874597
13320	0.40	1.50	18.47	5.50	22.33	35.00	-26.882677	26.874807
13321	0.20	2.00	24.63	5.20	21.11	33.70	-26.882813	26.875068
13322	0.30	1.40	17.24	4.60	18.68	28.90	-26.882902	26.875223
13323	0.30	1.40	17.24	6.70	27.20	36.40	-26.882897	26.87521
13324	0.40	1.60	19.70	4.80	19.49	32.60	-26.882893	26.87521
13325	0.50	2.20	27.09	3.10	12.59	32.10	-26.882898	26.875213
13326	0.30	1.10	13.54	6.50	26.39	34.10	-26.882898	26.875208
13327	0.40	0.90	11.08	3.40	13.80	24.40	-26.8829	26.875203
13328	0.40	0.80	9.85	5.30	21.52	29.20	-26.882898	26.875207
13329	0.30	2.80	34.48	4.70	19.08	38.10	-26.882902	26.875212
13330	0.30	2.10	25.86	4.30	17.46	32.80	-26.8829	26.875208
13331	0.30	1.20	14.78	5.50	22.33	30.70	-26.882897	26.875203
13332	0.20	0.80	9.85	4.60	18.68	22.90	-26.882897	26.875203
13333	0.30	1.50	18.47	4.30	17.46	29.40	-26.8829	26.875205
13334	0.30	1.60	19.70	5.80	23.55	34.20	-26.882897	26.875202
13335	0.30	3.10	38.17	3.20	12.99	35.20	-26.882895	26.875198
13336	0.50	2.00	24.63	4.30	17.46	35.30	-26.882895	26.875197
13337	0.30	1.30	16.01	4.80	19.49	29.40	-26.882895	26.875198
13338	0.40	1.70	20.93	5.00	20.30	33.20	-26.882895	26.8752
13339	0.40	1.10	13.54	4.80	19.49	30.10	-26.882897	26.8752
13340	0.20	2.80	34.48	4.70	19.08	37.00	-26.882897	26.875203
13341	0.30	0.60	7.39	6.10	24.77	27.50	-26.882897	26.875203
13342	0.30	1.70	20.93	4.80	19.49	31.90	-26.882898	26.8752
13343	0.50	2.40	29.55	4.50	18.27	37.60	-26.882898	26.875202
13344	0.30	1.10	13.54	5.60	22.74	30.60	-26.8829	26.875202
13345	0.20	1.50	18.47	4.60	18.68	28.10	-26.882902	26.875203
13346	0.50	0.30	3.69	4.70	19.08	24.30	-26.882905	26.875203
13347	0.40	1.40	17.24	6.30	25.58	35.20	-26.882907	26.875203
13348	0.30	3.00	36.94	5.40	21.92	42.40	-26.882908	26.875205
13349	0.30	3.10	38.17	8.10	32.89	51.80	-26.882907	26.875208
13350	0.50	1.20	14.78	3.60	14.62	26.90	-26.882905	26.87521
13351	0.20	1.50	18.47	6.20	25.17	33.60	-26.882903	26.875213
13352	0.40	1.50	18.47	5.80	23.55	34.10	-26.8829	26.875217

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13353	0.20	1.30	16.01	9.10	36.95	42.20	-26.882897	26.875218
13354	0.50	0.00	0.00	6.10	24.77	28.10	-26.882895	26.87522
13355	0.40	1.40	17.24	3.40	13.80	27.30	-26.88289	26.875222
13356	0.40	1.50	18.47	7.90	32.07	41.40	-26.882888	26.875223
13357	0.30	1.50	18.47	4.30	17.46	28.70	-26.882888	26.875225
13358	0.40	1.10	13.54	6.30	25.58	33.90	-26.882887	26.875225
13359	0.50	1.10	13.54	5.10	20.71	31.00	-26.882885	26.875227
13360	0.40	1.10	13.54	4.40	17.86	28.20	-26.882883	26.875228
13361	0.30	1.60	19.70	4.10	16.65	28.50	-26.882883	26.875228
13362	0.40	2.00	24.63	3.80	15.43	31.50	-26.88288	26.87523
13363	0.30	1.90	23.40	3.30	13.40	28.70	-26.882877	26.875232
13364	0.30	1.40	17.24	5.50	22.33	31.50	-26.882873	26.875232
13365	0.40	2.30	28.32	5.50	22.33	39.70	-26.88284	26.875198
13366	0.40	2.20	27.09	6.00	24.36	39.90	-26.882827	26.875188
13367	0.30	1.60	19.70	6.20	25.17	36.00	-26.88283	26.875185
13368	0.40	1.10	13.54	7.50	30.45	38.10	-26.882837	26.875195
13369	0.40	1.60	19.70	7.70	31.26	41.40	-26.882837	26.875177
13370	0.50	1.30	16.01	5.60	22.74	34.20	-26.883003	26.875153
13371	0.30	1.30	16.01	3.60	14.62	24.90	-26.883127	26.875257
13372	0.40	1.40	17.24	4.60	18.68	29.80	-26.883137	26.875362
13373	0.30	2.10	25.86	3.80	15.43	31.60	-26.882932	26.875517
13374	0.30	0.40	4.93	5.90	23.95	26.70	-26.882992	26.875838
13375	0.20	1.30	16.01	5.10	20.71	28.40	-26.883082	26.876175
13376	0.40	1.90	23.40	3.30	13.40	29.60	-26.883202	26.876488
13377	0.50	1.00	12.31	7.30	29.64	38.10	-26.883307	26.876747
13378	0.50	0.70	8.62	7.80	31.67	37.90	-26.883417	26.877
13379	0.30	1.70	20.93	5.50	22.33	34.50	-26.883573	26.877348
13380	0.20	2.60	32.01	4.50	18.27	35.60	-26.88379	26.877808
13381	0.30	2.00	24.63	5.50	22.33	35.50	-26.884022	26.878232
13382	0.30	0.40	4.93	5.60	22.74	25.60	-26.88424	26.878587
13383	0.40	1.60	19.70	5.50	22.33	35.50	-26.884442	26.878882
13384	0.40	1.90	23.40	3.80	15.43	31.70	-26.884677	26.879258
13385	0.30	2.90	35.71	2.30	9.34	32.00	-26.884915	26.879588
13386	0.60	1.90	23.40	3.30	13.40	33.30	-26.884955	26.879617
13387	0.30	2.10	25.86	5.20	21.11	35.90	-26.884948	26.879627
13388	0.40	1.10	13.54	4.60	18.68	28.80	-26.885058	26.879587
13389	0.30	1.90	23.40	4.00	16.24	30.40	-26.885458	26.879433
13390	0.40	1.60	19.70	4.10	16.65	30.80	-26.88591	26.87926
13391	0.50	1.00	12.31	6.80	27.61	35.70	-26.88613	26.879177
13392	0.40	1.40	17.24	5.50	22.33	32.90	-26.886092	26.879032
13393	0.40	1.00	12.31	5.60	22.74	31.50	-26.88601	26.878777
13394	0.20	1.30	16.01	3.40	13.80	23.20	-26.885902	26.878443
13395	0.30	0.80	9.85	5.30	21.52	27.90	-26.885795	26.878127
13396	0.30	0.90	11.08	4.60	18.68	24.90	-26.885707	26.877895
13397	0.30	1.70	20.93	5.80	23.55	35.40	-26.885608	26.877657
13398	0.30	1.90	23.40	4.30	17.46	30.40	-26.88553	26.877483
13399	0.40	1.60	19.70	5.80	23.55	35.30	-26.885415	26.877228
13400	0.40	1.60	19.70	6.20	25.17	37.90	-26.885282	26.876933
13401	0.40	0.80	9.85	5.80	23.55	30.70	-26.885167	26.876693
13402	0.30	1.40	17.24	6.00	24.36	34.30	-26.885105	26.876565
13403	0.40	2.10	25.86	6.70	27.20	41.90	-26.885092	26.87649
13404	0.30	2.00	24.63	4.30	17.46	32.70	-26.884997	26.876308
13405	0.20	0.80	9.85	8.50	34.51	36.30	-26.884833	26.876045
13406	0.10	1.70	20.93	6.20	25.17	32.70	-26.884625	26.875735
13407	0.30	0.90	11.08	5.60	22.74	29.10	-26.884458	26.875478
13408	0.30	0.70	8.62	5.10	20.71	25.70	-26.884353	26.875317
13409	0.20	1.80	22.16	3.60	14.62	26.10	-26.884353	26.875307

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13410	0.20	0.80	9.85	5.30	21.52	25.80	-26.884328	26.875255
13411	0.20	2.30	28.32	2.10	8.53	24.80	-26.884298	26.8752
13412	0.10	1.60	19.70	3.10	12.59	22.30	-26.884275	26.875173
13413	0.30	1.50	18.47	6.20	25.17	34.80	-26.884267	26.875147
13414	0.40	0.80	9.85	6.10	24.77	31.90	-26.884202	26.874925
13415	0.30	1.90	23.40	6.20	25.17	38.00	-26.884143	26.874722
13416	0.50	1.40	17.24	6.00	24.36	36.80	-26.884032	26.8747
13417	0.40	1.20	14.78	5.80	23.55	33.50	-26.88399	26.874653
13418	0.20	2.30	28.32	4.70	19.08	33.90	-26.883983	26.874522
13419	0.50	1.40	17.24	8.20	33.29	43.60	-26.883943	26.874223
13420	0.40	2.50	30.78	6.20	25.17	42.40	-26.883877	26.873907
13421	0.30	1.30	16.01	6.00	24.36	33.30	-26.883767	26.873485
13422	0.30	1.10	13.54	5.60	22.74	29.90	-26.883637	26.873
13423	0.50	1.30	16.01	5.30	21.52	34.40	-26.883498	26.87249
13424	0.30	0.90	11.08	5.10	20.71	28.00	-26.883362	26.871993
13425	0.30	1.10	13.54	3.10	12.59	22.00	-26.883222	26.871507
13426	0.60	1.00	12.31	4.60	18.68	30.80	-26.883087	26.871005
13427	0.40	0.80	9.85	7.00	28.42	34.60	-26.882912	26.87051
13428	0.40	1.10	13.54	6.00	24.36	33.60	-26.882705	26.870052
13429	0.60	0.90	11.08	6.30	25.58	36.50	-26.882538	26.869723
13430	0.50	0.70	8.62	5.10	20.71	28.70	-26.88235	26.869452
13431	0.50	1.50	18.47	4.80	19.49	32.70	-26.882175	26.869213
13432	0.50	1.70	20.93	4.30	17.46	33.20	-26.8819	26.86881
13433	0.80	0.50	6.16	6.60	26.80	37.30	-26.881718	26.868498
13434	0.40	1.20	14.78	5.50	22.33	32.60	-26.88156	26.868253
13435	0.50	1.70	20.93	6.70	27.20	41.70	-26.88137	26.86797
13436	0.50	1.90	23.40	6.50	26.39	41.70	-26.881142	26.86762
13437	0.40	1.80	22.16	4.80	19.49	34.10	-26.880928	26.867312
13438	0.50	1.60	19.70	5.80	23.55	37.60	-26.880683	26.866992
13439	0.40	1.10	13.54	8.20	33.29	41.10	-26.880403	26.866617
13440	0.50	2.80	34.48	6.40	25.98	47.50	-26.880102	26.866235
13441	0.50	1.90	23.40	5.50	22.33	37.40	-26.879788	26.865885
13442	0.70	1.10	13.54	5.30	21.52	35.70	-26.87946	26.865523
13443	0.50	1.10	13.54	6.50	26.39	36.90	-26.879127	26.865177
13444	0.40	1.20	14.78	6.50	26.39	36.30	-26.878812	26.864858
13445	0.60	1.90	23.40	6.00	24.36	41.50	-26.878503	26.86456
13446	0.80	3.20	39.40	9.00	36.54	63.30	-26.87827	26.864317
13447	0.70	1.80	22.16	9.60	38.98	54.60	-26.878115	26.864152
13448	0.30	1.90	23.40	7.20	29.23	40.20	-26.877798	26.86385
13449	0.30	1.20	14.78	6.80	27.61	34.90	-26.8778	26.863855
13450	0.40	0.00	0.00	7.10	28.83	29.50	-26.877788	26.863755
13451	0.50	0.90	11.08	5.60	22.74	31.40	-26.877968	26.863633
13452	0.40	1.00	12.31	4.80	19.49	28.40	-26.878337	26.863543
13453	0.30	1.90	23.40	6.70	27.20	39.30	-26.878743	26.863383
13454	0.20	2.30	28.32	6.70	27.20	40.20	-26.879178	26.863265
13455	0.50	1.50	18.47	6.70	27.20	39.40	-26.87929	26.863338
13456	0.50	1.90	23.40	7.20	29.23	44.30	-26.879422	26.863558
13457	0.60	1.50	18.47	7.00	28.42	42.00	-26.87957	26.863785
13458	0.60	1.60	19.70	5.50	22.33	37.90	-26.879695	26.864012
13459	0.40	1.20	14.78	5.50	22.33	31.90	-26.879868	26.86431
13460	0.60	1.20	14.78	5.10	20.71	34.10	-26.87999	26.864568
13461	0.20	2.40	29.55	5.70	23.14	38.10	-26.880133	26.864835
13462	0.50	2.60	32.01	4.70	19.08	40.50	-26.880297	26.865092
13463	0.40	0.70	8.62	6.60	26.80	32.70	-26.880472	26.8653
13464	0.50	1.20	14.78	10.10	41.01	48.40	-26.88065	26.865522
13465	0.40	1.00	12.31	7.00	28.42	35.90	-26.880858	26.865758
13466	0.50	1.60	19.70	4.60	18.68	34.20	-26.88109	26.866012

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13467	0.60	1.90	23.40	7.70	31.26	47.00	-26.88131	26.866235
13468	0.50	1.20	14.78	5.80	23.55	34.60	-26.881543	26.866477
13469	0.50	2.60	32.01	5.50	22.33	42.60	-26.881757	26.866713
13470	0.40	0.60	7.39	4.40	17.86	25.00	-26.881963	26.866967
13471	0.60	1.40	17.24	5.50	22.33	36.10	-26.88218	26.867248
13472	0.50	1.10	13.54	8.70	35.32	42.50	-26.882392	26.867528
13473	0.60	0.10	1.23	7.10	28.83	32.60	-26.882577	26.867757
13474	0.40	2.90	35.71	4.20	17.05	39.80	-26.882782	26.868017
13475	0.10	2.40	29.55	6.60	26.80	39.80	-26.882997	26.868297
13476	0.10	2.30	28.32	5.70	23.14	35.00	-26.883127	26.868518
13477	0.50	2.00	24.63	3.30	13.40	32.30	-26.883325	26.868853
13478	0.40	0.60	7.39	3.90	15.83	23.80	-26.883608	26.869252
13479	0.20	1.00	12.31	4.60	18.68	25.00	-26.883885	26.869593
13480	0.40	2.10	25.86	3.10	12.59	30.00	-26.884123	26.869882
13481	0.40	0.90	11.08	6.30	25.58	32.60	-26.88436	26.870168
13482	0.40	1.30	16.01	4.30	17.46	28.20	-26.88458	26.870442
13483	0.40	0.70	8.62	6.30	25.58	30.80	-26.88482	26.870738
13484	0.30	1.80	22.16	3.60	14.62	28.10	-26.885105	26.871145
13485	0.60	1.30	16.01	5.10	20.71	34.20	-26.885305	26.871463
13486	0.50	1.10	13.54	2.70	10.96	23.10	-26.885458	26.87177
13487	0.30	1.50	18.47	6.00	24.36	35.10	-26.885585	26.872097
13488	0.30	1.50	18.47	7.00	28.42	37.40	-26.885673	26.872372
13489	0.50	0.90	11.08	3.90	15.83	26.90	-26.885755	26.872703
13490	0.30	3.40	41.86	8.00	32.48	54.10	-26.885817	26.873038
13491	0.40	1.70	20.93	5.30	21.52	34.60	-26.885865	26.873307
13492	0.30	1.50	18.47	4.80	19.49	30.40	-26.885907	26.873565
13493	0.40	1.30	16.01	4.10	16.65	29.10	-26.885987	26.873877
13494	0.20	1.20	14.78	5.50	22.33	28.90	-26.886052	26.874153
13495	0.30	1.10	13.54	5.10	20.71	27.60	-26.886088	26.874408
13496	0.30	1.60	19.70	4.80	19.49	30.60	-26.886078	26.874553
13497	0.30	1.60	19.70	9.10	36.95	45.40	-26.886067	26.874615
13498	0.30	2.10	25.86	3.50	14.21	30.40	-26.886047	26.874747
13499	0.50	0.70	8.62	6.80	27.61	34.40	-26.886093	26.874977
13500	0.40	1.00	12.31	5.30	21.52	30.60	-26.886168	26.875272
13501	0.30	1.90	23.40	5.70	23.14	35.50	-26.886282	26.875642
13502	0.60	1.60	19.70	3.80	15.43	32.20	-26.88639	26.875913
13503	0.50	1.60	19.70	7.90	32.07	44.30	-26.886488	26.876085
13504	0.50	1.80	22.16	6.20	25.17	39.80	-26.886625	26.876332
13505	0.40	1.30	16.01	7.70	31.26	39.80	-26.886757	26.876565
13506	0.40	1.20	14.78	5.10	20.71	30.40	-26.886902	26.876835
13507	0.30	1.90	23.40	4.00	16.24	30.60	-26.887075	26.877128
13508	0.20	2.10	25.86	4.50	18.27	31.60	-26.887237	26.877375
13509	0.40	0.60	7.39	5.60	22.74	28.10	-26.887398	26.877583
13510	0.30	2.20	27.09	4.70	19.08	34.20	-26.8876	26.877823
13511	0.40	1.40	17.24	4.80	19.49	31.20	-26.887808	26.878105
13512	0.40	1.20	14.78	3.10	12.59	24.60	-26.888023	26.878362
13513	0.30	2.10	25.86	5.70	23.14	37.00	-26.888085	26.878415
13514	0.30	1.30	16.01	3.60	14.62	24.80	-26.888293	26.878342
13515	0.20	1.60	19.70	4.80	19.49	28.80	-26.888617	26.878177
13516	0.30	1.20	14.78	6.00	24.36	31.40	-26.88901	26.878025
13517	0.40	0.70	8.62	6.30	25.58	32.00	-26.889352	26.877887
13518	0.40	1.10	13.54	8.50	34.51	40.50	-26.889372	26.877845
13519	0.40	1.90	23.40	6.00	24.36	38.40	-26.889303	26.877623
13520	0.30	2.20	27.09	6.70	27.20	41.00	-26.88921	26.877313
13521	0.40	0.60	7.39	7.00	28.42	33.40	-26.889163	26.877075
13522	0.40	1.20	14.78	7.00	28.42	37.60	-26.88908	26.87681
13523	0.40	1.70	20.93	6.00	24.36	37.20	-26.88899	26.876508

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13524	0.40	1.70	20.93	5.00	20.30	33.50	-26.888923	26.876275
13525	0.40	0.60	7.39	5.80	23.55	29.40	-26.888845	26.875983
13526	0.50	0.60	7.39	6.60	26.80	33.80	-26.888758	26.875697
13527	0.50	1.40	17.24	5.10	20.71	33.80	-26.888705	26.87551
13528	0.40	0.70	8.62	4.90	19.89	26.60	-26.888623	26.875227
13529	0.30	0.70	8.62	6.50	26.39	30.70	-26.888538	26.874973
13530	0.60	1.00	12.31	5.30	21.52	33.40	-26.888563	26.874765
13531	0.30	2.50	30.78	4.50	18.27	35.80	-26.888497	26.874677
13532	0.30	1.70	20.93	5.00	20.30	33.00	-26.888397	26.874488
13533	0.30	2.30	28.32	2.10	8.53	26.10	-26.88825	26.874203
13534	0.10	1.00	12.31	4.30	17.46	23.10	-26.888092	26.87399
13535	0.20	2.60	32.01	3.00	12.18	30.50	-26.88794	26.873843
13536	0.10	2.90	35.71	5.40	21.92	38.70	-26.887918	26.873763
13537	0.30	2.10	25.86	6.00	24.36	37.50	-26.887962	26.873397
13538	0.30	0.60	7.39	4.40	17.86	22.30	-26.887913	26.873073
13539	0.30	1.10	13.54	4.60	18.68	26.90	-26.887835	26.872815
13540	0.20	2.10	25.86	3.50	14.21	28.60	-26.887738	26.872565
13541	0.50	0.60	7.39	4.40	17.86	26.10	-26.88761	26.872257
13542	0.30	1.00	12.31	4.80	19.49	27.70	-26.887485	26.871938
13543	0.40	2.00	24.63	4.30	17.46	33.40	-26.887343	26.871595
13544	0.40	1.70	20.93	5.50	22.33	35.40	-26.887252	26.871393
13545	0.40	1.10	13.54	4.60	18.68	29.40	-26.887122	26.87111
13546	0.50	1.40	17.24	3.90	15.83	29.30	-26.88699	26.87082
13547	0.50	0.90	11.08	6.30	25.58	34.00	-26.886825	26.870407
13548	0.20	1.40	17.24	7.90	32.07	38.80	-26.886648	26.87006
13549	0.50	1.90	23.40	5.50	22.33	38.20	-26.886432	26.869645
13550	0.30	0.20	2.46	7.50	30.45	30.90	-26.886298	26.869342
13551	0.40	1.10	13.54	6.80	27.61	35.10	-26.886165	26.86899
13552	0.40	1.70	20.93	4.80	19.49	33.70	-26.88606	26.868642
13553	0.30	1.30	16.01	9.40	38.16	44.10	-26.886	26.86834
13554	0.30	1.30	16.01	5.80	23.55	32.20	-26.885943	26.86807
13555	0.30	1.20	14.78	6.50	26.39	34.50	-26.885893	26.867812
13556	0.50	2.10	25.86	4.50	18.27	36.10	-26.885857	26.867525
13557	0.70	1.00	12.31	9.40	38.16	47.40	-26.885803	26.867055
13558	0.60	0.70	8.62	6.10	24.77	34.50	-26.885748	26.866643
13559	0.30	2.50	30.78	5.50	22.33	38.90	-26.885692	26.866345
13560	0.40	0.60	7.39	7.30	29.64	34.80	-26.885692	26.865898
13561	0.40	1.80	22.16	7.40	30.04	42.30	-26.885647	26.865645
13562	0.40	1.80	22.16	6.20	25.17	38.40	-26.885598	26.865382
13563	0.50	1.00	12.31	6.80	27.61	35.50	-26.88552	26.864918
13564	0.40	2.20	27.09	8.10	32.89	47.10	-26.885475	26.864465
13565	0.50	1.80	22.16	6.20	25.17	40.10	-26.885427	26.864055
13566	0.60	1.80	22.16	8.90	36.13	50.10	-26.885383	26.863642
13567	0.40	1.20	14.78	8.70	35.32	42.10	-26.88532	26.863298
13568	0.50	0.70	8.62	7.80	31.67	38.50	-26.885245	26.862963
13569	0.40	1.40	17.24	5.30	21.52	32.70	-26.88523	26.862555
13570	0.40	2.30	28.32	3.50	14.21	33.50	-26.885262	26.862245
13571	0.40	0.60	7.39	8.70	35.32	39.00	-26.885287	26.86172
13572	0.40	0.40	4.93	6.30	25.58	30.40	-26.885377	26.86128
13573	0.30	0.50	6.16	6.60	26.80	29.80	-26.885423	26.860875
13574	0.40	1.30	16.01	5.30	21.52	32.30	-26.885432	26.860427
13575	0.20	3.00	36.94	5.20	21.11	39.40	-26.88549	26.85999
13576	0.30	1.80	22.16	4.30	17.46	30.70	-26.88551	26.859878
13577	0.30	2.40	29.55	6.70	27.20	42.40	-26.886945	26.860188
13578	0.50	0.70	8.62	7.50	30.45	37.40	-26.88708	26.860542
13579	0.50	1.70	20.93	6.50	26.39	41.20	-26.887217	26.860867
13580	0.60	1.90	23.40	4.50	18.27	36.20	-26.887285	26.86104

Sample Id	K[%]	U[ppm]	U(Bq/kg)	Th[ppm]	Th (Bq/kg)	Dose (nSv/h)	Latitude	Longitude
13581	0.50	1.80	22.16	6.00	24.36	38.90	-26.887377	26.861298
13582	0.40	1.80	22.16	4.10	16.65	32.20	-26.887443	26.861452
13583	0.60	1.20	14.78	7.70	31.26	41.90	-26.887543	26.861773
13584	0.60	0.90	11.08	10.20	41.41	49.00	-26.887662	26.862107
13585	0.60	2.10	25.86	4.80	19.49	39.30	-26.887785	26.862485
13586	0.50	2.70	33.25	5.70	23.14	44.50	-26.887913	26.862805
13587	0.60	0.90	11.08	7.30	29.64	39.10	-26.888072	26.863177
13588	0.40	1.00	12.31	7.30	29.64	36.90	-26.888265	26.863562
13589	0.40	1.50	18.47	6.30	25.58	36.90	-26.888467	26.86387
13590	0.30	1.80	22.16	5.00	20.30	33.30	-26.888587	26.864388
13591	0.50	2.10	25.86	5.50	22.33	40.20	-26.888693	26.864885
13592	0.50	0.50	6.16	6.60	26.80	32.10	-26.888788	26.865402
13593	0.40	1.90	23.40	6.70	27.20	40.20	-26.888902	26.865897
13594	0.50	0.90	11.08	3.70	15.02	25.50	-26.88901	26.866412
13595	0.40	1.60	19.70	7.90	32.07	42.70	-26.889128	26.866922
13596	0.50	0.80	9.85	5.40	21.92	31.10	-26.889247	26.86745
13597	0.40	1.30	16.01	6.80	27.61	37.50	-26.88936	26.867945
13598	0.40	1.50	18.47	7.20	29.23	40.00	-26.88948	26.868457
13599	0.40	1.40	17.24	3.60	14.62	27.50	-26.889592	26.86895
13600	0.40	0.40	4.93	3.90	15.83	21.50	-26.889702	26.86946
13601	0.40	0.70	8.62	5.80	23.55	29.30	-26.889813	26.869973
13602	0.50	0.80	9.85	6.60	26.80	34.80	-26.889932	26.870465
13603	0.40	1.50	18.47	4.30	17.46	30.60	-26.890062	26.870962
13604	0.40	1.50	18.47	6.00	24.36	36.70	-26.890162	26.871478
13605	0.60	3.40	41.86	7.60	30.86	56.90	-26.890283	26.87198
13606	0.40	1.80	22.16	6.50	26.39	38.80	-26.890382	26.872495
13607	0.40	1.20	14.78	5.80	23.55	32.80	-26.890512	26.873003
13608	0.50	2.10	25.86	7.20	29.23	44.90	-26.890648	26.873503
13609	0.10	1.60	19.70	6.50	26.39	33.30	-26.890755	26.874005
13610	0.20	1.70	20.93	5.50	22.33	31.70	-26.890817	26.874265
13611	0.30	1.60	19.70	3.40	13.80	26.20	-26.890878	26.874522
13612	0.20	1.80	22.16	6.90	28.01	37.10	-26.890967	26.874965
13613	0.50	1.20	14.78	4.80	19.49	31.10	-26.891062	26.875388
13614	0.40	1.90	23.40	5.30	21.52	36.20	-26.891243	26.875593
13615	0.30	1.40	17.24	4.60	18.68	28.20	-26.891553	26.875922
13616	0.30	2.30	28.32	5.20	21.11	36.60	-26.89184	26.876258
13617	1.00	1.80	22.16	8.70	35.32	55.90	-26.892027	26.87648
13618	1.20	4.00	49.25	5.20	21.11	62.60	-26.892365	26.876677