



GOLD FIELDS
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Wednesday, 31 March, 2021

Our ref.: COR18A0706
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Dear Ms M Makgale,

ACR No. 132: PUBLIC SAFETY ASSESSMENT FOR SOUTH DEEP GOLD MINE FOR SOUTH DEEP GOLD MINE (COR-18).

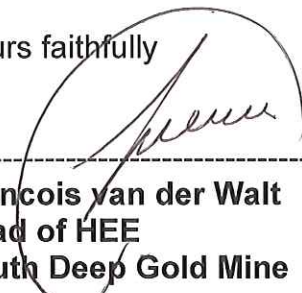
Please find attached the Public Safety Assessment for South Deep Gold Mine, Volume I and Volume II.

ACR Number	Section to be Revised	New Revised Delete Document	Document short title.	Document Full Title	Revision No. if required
132	All	Revised	PSA	Public Safety Assessment	09

Should you require further information, please do not hesitate to contact C. Tshabalala at (011) 411 1675

Please address all correspondences to the Head of HEE for South Deep Gold Mine.

Yours faithfully



Francois van der Walt
Head of HEE
South Deep Gold Mine

* South Deep Joint Venture is an unincorporated joint venture between GFI Joint Venture Holdings Proprietary Limited (Reg. No. 1998/023354/07) and Gold Fields Operations Limited (Reg. No. 1959/003209/06), both wholly-owned subsidiaries of Newshelf 899 Proprietary Limited (Reg. No. 2007/019941/07) a subsidiary of Gold Fields Limited (Reg. No. 1968/004880/06).

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SOUTH DEEP GOLD MINE

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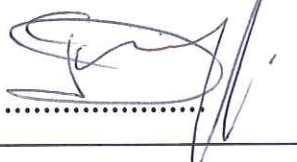
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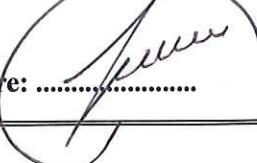
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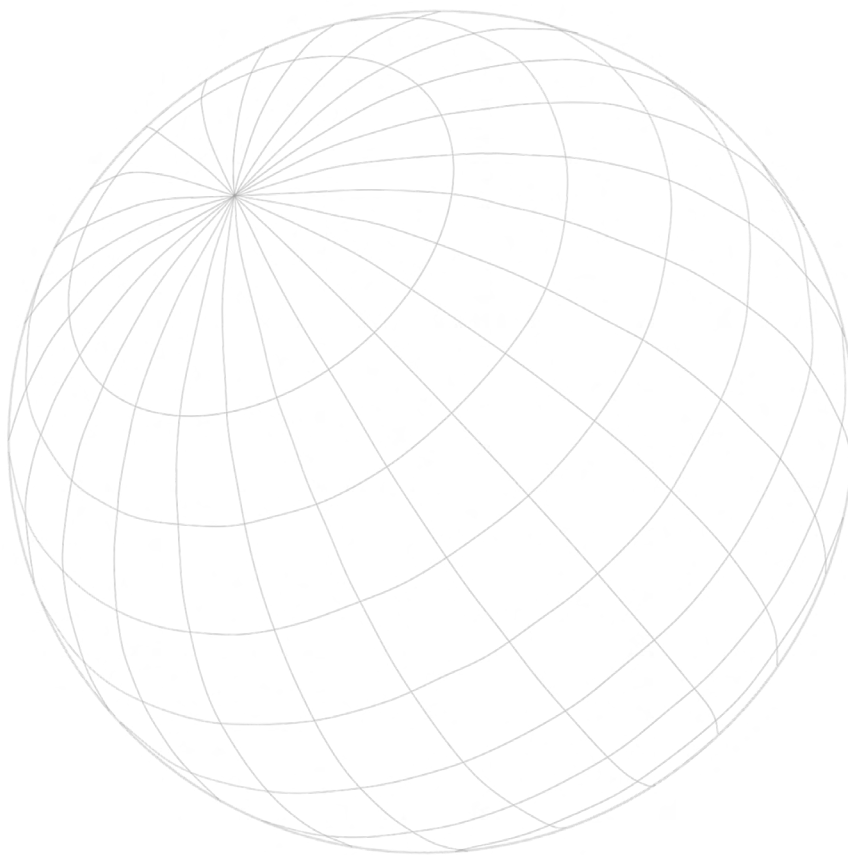
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2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine



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Technical Report



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* = Distributed via e-mail

REVISION TABLE

Revision 0

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LIST OF ACRONYMS

Bq	Becquerel
CoR	Certificate of Registration
GFI	Gold Fields Limited
IAEA	International Atomic Energy Agency
LLα	Long-Lived Radioactive Dust (Alpha)
MPRD Act	Minerals and Petroleum Resources Development Act
mSv	millisievert
NEA	Nuclear Energy Act (Act No. 46 of 1999)
NNR	National Nuclear Regulator
NNRA	National Nuclear Regulator Act (Act 47 of 1999)
NORM	Naturally Occurring Radioactive Materials
PM ₁₀	Particulate matter less than 10 micron in size
RGMS	Radon Gas Monitors
RPP	Radiation Protection Programme
RPS	Radiation Protection Specialist
RPSA	Radiological Public Safety Assessment
RWD	Return Water Dam
SPR	Source-Pathway-Receptor
TSFs	Tailings Storage Facilities
TSP	Total Suspended Particles
VCR	Ventersdorp Contact Reefs
WRD	Waste Rock Dump

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1 Introduction

1.1 Background

Gold Fields has operated in South Africa since 1887 when Cecil John Rhodes and Charles Rudd formed Gold Fields of South Africa. In 1932, the company began mining the mineral-rich West Rand, where it discovered high-yielding gold deposits. A merger between Gold Fields of South Africa and Gencor in 1998 led to the formation of Gold Fields Limited (GFI). Today, GFI is an unhedged, globally diversified producer of gold that has built on its South African reserves and resources, with a portfolio of eight operating assets and several exploration projects grouped into four regions, namely Australia, Ghana, Peru and South Africa. Gold Fields has a primary listing on the Johannesburg Stock Exchange, with secondary listings on the New York Stock Exchange and the Swiss Exchange.

The only remaining GFI mining operation in South Africa is the South Deep Gold Mine,, which conducts gold mining and processing operations in a lease area comprising approximately 4,268 hectares. All required authorisations have been obtained and are in good standing. The conversion of the old order mining right to a new order mining right, as required in terms of the Minerals and Petroleum Resources Development Act (MPRD Act) (Act 28 of 2002) was approved in July 2010.

Geographically, the South Deep Gold Mine, is situated in the magisterial districts of Westonaria and Vanderbijlpark in the Gauteng Province of South Africa, some 45 kilometres south-west of Johannesburg (see Figure 1.1). It is accessed *via* the N12 provincial road between Johannesburg and Potchefstroom. Neighbouring towns include Fochville, which is situated 25 km to the west, Carletonville situated about 35 km to the north-west, Westonaria situated 15 km to the north, Randfontein situated 30 km to the north and Vereeniging situated 40 km to the south-east of the South Deep Gold Mine,. Figure 1.2 presents a map showing the South Deep Gold Mine, in relation to major towns and other mining operations, while Figure 1.3 presents the present underground Mining Right Area.

The South Deep Gold Mine, has extensive underground workings and surface production facilities, with associated infrastructure that are used to access and extract gold-bearing ore from the Ventersdorp Contact Reefs (VCR) and the Upper Elsburg formation conglomerates of the Witwatersrand Basin (see Figure 1.3). The Upper Elsburg Reefs constitute ~98% of the Mineral Reserve ounces, while the VCR makes up the remaining ~2%. It is estimated that the current Mineral Reserves will be depleted in 2093 (75 years).

The surface production facilities and associated infrastructure include a metallurgical gold processing plant, backfill and water treatment plants, access and ventilation shaft complexes, historical and new tailings storage facilities (TSFs), waste rock dumps (WRDs), return water dams (RWDs), process water dams, transfer pipelines for water and tailings and an administrative office complex.

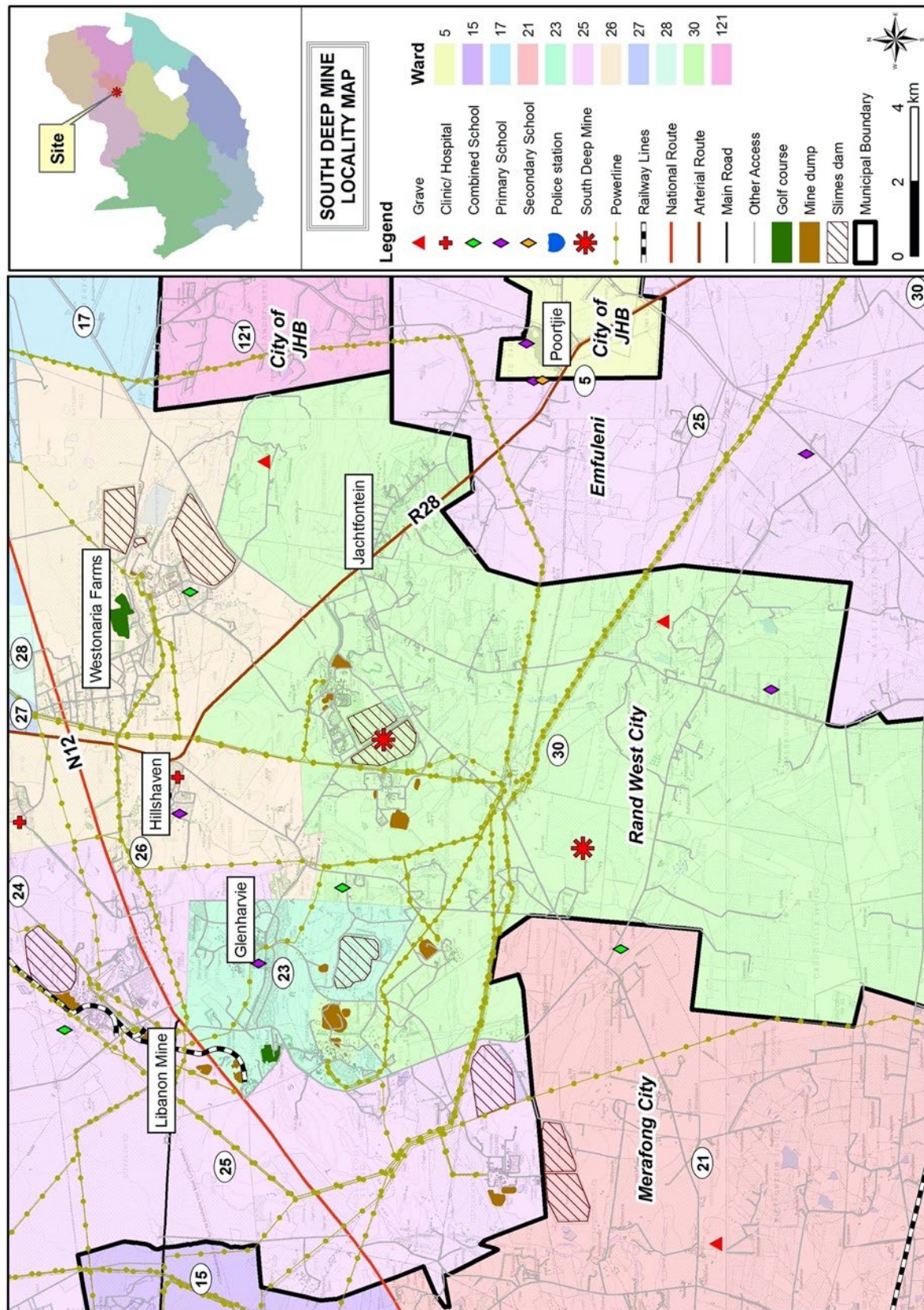


Figure 1.1 Map showing the South Deep Gold Mine, is located within the magisterial districts of Westonaria and Vanderbijlpark (Gauteng province), some 45 kilometres south-west of Johannesburg (Equispectives, 2020).

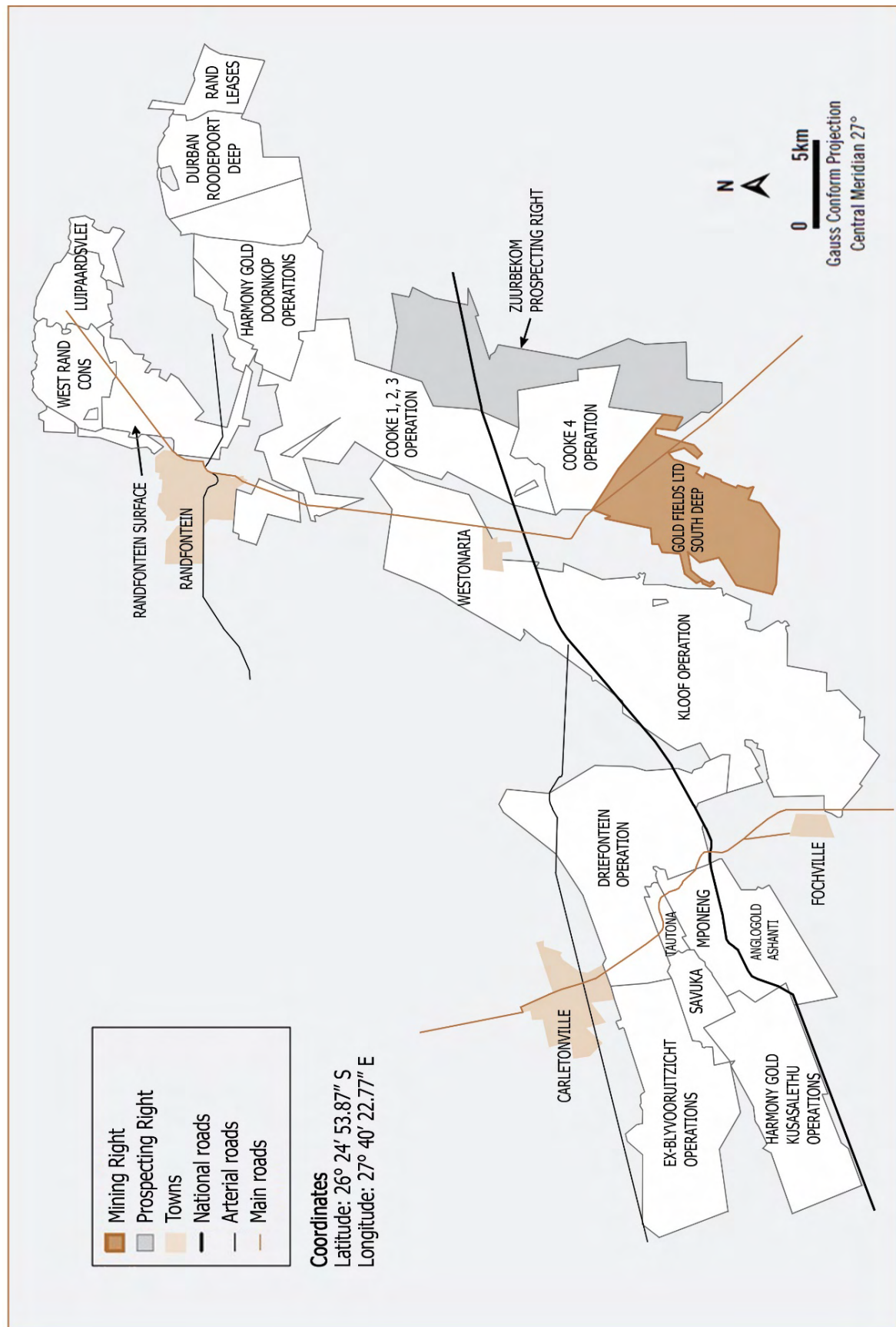


Figure 1.2 Map showing the South Deep Gold Mine, in relation to major towns and other nearby mining operations.

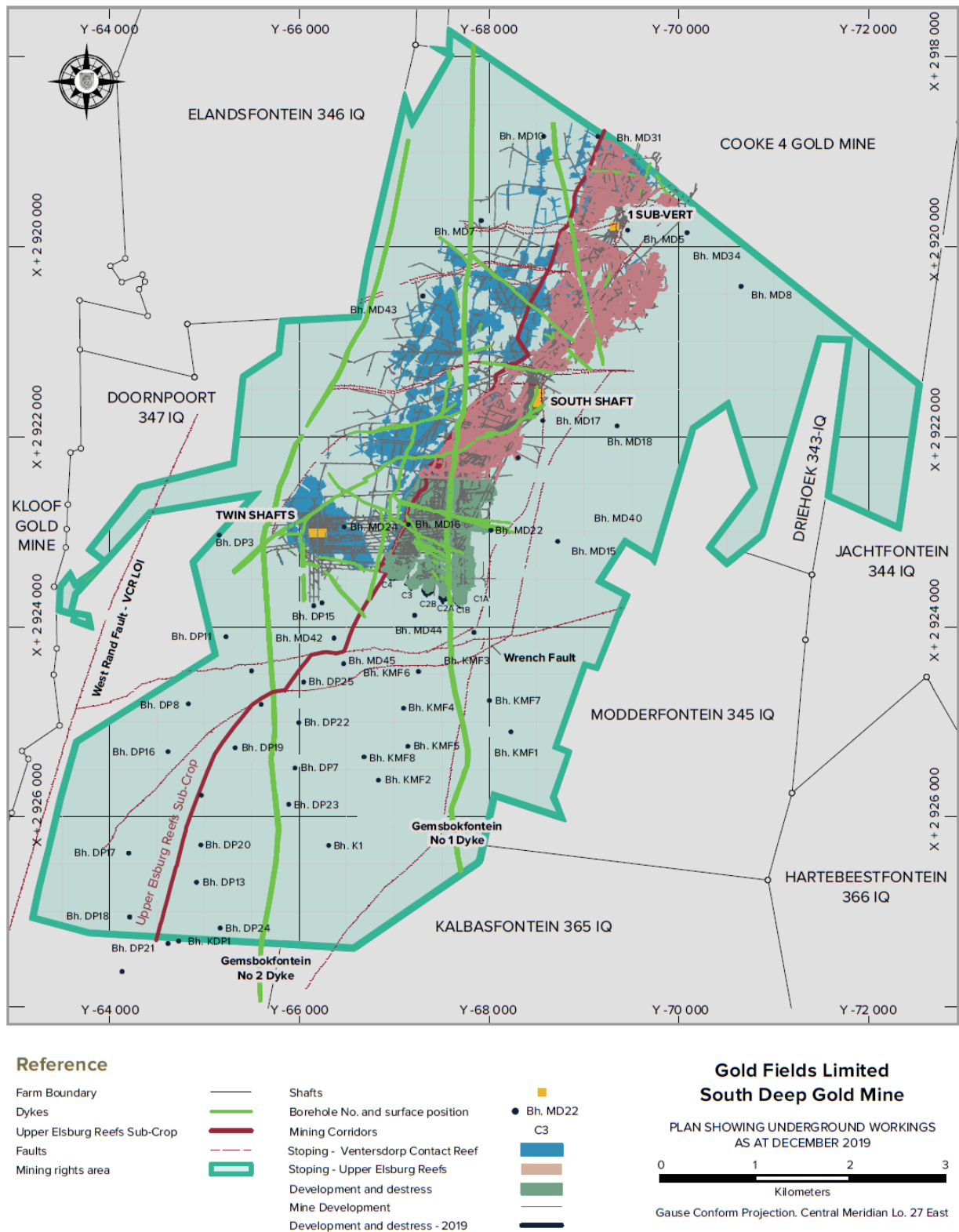


Figure 1.3 Map showing the present Mining Right Area and scope of the South Deep Gold Mine, operations.

1.2 Naturally Occurring Radionuclides

Naturally occurring radionuclides associated with the uranium, thorium and actinium decay series are associated in varying degrees with the gold-bearing reefs of the Witwatersrand Basin. These naturally occurring radionuclides are present in ore brought to the surface for processing and consequently was carried through to the mineral processing residues that are now stored on the surface as tailings or sand facilities. These materials and residues that contain naturally occurring radionuclides are generally referred to as Naturally Occurring Radioactive Materials (NORM) (IAEA, 2007).

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). 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 other wastes.

Industries such as NORM generating mining and mineral processing operations and associated facilities and activities thus have the potential to alter the natural background radiation, and potentially increase radiation exposure to human beings and the environment, by:

- Moving naturally occurring radionuclides from inaccessible locations to locations where humans are present and can be exposed;
- Concentrating naturally occurring 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).

1.3 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 safety 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”.

Gold Fields holds a Certificate of Registration (CoR-18) granted by the NNR in terms of Section 22 of the NNRA for the South Deep Gold Mine. Under the regulatory process administered by the NNR and in line with internationally accepted radiation protection and management practices, a CoR holder must submit an updated Radiological Public Safety Assessment (RPSA) regularly (every 3 to 5 years) to retain the nuclear authorisation. The purpose of these revisions is to reflect

on regulatory and operational changes incurred during this period and to assess the radiological consequences of these changes to members of the public. At the same time, new information that became available on the current operation can be incorporated into the RPSA and the associated public Radiation Protection Programme (RPP) can be revised and updated accordingly. Collectively, this ensures that the protection of members of the public against exposure to ionizing radiation-induced by facilities and activities incorporated within the scope of the CoR is in line with the national safety standards.

The current radiological public safety assessment for the South Deep Gold Mine, was performed and submitted to the NNR in 2017 (Van Blerk and Potgieter, 2017). Aquisim Consulting (Pty) Ltd (Aquisim) was appointed as Radiation Protection Specialist (RPS) to update the 2017 Radiological Public Safety Assessment of the South Deep Gold Mine, in accordance with the provision, requirements, and guidelines provided by the NNR (hereafter referred to as the 2020 South Deep Gold Mine, RPSA).

1.4 Purpose, Scope, and Structure of the Report

The purpose of this report is to present the 2020 South Deep Gold Mine, RPSA as a compilation of the five reports listed below. The five reports that are attached as Appendices to this report are the following:

- Appendix A: 2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine,: Assessment Context (Reference No. ASC-1048B-1) (Aquisim, 2020a).
- Appendix B: 2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine,: System Description (Reference No. ASC-1048B-2) (Aquisim, 2020b).
- Appendix C: 2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine, Development of Scenarios and Exposure Conditions (Reference No. ASC-1048B-3) (Aquisim, 2020c).
- Appendix D: 2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine,: Mathematical Model Development (Reference No. ASC-1048B-4) (Aquisim, 2020d).
- Appendix E: 2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine,: Consequence Analysis and Interpretation of Results (Reference No. ASC-1048B-5) (Aquisim, 2020e).

Each of these reports represents a standalone document but collectively represents the 2020 South Deep Gold Mine, RPSA. Also, some of the introductory text in each of these reports are repeated, to facilitate the standalone nature of the documents in a consistent manner. Further to the standalone nature of this report, an executive summary of the 2020 Gold Fields South Deep Gold Mine, RPSA is presented in Section 2. Section 2.7 summarises the current state of radiation monitoring and surveillance at the South Deep Gold Mine, as contained in the current public RPP, supplemented with recommendations for additional monitoring in light of the 2020 South Deep Gold Mine, RPSA findings. Conclusions and recommendations are presented in Section 3.

2 Executive Summary

2.1 General

The purpose of this section is to present an executive summary of the 2020 South Deep Gold Mine, Radiological Public Safety Assessment. The details of the assessment are presented in a compilation of five reports listed in Section 1.4. Section 2.2 summarises the purpose and objectives of the assessment, while Section 2.3 to Section 2.6 summarises the outcome of each of these objectives. Recommendations for the improvement of the public RPP is presented in Section 2.7.

2.2 Purpose and Objectives of the Assessment

The purpose of the 2020 South Deep Gold Mine, RPSA was defined in the *Assessment Context* report (Aquisim, 2020a) as follows:

To assess the radiological safety to members of the public from conditions induced by the South Deep Gold Mine, in a comprehensive, systematic, and transparent manner that is consistent with the NNRA and NEA, as well as with NNR requirements, guidance, and regulations.

The main objective of the assessment was defined as to demonstrate to the NNR with confidence that members of the public residing near the South Deep Gold Mine, are not exposed to levels of ionising radiation-induced by these operations above the regulatory compliance criteria set for public exposure. The following specific objectives were subsequently defined for the 2020 South Deep Gold Mine, RPSA:

- Assess the radiological impact to members of the public induced by the South Deep Gold Mine, within a systematic, structured, and transparent methodological safety assessment framework (see Section 2.3);
- Describe the operational, environmental and associated human behavioural conditions relevant to the South Deep Gold Mine, including any relevant changes that may have occurred the past 5 years, as well as any new information and data that may have become available (see Section 2.3);
- Develop and justify a discrete set of public exposure conditions using a systematic approach that are representative of the operational and prevailing environmental conditions, but also the associated human behavioural conditions observed near the South Deep Gold Mine, (see Section 2.4);
- Use the current understanding of the total system, to comprehensively assess the radiological consequence of the public exposure conditions defined for the assessment, based on appropriate and well-justified *Process Level* and *System Level* modelling results (see Section 0 and Section 2.6);

- Use the outcome and results of the radiological public safety assessment as a basis to propose revisions to the Public Radiation Protection Programme (RPP) as appropriate, with the purpose to ensure that members of the public are protected from radiation exposure induced by the South Deep Gold Mine, (see Section 2.7); and
- Compile a *safety case* of the South Deep Gold Mine,, aimed at integrating all safety arguments into a confident safety statement of the South Deep Gold Mine, and its potential impact on members of the public.

The purpose and objectives of the 2020 South Deep Gold Mine, RPSA were further bounded by a definition of the scope and focus of the assessment in terms of aspects such as the contribution of natural background radiation to public exposure, contaminants of concern in the assessment, cumulative effects between the South Deep Gold Mine, and nearby mining operations, spatial and temporal periods of concern to the assessment, human behavioural conditions, and the assessment of non-human biota.

Furthermore, the assessment was performed within a regulatory framework that is defined and based on national laws and regulations, supplemented with international principles, requirements, and guidance. This ensures that due process was followed for the protection of members of the public from exposure to ionizing radiation potentially induced by the South Deep Gold Mine,.

2.3 Supporting Structures for the Safety Assessment

2.3.1 Safety Assessment Methodology

The 2020 South Deep Gold Mine, RPSA was performed within the structures of a predefined safety assessment methodology schematically illustrated in Figure 2.1. It is inherently systematic, if applied as intended, and resembles the International Atomic Energy Agency (IAEA) ISAM safety assessment methodology developed for near-surface radioactive waste disposal facilities (IAEA, 2004). Slight modifications have been introduced to make the methodology more rigorous for typical mining and mineral processing operations.

As illustrated in Figure 2.1, the methodology consists of several key elements, each one of which is defined to collectively ensure that the approach followed in the assessment process is systematic, comprehensive and transparent. Consistent with the assessment methodology and the technical approaches therein, the following reports were produced in support of the 2020 South Deep Gold Mine, RPSA:

- The *assessment context* report defines the overall scope within which the assessment will be conducted. It states how the stakeholders or target audience are informed of what is included or excluded from the assessment and justification for the choices made. Viewed from this perspective, the purpose of the context document is to describe the purpose, scope, and focus of the assessment and to define the assumptions and constraints that reflect the regulatory and technical requirements of the assessment.
- Consistent with the second objective of the assessment (see Section 2.2), the purpose of the *system description* report is to provide a summary description of the South Deep Gold Mine,,

supplemented with a description of the associated environmental and human behavioural characteristics. These included any relevant changes that may have occurred in the past 5 years, as well as any new information and data that may have become available.

- The purpose of the *definition and justification of scenarios and public exposure conditions* report is to define and justify a limited set of discrete public radiation exposure conditions that are consistent with the South Deep Gold Mine, and associated environmental and human behavioural conditions. As illustrated in Figure 2.1, the output from the environmental *Process Level* modelling provides input into this step.

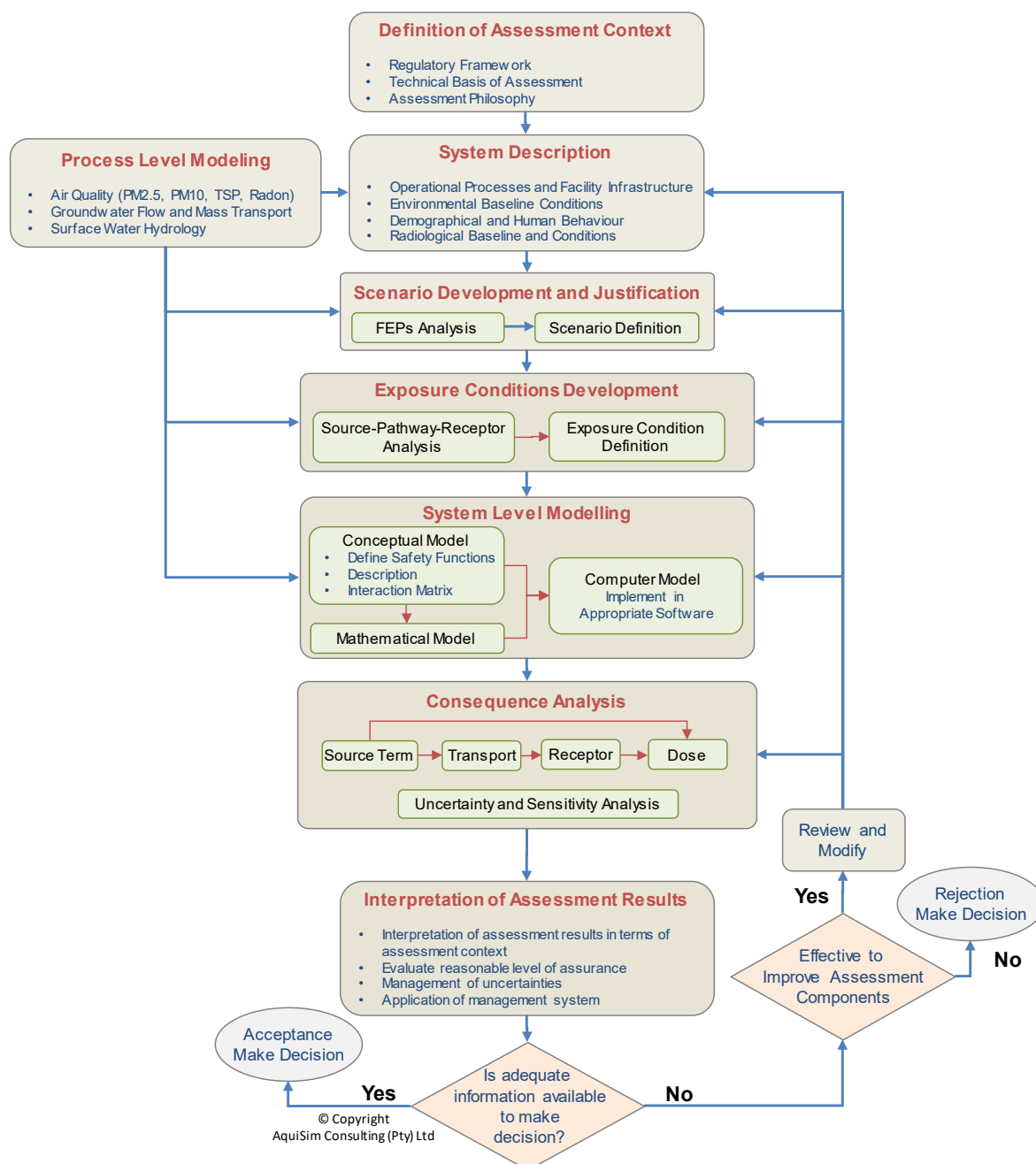


Figure 2.1 Schematic illustration of the safety assessment framework, within which the 2020 South Deep Gold Mine, RPSA was performed (Aquisim, 2020a).

- The *mathematical model development* report translates the conceptual models developed for each exposure condition into the necessary mathematical models and associated parameter values and presents the implementation of these models in appropriate computer software for the assessment.
- The *consequence analysis and interpretation of results* report documents the actual dose calculations and results, present discussions on sensitivity and uncertainty analysis, and interpret the results against the regulatory requirements and conditions as defined in the assessment context. In some cases, this requires an abstraction of *System Level* information from the *Process Level* models. This report also presents some conclusions and recommendations as appropriate.

Each one of these elements and associated reports ensures that the approach followed for the 2020 South Deep Gold Mine, RPSA is systematic, structured, comprehensive, and transparent. Collectively, this reduces uncertainties and increase stakeholder confidence in the safety assessment results.

2.3.2 Safety Assessment Approach

By examining a range of potential conditions of concern, it is possible to develop confidence that the public is protected from radiation exposure, even though exact statements about future exposures cannot generally be made. In other words, the inherent nature of the assessment methodology - from the release of radioactive contaminants, the migration of these contaminants into the environment, the subsequent uptake of radionuclides into the human body to pose a radiological exposure - is not an *exact science*. The safety assessment approach draws from the fundamental principles of exact sciences and parts of the assessment methodology are sometimes amenable to “normal” scientific approaches. However, the time scales, spatial scales, uncertainties in boundary conditions and uncertainties in future human behaviour make it impossible to test and verify (or falsify) the overall assessment.

Within the context of the assessment philosophy as defined in the *Assessment Context* report (Aquisim, 2020a), the objective of the safety assessment is to develop an understanding of the limits of potential radiological exposure to members of the public for an assumed set of conditions and parameter values. Given the nature and associated uncertainties associated with the safety assessment process, the overall approach adopted for the assessment is to demonstrate a *reasonable assurance of compliance* using a cautious (conservative) realistic approach as opposed to an *absolute assurance of compliance*.

2.3.3 Continual Improvement of the Safety Assessment

An inherent feature of the safety assessment methodology is the iterative nature of the approach, aimed at the continual improvement and refinement of the safety case and supporting safety assessment.

The regulatory context presented in Section 1.3 emphasises the fact that it is internationally accepted as good radiation protection and management practice to revise and update an assessment regularly, say every 3 to 5 years. The purpose of the revision is to reflect on regulatory

and operational changes that may have incurred during this period and to assess the radiological consequences of these changes to members of the public. At the same time, new information that became available on the current operation can be incorporated into the safety assessment.

The first safety assessment for the South Deep Gold Mine, dates back to 2002 (Van Blerk, 2002), with updated assessments submitted to the NNR in 2010 (South Deep Gold Mine, 2010) and 2017 (Van Blerk and Potgieter, 2017). The 2020 South Deep Gold Mine, RPSA followed the same comprehensive approach used in 2017, with further iterations to follow is needed. The emphasis of these iterations would be to improve the safety assessment and safety case for the South Deep Gold Mine. The decision to go through subsequent iterations will depend on, amongst others, to what extent a defensible safety case can be or has been demonstrated.

2.3.4 Transparency

Efforts were made to be transparent during each stage of the assessment process. All information necessary for the assessment were documented extensively, while all assumptions and conditions imposed on the assessment were documented and justified to the extent possible. This led to a comprehensive system description, which describes the South Deep Gold Mine, processes and associated features, the prevailing environmental, human behavioural and land use conditions, as well as the operational and environmental radiological conditions, in detail. The system description then served as the basis for the definition and justification of the public exposure conditions considered in the assessment, which was again documented in detail. The definition and justification of the public exposure conditions serve as an example of the transparent nature of the assessment.

A further example is the transparent nature of the assessment is the comprehensive documentation and justification of the mathematical models and associated parameter values used in the assessment. All values needed for the dose assessment, for example, were compared to a range of values from the literature. Also, conceptual models were represented using different methods.

2.3.5 Specialist Studies

Two specialist studies were performed in support of the 2020 South Deep Gold Mine, RPSA. These studies are:

- A specialist social research study of the communities surrounding the South Deep Gold Mine,, their human behavioural conditions, and their interaction with the environment. This study was performed by Equispectives (Equispectives, 2020); and
- A specialist study to quantify impacts on the atmospheric pathway induced by the South Deep Gold Mine,, with specific consideration of the contribution of PM₁₀, TSP and radon gas to the radiological public impact. This study was performed by ParcScientific (Parc Scientific, 2020).

2.4 Public Radiation Exposure Conditions

A key element in the safety assessment framework is the use and definition of public exposure conditions. Ideally, one would have preferred to assess the *actual* radiological exposure to each individual residing near the South Deep Gold Mine,. However, this would require in-depth knowledge of the human behavioural conditions (i.e., what, when, and how much they eat and drink, how much time they spent where, etc.) for as long as they reside in the area. Also, it would require detailed knowledge (measurements) of activity concentration in environmental media that members of the public would interact with, and more importantly, *only in terms of the actual contribution from the mining and mineral processing operation*. This is not practical or viable and an alternative approach was needed.

The approach followed in this assessment, was to derive a discrete set of exposure conditions. The key point of judgement whether the discrete set of exposure conditions are representative for the radiological public safety assessment is whether the *potential* receptors of radiation exposure (i.e., members of the public residing in the vicinity of the South Deep Gold Mine,) can *relate to at least one of these exposure conditions*.

Different approaches can be used to derive public exposure conditions for a mining and mineral processing operation. Consistent with the safety assessment framework in Figure 2.1, a Source-Pathway-Receptor (SPR) analysis approach was judged appropriate to define a limited set of discrete representative public exposure conditions for the 2020 South Deep Gold Mine, RPSA. The definition and justification of public exposure conditions within the safety assessment framework are designed as a logical process for screening the myriad of possible circumstances that may result in radiation exposure to members of the public. This process simplifies the selection of appropriate parameter values but also enhances the systematic and structured approach to present a defensible safety case.

Taken into consideration site-specific conditions, two discrete public exposure conditions were defined to evaluate the radiological consequences associated with the normal evolution of the South Deep Gold Mine,:

- A Residential Area Exposure Condition; and
- A Commercial Agricultural Exposure Condition.

It is believed that these exposure conditions are conservative, as well as reasonable comprehensive and representative of the broader set of potential public exposure conditions associated with the area. The derivation, as well as detail descriptions of each of these exposure conditions, are presented in the *Definition and Justification of Scenarios and Public Exposure Conditions* report (Aquisim, 2020c).

2.5 Environmental Pathway Analysis

2.5.1 General

Three environmental pathways are of importance to assess the distribution of radionuclides released from the NORM facilities associated with the South Deep Gold Mine. These are the atmospheric pathway, the groundwater pathway, and to a lesser extent the surface water pathway. Where applicable, these pathways were evaluated using a *Process Level* modelling approach, which was then used as the basis for *System Level* modelling (see Figure 2.1).

2.5.2 Atmospheric Pathway

The atmospheric pathway analysis is based on an air quality assessment documented in Parc Scientific (2020). This study was performed comprehensively, with the potential annual average PM₁₀ airborne concentration, the potential annual average TSP deposition rate (dust fallout) and the potential airborne radon concentration as output. These results were used to calculate the spatial distribution of the nuclide specific airborne activity and dust fallout concentrations.

The output from the air quality studies become the basis for evaluating the contribution of the atmospheric pathway for the public exposure conditions. The atmospheric pathway was considered in all the exposure conditions, with the main impact in an east and south-south-easterly direction. This can be attributed to the local wind rose on an annual average basis. Confidence in the dose assessment results is thus related to confidence in the air quality studies. The following can be noted:

- Airborne radon contributed by releases from the ventilation shafts was shown to be notable, even relative to that of the TSFs. However, the localised nature of these releases leads to a rapid decrease in concentration with distance from the source. The relative contribution of radon emitted from these shafts to the annual effective public dose is, therefore, comparatively small and largely restricted to the operational areas where the shafts are situated. A similar restriction in the dispersion of particulates from the ventilation shafts was observed.
- As expected, the contribution of the atmospheric pathway shows a strong correlation with the location of the TSFs. Measures put in place by the South Deep Gold Mine, to prevent wind erosion of the TSFs were considered in the estimation of windblown dust emissions. These include vegetation of side slopes as well as moisture present in the surface of tailings. The latter is especially applicable to the Doornpoort TSF. However, no mitigation was considered for radon emissions from the tailings. It was conservatively assumed that the entire surface area of the TSFs serves as a source of radon, irrespective of the physical nature or cover applied.
- The contribution of waste rock dumps towards airborne concentrations of both particulates and radon was considered in the determination of the total effective dose. However, the two waste rock dump areas are relatively small, with some rehabilitation work in progress in those areas. The contribution of the waste rock dumps is consequently more because of the material handling activities, as far as the contribution from particulates is concern.

- The contribution of the material handling operations to PM₁₀ and TSP at the metallurgical plant, such as crushing, milling and screening of material, is significant but localised. This means that their contribution as a radiation exposure source was still limited.
- The air dispersion pattern of airborne dust and radon gas is similar, with the result that the areas of impact for airborne dust (including deposition) and airborne radon concentration add to the cumulative impact from all sources of radiation exposure. In all cases, the steep decrease in the atmospheric pathway contribution away from the sources, result in large differences over short distances.

2.5.3 Groundwater Pathway

Process Level groundwater flow and mass transport models using sulphate as contaminant indicator are available for the South Deep Gold Mine, (Metago, 2011; Rison Groundwater Consulting, 2014), which were used as the basis for the development of a *System Level* model to evaluate the contribution of the groundwater pathway to a total effective dose.

The piezometric levels in the weathered aquifer tend to follow the topography, which means that the groundwater flow regime is expected to be towards the low-lying areas that coincide with the surface water drainage.

The groundwater pathway was included as a contributing pathway for the Commercial Agricultural Exposure Condition. However, the pathway was excluded as a contributing pathway from all dose calculations. It was argued and demonstrated through the *System Level* modelling that the contribution of the groundwater pathway sources to a potential total effective dose would be minimal in the short term (i.e., operational period). Even in the long-term, the effected contribution is minimal. It was illustrated that assuming the TSFs remains a source at the surface for 1,000 years, it is unlikely that groundwater leached from the area and migrated downgradient to a borehole 500 m away, will contribute to the total effective dose within 10,000 years, even with the conservative set of parameter values. The maximum estimated water ingestion dose under these conditions is less than 200 $\mu\text{Sv}\cdot\text{year}^{-1}$.

While the conclusion to exclude the groundwater pathway from the dose calculations for the exposure condition is justified over the timescales of concern, it is still important that the South Deep Gold Mine, groundwater monitoring programme maintained as part of the public Radiation Protection Programme confirms that there is indeed no contribution from the groundwater pathway from the relevant sources.

Note that the contribution of the groundwater pathway to a potential radiological impact to members of the public was further evaluated as an uncertainty factor using the results of the environmental monitoring that is being done as part of the public Radiation Protection Programme.

2.5.4 Surface Water Pathway

The surface water pathway was not evaluated as a dynamic system. Under normal operational conditions, the surface water pathway is an extension of the groundwater pathway with the various surface water bodies in the receiving environment (e.g., Leeu Spruit, Kariega Spruit). One can expect some contribution from the atmospheric pathway, but normally that is insignificant

due to the timescales of concern and the physical and dynamic properties of the surface water bodies. In some cases, controlled and uncontrolled releases to surface water bodies may further contribute to the radiological impact. The contribution of the surface water pathway to a potential radiological impact to members of the public was evaluated as an uncertainty factor using the results of the environmental monitoring that is being done as part of the public Radiation Protection Programme.

2.6 Consequence Analysis

2.6.1 General

The purpose of this section is to present a summary of the consequence analysis, with the emphasis on the dose assessment results as calculated for each exposure condition, and with the atmospheric pathway as the main contributor. Also, the potential contribution of the aquatic pathway is discussed, which was evaluated as an uncertainty factor. Note that the emphasis is on the normal evolution of the system, as expected during the operational period of the South Deep Gold Mine,.

2.6.2 Exposure Conditions

A discrete set of two public exposure conditions were defined to evaluate the radiological consequences associated with the normal evolution of the system. It is believed that these exposure conditions are conservative, as well as reasonable comprehensive and representative of the broader set of potential public exposure conditions associated with the area. These exposure conditions were derived using a systematic approach that considers the sources, pathways, and potential receptors (i.e., members of the public) in the area.

As expected, the potential radiological impact for each exposure condition is most significant near the sources. The locations identified for the assessment were conservatively selected as close as realistically possible to the South Deep Gold Mine, given the conditions assumed for the exposure condition. However, the decrease in the radiological impact with distance away from the facilities is significant. Note that the dispersion characteristics of airborne dust and airborne radon are not necessarily the same, with the result that the area of the highest impact associated with airborne dust dispersion and airborne radon dispersion is also not necessarily the same for the different exposure conditions.

The following were observed and concluded for the current operating conditions as well as the conditions and assumptions defined for the different exposure conditions:

- *Residential Area Exposure Condition:* Members of the public residing in formal structures in any of the residential areas near the South Deep Gold Mine, will not be subject to a total effective dose of more than 200 $\mu\text{Sv}\cdot\text{year}^{-1}$. The most significant contribution to the estimated dose is from radon and dust inhalation, as well as ingestion for the 12 to 17-year age group, most likely to be observed in the South Deep Gold Mine, worker residences and village.
- *Commercial Agricultural Exposure Condition:* Members of the public practising commercial agriculture near the South Deep Gold Mine, will not be subject to a total effective dose above

250 $\mu\text{Sv}\cdot\text{year}^{-1}$. The most significant contribution to the estimated dose is from radon and dust inhalation, as well as ingestion for the 12 to 17-year age group, with the highest potential impact to the south of the Doornpoort TSF.

2.6.3 The Contribution of the Aquatic Pathway to a Total Effective Dose

2.6.3.1 General

The contribution of the aquatic pathway was evaluated using the results from the surface water and groundwater monitoring programmes. For this purpose, conditions and assumptions consistent with a Subsistence Agricultural Exposure Condition were used. This is a conservative assumption, assuming members of the public use groundwater or surface water (e.g., dam or stream) to sustain a farm system for all their annual food needs. A consistent set of data were used for ease of reference. No attempt was made to define or subtract the contribution from the natural background or other operations, which was viewed as difficult for a complex and widespread operation such as the South Deep Gold Mine,. Averages of available monitoring data were used and secular equilibrium with the parent radionuclide was assumed in cases where data was not available. A 75-year irrigation period was assumed.

2.6.3.2 Groundwater

Monitoring data is available for groundwater close to operational areas as well as at boreholes on land used for agricultural purposes. Results of a dose assessment performed on the available groundwater activity concentrations indicated that the total annual effective doses vary between 10 $\mu\text{Sv}\cdot\text{year}^{-1}$ and 960 $\mu\text{Sv}\cdot\text{year}^{-1}$, with most of the groundwater monitoring points below 250 $\mu\text{Sv}\cdot\text{year}^{-1}$ for all age groups, as generally expected for groundwater samples. The exception is SIDA21, SIDA09, and SIDA13. The results for SIDA21 are influenced by a sample taken in 2018 with a high Ra-226 content (459 $\text{mBq}\cdot\text{L}^{-1}$) and the Pb-210 and Po-210 that was assumed to be in equilibrium with the Ra-226. SIDA09 is a sampling point close to the old TSF Complex return water dam and in all likelihood is influenced by the quality of the water. Only 2 full-spectrum analysis results from 2013 are available for SIDA09.

More uncertain to explain is the relative high results for SIDA13, which is located at the farmhouse near the Doornpoort TSF. Results for SIDA13 dates back to 2011 and was consistently high between 2011 and 2016. However, the results from 2019 were low. SIDA20, on the other hand, is located on the edge of the South Deep No. 2 TSF, between the TSF and the Return Water Dam. One would expect this result to be higher (one sample from 2019). However, the total effective dose derived from these results is relatively low (130 to 180 $\mu\text{Sv}\cdot\text{year}^{-1}$).

Note that except SIDA13, SIDA09 and SIDA21 are close to operational features of the South Deep Gold Mine, and, therefore, less accessible to members of the public or subsistence farming, whereas the other boreholes are at distances of 2 km from the mine. However, the results emphasise the importance of a groundwater monitoring programme and that monitoring, especially in areas close to operational features, be expanded to delineate the extent of potential radionuclide contamination of the groundwater pathway.

2.6.3.3 Surface Water

A similar evaluation was performed for the surface water pathway, using monitoring data of surface water collected from locations near the operational features, as well as upstream and downstream of the South Deep Gold Mine,. Evaluation of the activity concentrations indicated that surface water close to the operational features contains lower radionuclide concentrations than water upstream of the South Deep Gold Mine,. Results of a dose assessment performed on the available surface water activity concentrations indicated that the total annual effective doses vary between $13 \mu\text{Sv}\cdot\text{year}^{-1}$ and $1,960 \mu\text{Sv}\cdot\text{year}^{-1}$, with most of the surface water monitoring points are below $350 \mu\text{Sv}\cdot\text{year}^{-1}$ for all age groups.

The exception is SIDA11 and SIDA12, both of which is significantly higher than $1,000 \mu\text{Sv}\cdot\text{year}^{-1}$ for most age groups. These points are sampling points in the Leeu Spruit before and after the plant and shaft area. This suggests, with data that stretch from 2011 to 2019, that some contaminated water is released into the Leeu Spruit. However, downstream of these two monitoring points, the doses are much lower (e.g., SIDA02 and SIDA04). This again emphasises the importance of surface water monitoring at the South Deep Gold Mine, to ensure public safety.

2.6.4 Cumulative Radiological Impact

On a local scale, it can be noted that the 2020 South Deep Gold Mine, RPSA calculated the total effective dose to members of the public from all relevant exposure pathways included in the public radiation exposure conditions defined for the assessment. To the extent justified, the results, therefore, include the cumulative contribution from all exposure routes (e.g., inhalation, ingestion and external gamma radiation).

On a more regional scale, it was noted that the focus of the 2020 South Deep Gold Mine, RPSA is the South Deep Gold Mine,. The results provide a reasonable level of assurance that members of the public residing near the wider South Deep Gold Mine, will not be subject to a radiological impact above $250 \mu\text{Sv}\cdot\text{year}^{-1}$. For the cumulative contribution from other authorised facilities and operations, it was noted that the public *dose limit* applies, whereas for facility-specific assessments the *dose constraint* is more applicable, especially to address the issue of multiple contributions. It was argued, based on the results presented in the 2020 South Deep Gold Mine, RPSA, that it seems unlikely that the public dose limit would be exceeded in the areas where more than one authorised facility or operation are present.

2.6.5 Variations in Public Exposure Conditions

A distinction was made between variation in the defined exposure conditions and alternative exposure conditions.

It was argued that the defined exposure conditions were defined to be as broad as possible in its description of the site-specific conditions in the area. Also, the Commercial Agricultural Exposure Condition is very conservative and include all the potential exposure routes (i.e., inhalation, ingestion and external exposure) and at maximum exposure factors (i.e., exposure periods and ingestion rates of all products). One would, therefore, expect that any variation in the public exposure condition would be less than the total effective doses.

The two public exposure conditions defined and evaluated in the 2020 South Deep Gold Mine, RPSA is considered comprehensive and representative of a wide range of site-specific conditions. It was also argued that variations can be expected but that these variations will lead to a lower radiological impact than those considered in the assessment.

2.6.6 Variation in Parameter Values

Variation in various parameter values was considered to evaluate their impact on the assessment results and the conclusion reached in terms of regulatory compliance. For this purpose, the following were considered:

- *Human consumption rates:* Compared to literature values, some of the human consumption rates used are high and on the conservative side. This means that the definition and use of more realistic values will reduce the calculated ingestion doses. Since most of the calculated ingestion doses for the different exposure conditions are relatively low, lower consumption rates will just reduce the ingestion doses even further (linearly).
- *Dust deposition period:* The dose calculations for the different exposure conditions were performed assuming a 75-year deposition period, which was assumed to be realistic given the history of the South Deep Gold Mine. The dose assessment models assumed a build-up of activity on the soil surface over this period, which by implication influences the total effective dose. Longer deposition periods will result in higher ingestion and external gamma radiation but is not expected to change the conclusions during the operational period of the South Deep Gold Mine.
- *Groundwater pathway parameters:* The *System Level* evaluation of the groundwater pathway assumed conservative parameter values to evaluate the leaching and migration of naturally occurring radionuclides through the tailings storage facilities and underlying hydrogeology (i.e., unsaturated and saturated zones). The results have shown that it is highly unlikely that the groundwater pathway would be a significant contribution within the next 10,000 years.

The reason why these variations were considered is because of the uncertainty in the site-specific values. An evaluation of the sensitivity of some of the parameter values assumed for the groundwater pathway analysis was consequently presented, which included changes for the following parameters:

- Source duration (i.e., how long the TSF remains at the surface as a source of radiation exposure;
- Variation in the distribution coefficients (K_d -values for the tailings unsaturated zone and saturated zone;
- Variations in the hydraulic conductivity of the saturated zone;
- Variations in the distance to the abstraction borehole from the TSF;
- The aquifer thickness; and
- Initial activity concentrations of tailings material.

The effect of these variations varied from changes in the peak dose to earlier times that the peak dose at the abstraction borehole is reached. However, none of these variations

affected the general conclusions about the contribution of the groundwater pathway to the total effective dose for the different public exposure conditions.

- *Atmospheric pathway parameters:* The atmospheric pathway was evaluated in detail for the two public exposure conditions, assuming a well-justified set of parameter values. As part of the uncertainty analysis, two conditions were evaluated:
 - Initial activity concentrations of tailings material. The effect from a lower initial activity concentration for the Doornpoort TSF tailings has a significant effect resulting in a reduction of the total effective dose near the TSF (Agri 3 receptor point) from 232 $\mu\text{Sv}\cdot\text{year}^{-1}$ to about 90 $\mu\text{Sv}\cdot\text{year}^{-1}$.
 - The source term release rate of dust from the material handling activities. Given the localised nature of the material handling (e.g., crushing and screening) at the metallurgical plant, an increase in the source term release rate only has a localised impact on the total effective dose in that area.

2.7 Public Radiation Protection Programme

2.7.1 General

As part of the 2017 South Deep Gold Mine, RPSA (Van Blerk and Potgieter, 2017), an extensive review was performed of the South Deep Gold Mine, public Radiation Protection Programme (RPP) that was available at that time. Recommendations for the improvement of the public RPP based on the outcome of the 2017 South Deep Gold Mine, RPSA were made, which led to the current version of the public RPP (South Deep Gold Mine, 2017). Presented here is a re-emphasis of some of the recommendations made in 2017 as well as additional recommendations based on the outcome of the 2020 South Deep Gold Mine, RPSA, with due consideration of the operational changes at South Deep Gold Mine,.

2.7.2 Control Programme

The primary purpose of the control mechanisms at mining and mineral processing operations is to reduce the potential radiological impact that activities involving NORM could have on members of the public. These mechanisms may include both administrative aspects and engineering controls, with the collective purpose to eliminate or reduce radiation emission from the site to the environment. The following measures can be identified to control the releases from the various sources of potential public radiation exposure:

- At the South Deep Gold Mine,, dust suppression should be applied during the crushing, milling, and screening at the metallurgical processing plant, as well as during the handling of the waste rock during the handling and rehabilitation of the waste rock dumps. This includes the re-mining of the Old TSF.
- At the two historical TSFs, extensive control measures should be applied to reduce wind erosion. These include the installation of the windbreak, vegetation, irrigation of the side slopes, and partial covering of the TSFs with rock cladding.
- At the Doornpoort TSF, a wet deposition process should be applied, which inevitably reduce wind erosion.

- At the two historical TSFs, toe, elevator and blanket underdrains could be used to collect and control any seepage and runoff that may occur on the perimeter of the TSFs. This seepage is then collected into a trench system that feeds into the cascade system. Runoff from the TSF could be collected in toe paddocks from where it gravitates to the cascade pond RWDs.
- At the Doornpoort TSF, the design includes an underdrainage system comprising of toe drains and inner blanket drains, both draining to a concrete-lined solution trench around the perimeter of the TSF. The solution trench channels the water to a dedicated and lined RWD. There are also scavenger wells and a seepage cut-off curtain-drain downgradient of the Doornpoort TSF to collect any seepage moving underneath the solution trench.
- The operational areas of the Twin Shaft Complex and South Shaft Complex should be managed as a closed system, and any runoff is collected in the pollution control dam and diverted back into the system for reuse in the processing plant.

2.7.3 Surveillance Programme

The main purpose of the surveillance programme is to provide for the prompt identification of conditions that could lead to the migration of radioactive material into the environment or condition that might lead to the public exposure situation. At the South Deep Gold Mine, the surveillance program mainly focusses on monitoring/inspecting the control measures to ensure these remain in place. These may include but not necessarily limited to the following:

- Verify the integrity of the control mechanisms around the existing TSFs to reduce the effect of the run-off of effluent;
- Verify the implementation of the dust control mechanisms at the TSFs to prevent the spread of windblown dust into the environment;
- Verify that the land use of areas surrounding the authorized site is still similar to what was recorded in the 2020 South Deep Gold Mine, RPSA;
- Verify the integrity of surface water impoundments, such as the RWD and pollution control dam; and
- Identify any accidental and unauthorized release (e.g., flooding, theft of materials, etc.);

Formal inspections should be carried out by the RPO on an annual basis on all the above control measures. Accidental releases that could impact the public should be reported through the internal non-conformance reporting, or the occurrence reporting mechanism, as appropriate. The results of these inspections should be recorded and retained according to the requirements of the Internal Recordkeeping procedure.

2.7.4 Monitoring Programme

The current public Radiation Protection Programme makes provision for the monitoring of some environmental media that may contribute to a radiological impact on members of the public. The environmental media, which is consistent with the public exposure conditions defined for the 2020 South Deep Gold Mine, RPSA, includes surface water, groundwater, airborne radon gas, dust fallout buckets, and sediments monitoring (see Table 2.1).

Table 2.1 Summary of the environmental monitoring proposed for the South Deep Gold Mine,.

Source/Media	Measurement/Analysis	Frequency	Note
Ventilation Shafts	Radon (Estimated)	Annually	The source characterization recommended to be included in the monitoring and surveillance programme, does not represent specific locations, but are source or facility specific.
Ore	Full-spectrum analysis	Every three years	
Tailings	Full-spectrum analysis	Every three years	
	Radon exhalation rate	Every three years	
Waste Rock	Full-spectrum analysis	Every three years	
Return Water	Full-spectrum analysis	Annually	
	Total Uranium, Thorium and Radium	Quarterly	
Dust fallout and PM10	Total Uranium, Thorium, and Radium	Period of 12 months, every 3 years.	The dust fallout and PM ₁₀ monitoring programme should be coordinated with the air quality specialist, to coincide with the wider environmental monitoring programme.
Radon	Airborne radon activity concentrations	Period of 12 months, every 3 years.	See Table 2.5 for monitoring positions
Surface water	Full-spectrum analysis	Annually	See Table 2.2 for sampling positions.
	Total Uranium, Thorium and Radium	Quarterly	
Sediment	Full-spectrum analysis	Annual	See Table 2.3 for sampling positions
Groundwater	Full-spectrum analysis	Every three years	See Table 2.4 for sampling positions.
	Total Uranium, Thorium, and Radium	Bi-annually	
Meat, other foodstuffs	Remove from the monitoring programme		Recommended to be removed from the monitoring programme
Fish	Remove from the monitoring programme		

The monitoring locations for surface water, sediment, groundwater and RGMs are listed in Table 2.2 to Table 2.5. Note that those monitoring points highlighted in slight blue are recommended to be removed from the current public RPP since they are not appropriate as monitoring points anymore.

Table 2.2 Summary of the surface water monitoring points for the South Deep Gold Mine,.

GPS Co-Ordinates	Old Sample ID	New Sample ID	Location
Surface Water			
S26°25,326'	WS1	SIDA3	Old tailings complex RWD
E027°40,790'			
S26°28,400'	WS2	SIDA4	Leeuspruit S14
E027°41,523'			
S26°25,363'	WS5	SIDA2	Leeuspruit S6
E027°40,883'			
S26°25,509'	WS6	SIDA8	New tailings complex RWD
E027°40,404'			
S26°25,695'	WS8	SIDA1	Kariegaspruit S10
E027°40,420'			
S26°24,200'	WS9	SIDA11	Leeuspruit S11A
E027°41,266'			
S26°25,114'	WS10	SIDA10	Sewage water
E027°41,229'			
	WS11	SIDA19	Mine Return Water Dam
S26°24,870'	WS12	SIDA12	Leeuspruit S13
E027°41,026'			

Table 2.3 Summary of the sediment monitoring points for the South Deep Gold Mine,.

GPS Co-Ordinates	Sample ID	Location
S26°28,400'	S 14	Leeuspruit S14
E027°41,523'		
S26°25,363'	S 6	Leeuspruit S6
E027°40,883'		
S26°25,695'	S 10	Kariegaspruit S10
E027°40,420'		
S26°24,200'	S 11A	Leeuspruit S11A
E027°41,266'		
S26°23'457'	S 11B	Leeuspruit S11B
E027°41'591'		
S26°24,870'	Doornport	Doornport
E027°41,026'		

Table 2.4 Summary of the groundwater monitoring points for the South Deep Gold Mine,.

GPS Co-Ordinates	Old Sample ID	New Sample ID	Location
Surface Water			
S26°25,346 E027°40,787'	WS3	SIDA7	SD9 borehole next to old RWD
S26°29,114' E027°41,321'			
S26°28,432' E027°41,624'	WS4	SIDA5	Rheeders' borehole
S26°28,432' E027°41,624'	WS7	SIDA6	Orion's borehole
S26°28,432' E027°41,624'			

Table 2.5 Summary of the RGM monitoring points for the South Deep Gold Mine,.

GPS Co-Ordinates	Workplace
S26°07,970' E027°35,37'	Brandvlei
S26°00,041' E027°32,833'	Magaliesburg
S26°26,234' E027°41,592'	Orion peach farm
S26°25,432' E027°40,550'	New tailing dam next to the road SD10
S26°26,700' E027°41,338'	Perskes Modderfontein Veggie Farm
S26°24,895' E027°42,086'	Thusanong House No.24
S26°25,013' E027°40,868'	Corner of old tailings
S26°25,177' E027°40,699'	Old tailings dam road
S26°25,54' E027°40,315'	New slimes dam
S26°24,779' E027°41,309'	Elvis Farmhouse
S26°29,718' E027°41,098'	Kalbasfontein Tuckshop
S26°23,506' E027°33,652'	Elandfontein
S26°22,307' E027°39,559'	Hillshaven primary school
S26°23,161' E027°41,413'	Ezulwini junction
S26°23,768' E027°41,914'	Leeuspruit S11B
S26°22,104' E027°39,789'	Hillshaven flats
S26°21,338' E027°40,629'	Waterpan farm
S26°25'094' E027°41,234'	Sewage



3 Conclusions and Recommendations

3.1 Conclusion

A robust methodological assessment framework and approach that is comprehensive, systematic and transparent was followed to present the potential radiological impact on members of the public residing near the South Deep Gold Mine,. Care was taken to ensure that all assumptions, data and parameter values used in the assessment are documented and justified and based on relevant and available site-specific information as far as practically possible.

The assessment considered the operational period of the South Deep Gold Mine, and represent the most conservative set of conditions with regards to potential sources and pollutant emissions. Although it is expected that many of the sources will be removed or otherwise remediated following the closure of the operations, the assessment was performed as if the South Deep Gold Mine, will remain operational.

Based on the results of the 2020 South Deep Gold Mine, RPSA presented in this and other reports (Aquisim, 2020a; b; c; d; e), it can be concluded with a reasonable level of assurance that in all likelihood, members of the public residing permanently near the South Deep Gold Mine, will not be subject to radiation exposure levels above the public dose constraint of $250 \mu\text{Sv}\cdot\text{year}^{-1}$, *as a contribution from the South Deep Gold Mine,*.

3.2 Recommendations

While it is believed that the radiological safety of members of the public residing near the South Deep Gold Mine, has been demonstrated with a reasonable level of assurance, some general recommendation can be made to improve the overall safety case for the South Deep Gold Mine,. These include the following:

- Revise the current public Radiation Protection Programme (see Section 2.7) with the conditions as stipulated;
- Continue with the current South Deep Gold Mine, Environmental Management Programme, to ensure a sufficient level of understanding of the nature of the surface water, groundwater and atmospheric pathways. It is recommended that the *Process Level* air quality, groundwater, and surface water models for the South Deep Gold Mine, (as appropriate) be maintained and updated regularly (as required from an environmental management perspective) for use in future iterations of the radiological public safety assessment.
- Ensure that the public RPP capture any variation in land use conditions in the vicinity of the South Deep Gold Mine, continuously. These variations and the detail thereof should be captured, which will feed into more detailed land use and human behavioural study of members of the public for use in future iterations of the radiological public safety assessment.
- Keep and record the historic and new results and data generated as part of the radiation monitoring and surveillance programme in a consistent and auditable manner in a database.

This will not only improve quality control during the radiological public safety assessment process but also allows help to demonstrate to authorities the current state of the atmospheric and aquatic pathways concerning radionuclide concentrations and potential radiological impact to members of the public.



4 References

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Appendix A:
2020 Radiological Public Safety Assessment of the Gold Fields South Deep
Gold Mine: Assessment Context
(Reference No. ASC-1048B-1) (Aquisim, 2020a)

Appendix B:
2020 Radiological Public Safety Assessment of the Gold Fields South Deep
Gold Mine: System Description
(Reference No. ASC-1048B-2) (Aquisim, 2020b)

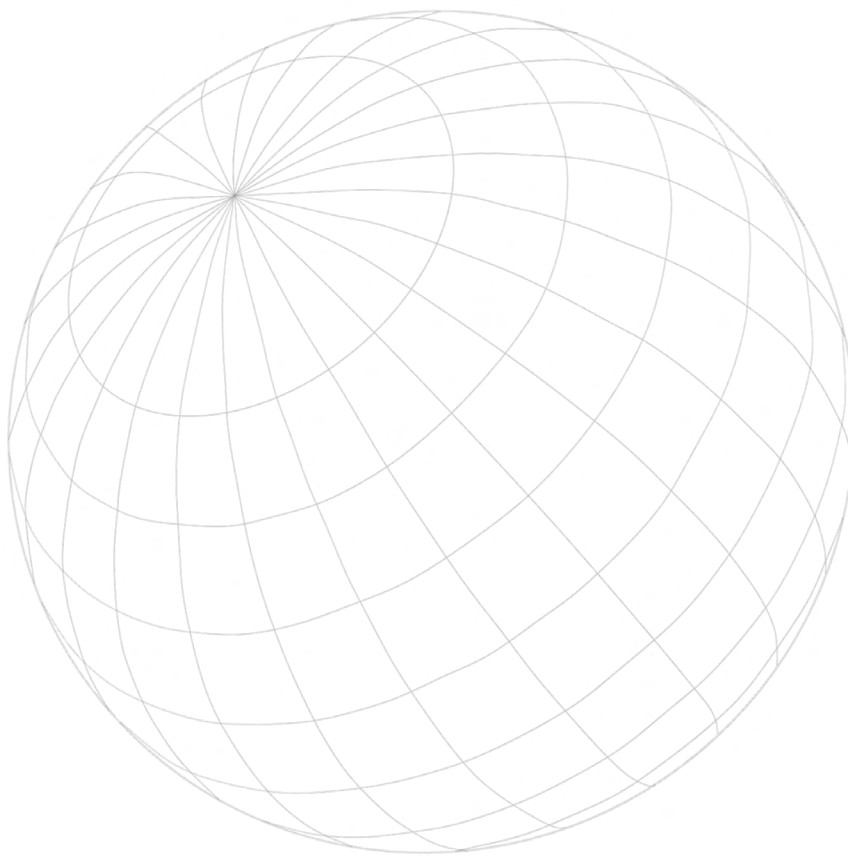
Appendix C:
2020 Radiological Public Safety Assessment of the Gold Fields South Deep
Gold Mine: Development of Scenarios and Exposure Conditions (Reference
No. ASC-1048B-3) (Aquisim, 2020c)

Appendix D:
2020 Radiological Public Safety Assessment of the Gold Fields South Deep
Gold Mine: Mathematical Model Development
(Reference No. ASC-1048B-4) (Aquisim, 2020d)

Appendix E:
2020 Radiological Public Safety Assessment of the Gold Fields South Deep
Gold Mine: Consequence Analysis and Interpretation of Results (Reference
No. ASC-1048B-5) (Aquisim, 2020e)

2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine:

Assessment Context



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REVISION TABLE

Revision 0

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LIST OF ACRONYMS

ACR	Authorization Change Request
ALARA	As Low As Reasonably Achievable
BSS	Basic Safety Standards
Bq	Becquerel
CoR	Certificate of Registration
DME	Department of Mineral and Energy
DoE	Department of Energy
FEPs	Features, Events And Processes
GFI	Gold Fields Limited
GSR	IAEA General Safety Requirement
IAEA	International Atomic Energy Agency
ICR	Congress of Radiology
ICRP	International Commission on Radiological Protection
LLα	Long-Lived Radioactive Dust (Alpha)
LoM	Life of Mine
MPRD Act	Minerals and Petroleum Resources Development Act
mSv	millisievert
NEA	Nuclear Energy Act (Act No. 46 of 1999)
NNR	National Nuclear Regulator
NNRA	National Nuclear Regulator Act (Act 47 of 1999)
NORM	Naturally Occurring Radioactive Materials
NRWDI	National Radioactive Waste Disposal Institute
NRWDIA	National Radioactive Waste Disposal Institute Act
NRWMP	National Radioactive Waste Management Policy and Strategy
PM ₁₀	Particulate matter less than 10 micron in size
QA/QC	Quality assurance/Quality control
RG	Regulatory Guide
RPP	Radiation Protection Programme
RPS	Radiation Protection Specialist
RPSA	Radiological Public Safety Assessment
RWD	Return Water Dam
SPR	Source-Pathway-Receptor
TSFs	Tailings Storage Facilities
TSP	Total Suspended Particles
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VCR	Ventersdorp Contact Reefs
WRD	Waste Rock Dump

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1 Introduction

1.1 Background

Gold Fields has operated in South Africa since 1887 when Cecil John Rhodes and Charles Rudd formed Gold Fields of South Africa. In 1932, the company began mining the mineral-rich West Rand, where it discovered high-yielding gold deposits. A merger between Gold Fields of South Africa and Gencor in 1998 led to the formation of Gold Fields Limited (GFI). Today, GFI is an unhedged, globally diversified producer of gold that has built on its South African reserves and resources, with a portfolio of eight operating assets and several exploration projects grouped into four regions, namely Australia, Ghana, Peru and South Africa. Gold Fields has a primary listing on the Johannesburg Stock Exchange, with secondary listings on the New York Stock Exchange and the Swiss Exchange.

The only remaining GFI mining operation in South Africa is the South Deep Gold Mine, which conducts gold mining and processing operations in a lease area comprising approximately 4,268 hectares. All required authorisation has been obtained and is in good standing. The conversion of the old order mining right to a new order mining right, as required in terms of the Minerals and Petroleum Resources Development Act (MPRD Act) (Act 28 of 2002) was approved in July 2010.

Geographically, the South Deep Gold Mine is situated in the magisterial districts of Westonaria and Vanderbijlpark in the Gauteng Province of South Africa, some 45 kilometres south-west of Johannesburg (see Figure 1.1). It is accessed *via* the N12 provincial road between Johannesburg and Potchefstroom. Neighbouring towns include Fochville, which is situated 25 km to the west, Carletonville situated about 35 km to the north-west, Westonaria situated 15 km to the north, Randfontein situated 30 km to the north and Vereeniging situated 40 km to the south-east of the South Deep Gold Mine. Figure 1.2 presents a map showing the South Deep Gold Mine relative to major towns and other mining operations, while Figure 1.3 presents the current underground Mining Right Area.

The South Deep Gold Mine has extensive underground workings and surface production facilities, with associated infrastructure that are used to access and extract gold-bearing ore from the Ventersdorp Contact Reefs (VCR) and the Upper Elsburg formation conglomerates of the Witwatersrand Basin (see Figure 1.3). The Upper Elsburg Reefs constitute ~98% of the Mineral Reserve ounces, while the VCR makes up the remaining ~2%. It is estimated that the current Mineral Reserves will be depleted in 2093 (75 years).

The surface production facilities and associated infrastructure include a metallurgical gold processing plant, backfill and water treatment plants, access and ventilation shaft complexes, historical and new tailings storage facilities (TSFs), waste rock dumps (WRDs), return water dams (RWDs), process water dams, transfer pipelines for water and tailings and an administrative office complex.

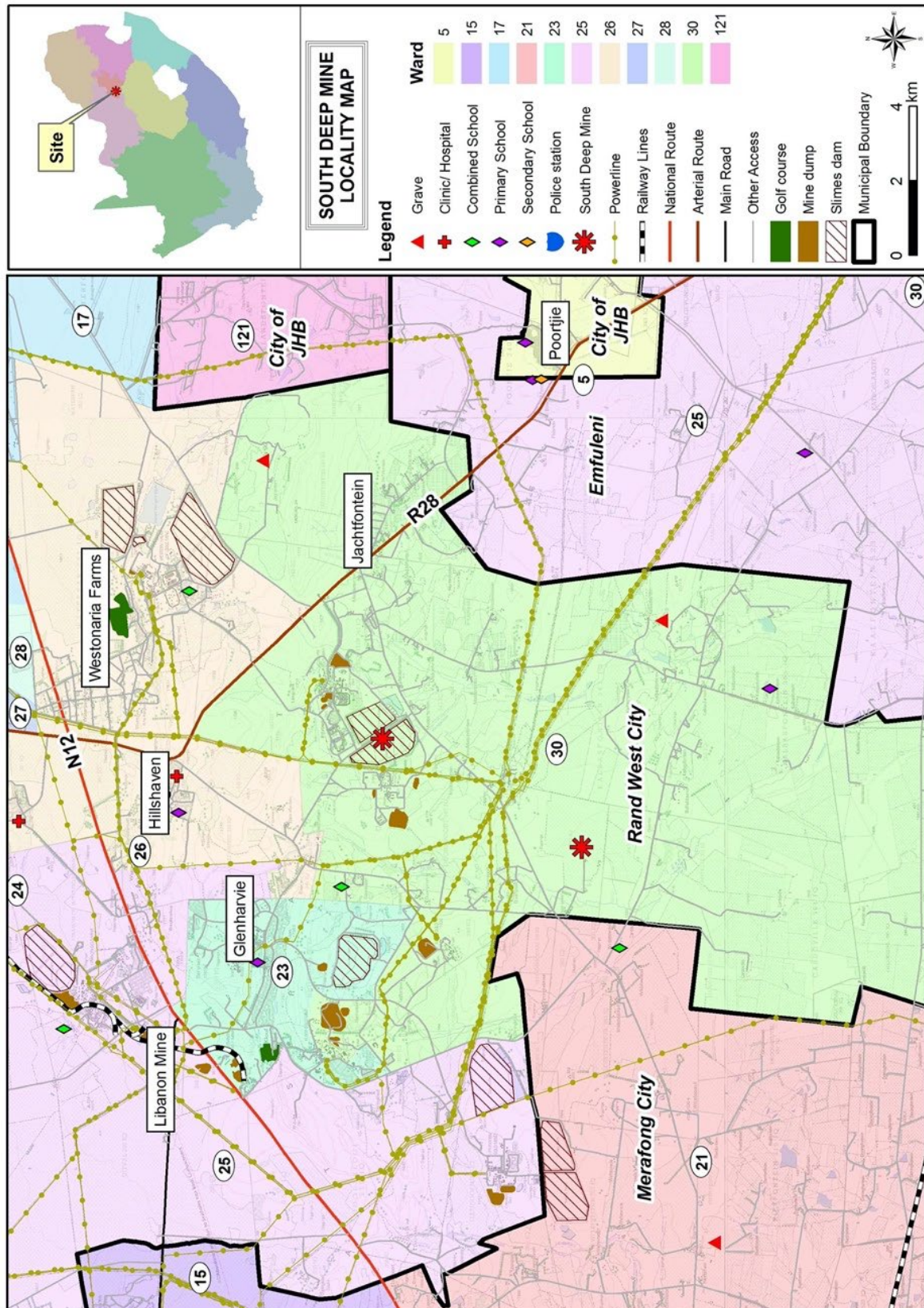


Figure 1.1 Map showing the South Deep Gold Mine is located within the magisterial districts of Westonaria and Vanderbijlpark (Gauteng province), some 45 kilometres south-west of Johannesburg (Equispectives, 2020).

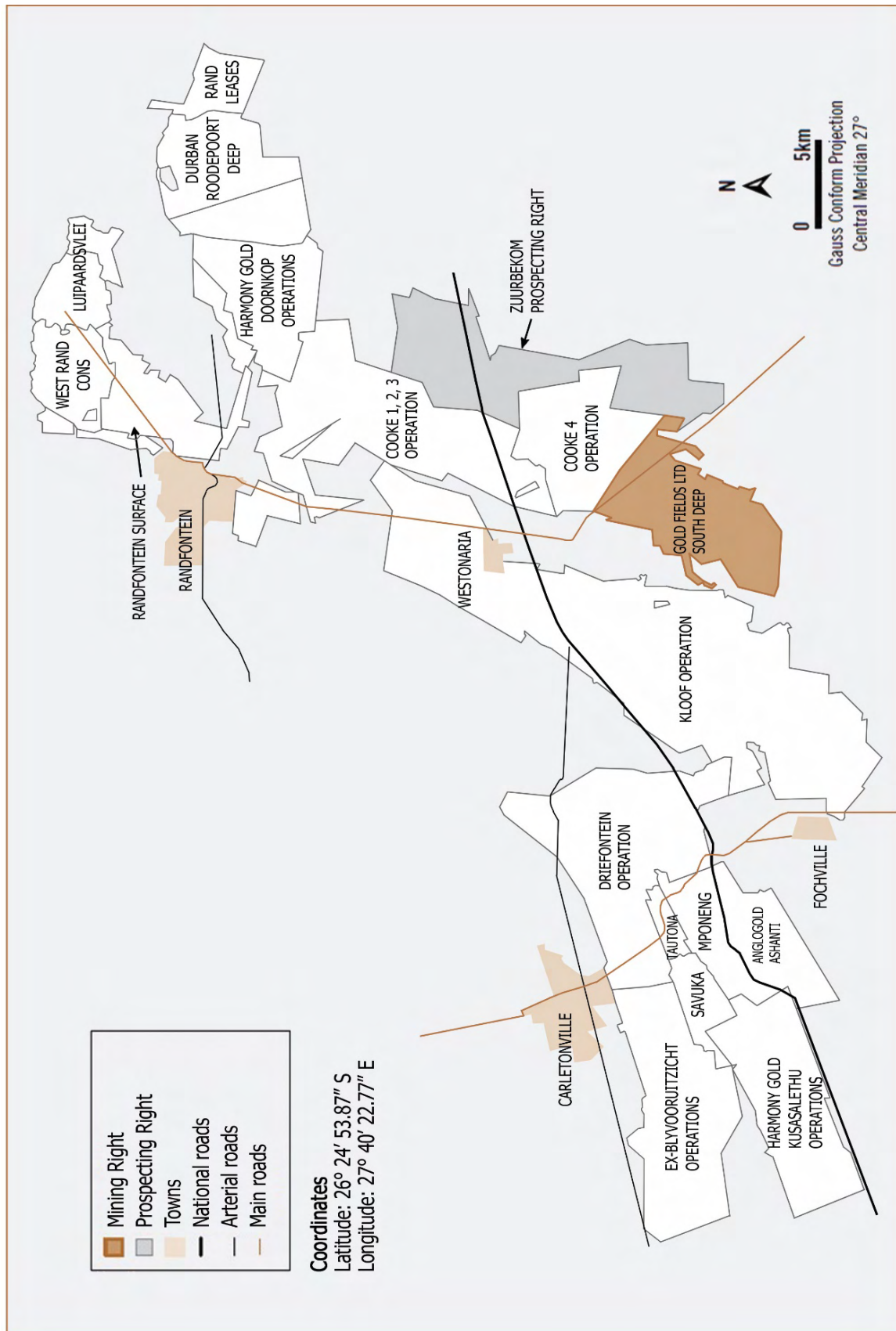


Figure 1.2 Map showing the South Deep Gold Mine relative to major towns and other nearby mining operations.

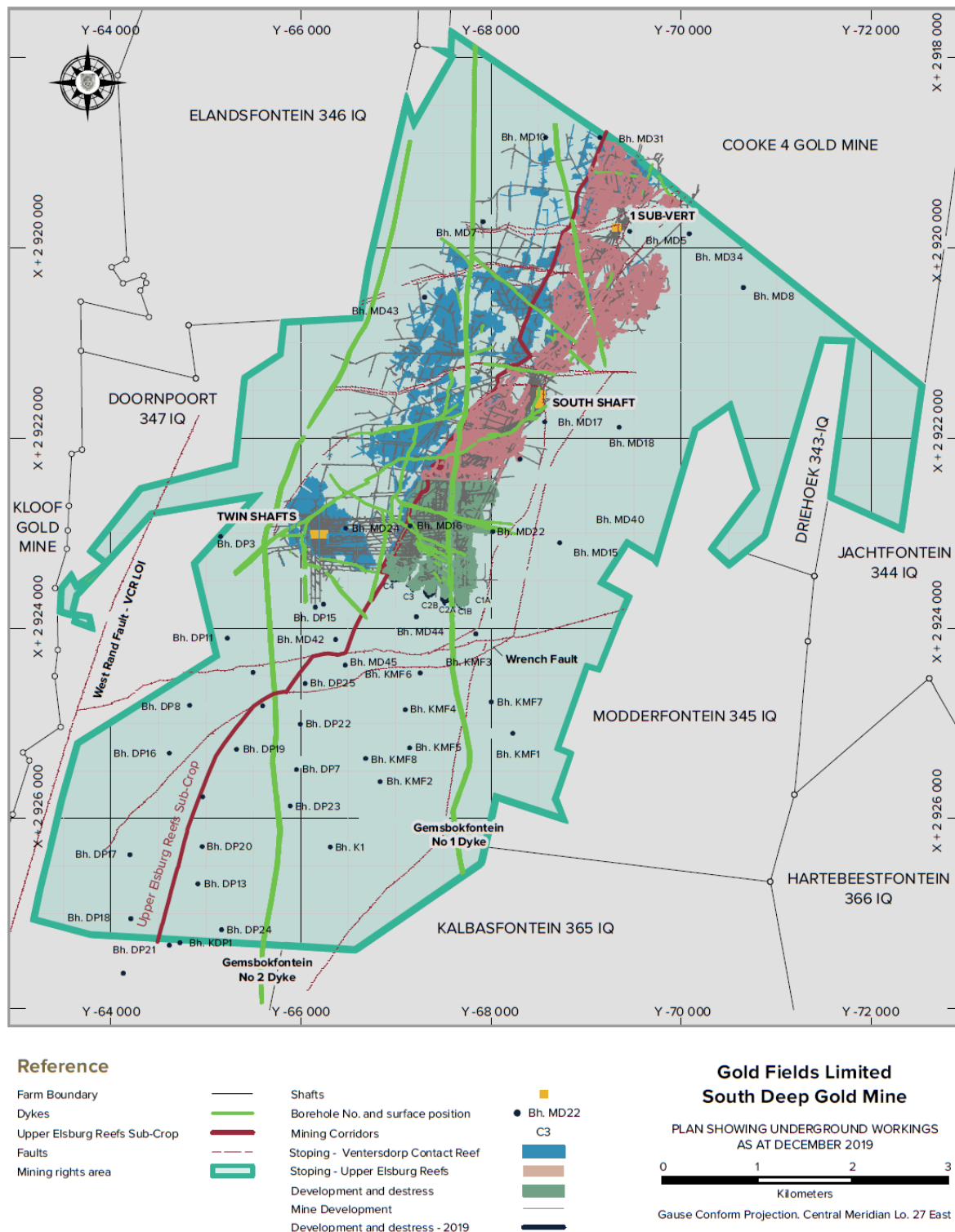


Figure 1.3 Map showing the present Mining Right Area and scope of the South Deep Gold Mine operations.

1.2 Naturally Occurring Radionuclides

Naturally occurring radionuclides associated with the uranium, thorium and actinium decay series are associated in varying degrees with the gold-bearing reefs of the Witwatersrand Basin.

These naturally occurring radionuclides are present in ore brought to the surface for processing and consequently was carried through to the mineral processing residues that are now stored on the surface as tailings or sand facilities. These 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). 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 other wastes.

Industries such as NORM generating mining and mineral processing operations and associated facilities and activities thus have the potential to alter the natural background radiation, and potentially increase radiation exposure to human beings and the environment, by:

- Moving naturally occurring radionuclides from inaccessible locations to locations where humans are present and can be exposed;
- Concentrating naturally occurring 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).

1.3 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 safety 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".

Gold Fields holds a Certificate of Registration (CoR-18) granted by the NNR in terms of Section 22 of the NNRA for the South Deep Gold Mine. Under the regulatory process administered by the NNR and in line with internationally accepted radiation protection and management practices, a CoR holder must submit an updated Radiological Public Safety Assessment (RPSA) regularly (every 3 to 5 years) to retain the nuclear authorisation. The purpose of these revisions is to reflect on regulatory and operational changes incurred during this period and to assess the radiological consequences of these changes to members of the public. At the same time, new information that became available on the current operation can be incorporated into the RPSA and the associated

public Radiation Protection Programme (RPP) can be revised and updated accordingly. Collectively, this ensures that the protection of members of the public against exposure to ionizing radiation-induced by facilities and activities incorporated within the scope of the CoR is in line with the national safety standards.

The current radiological public safety assessment for the South Deep Gold Mine was performed and submitted to the NNR in 2017 (Van Blerk and Potgieter, 2017). AquiSim Consulting (Pty) Ltd (AquiSim) was appointed as Radiation Protection Specialist (RPS) to update the 2017 Radiological Public Safety Assessment of the South Deep Gold Mine in accordance with the provision, requirements, and guidelines provided by the NNR (hereafter referred to as the 2020 South Deep Gold Mine RPSA).

1.4 Purpose of the Report

Historically, various methodologies have been developed and are available that can be used to perform a radiological public safety assessment of mineral processing operation such as the South Deep Gold Mine. None of these methodologies can be considered the singular or correct approach. What is more important is that the methodological approach followed for an assessment of this nature is fit for purpose and induces confidence in the assessment results, with due consideration of the graded approach to safety assessments (IAEA, 2009a).

The methodological safety assessment framework that is followed for the 2020 South Deep Gold Mine RPSA, is presented in detail in Section 4 of this report. One of the key features of this assessment framework is that it is inherently systematic and structured. The purpose of this report is to provide a detailed description of the first element of the assessment framework, i.e., the context within which the 2020 South Deep Gold Mine RPSA was performed.

1.5 Scope and Structure of the Report

The first step in the assessment framework schematically illustrated in Figure 4.1 is the definition of the *assessment context*, which in general and simple terms define the *basis* or *context* within which the safety assessment is performed. Once developed, it serves as a communication tool that provides a mean how stakeholders or target audiences (see Section 3.2) are informed of what is included or excluded from the assessment, and justification for the choices made clearly and consistently.

Viewed from this perspective, the assessment context defines the boundary conditions, within which the assessment is performed. This includes the regulatory framework that applied to the assessment, the technical basis of the assessment (e.g. purpose, scope and focus of the assessment), spatial and temporal boundaries, the assessment endpoints, and the assessment philosophy that is applied.

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, examples of

which include documents entitled '*Radiation, People and the Environment*' published by the International Atomic Energy Agency (IAEA, 2004a) or '*Radiation Effects and Sources*' published by the United Nations Environmental Programme (UNEP, 2016).

The report is structured as follows:

- Section 2 defines the regulatory framework, i.e., the national and international nuclear regulations, requirement and guidelines within which the assessment was performed;
 - Section 3 defines the technical basis of the assessment, which is largely defined by the purpose, scope and focus of the 2020 South Deep Gold Mine RPSA;
 - Section 4 defines the methodological safety assessment framework; and
 - Section 5 defines the assessment philosophy applied to the 2020 South Deep Gold Mine RPSA.
-

2 Regulatory Framework

2.1 General

The purpose of this section is to provide an overview of the regulatory framework as a basis for the 2020 South Deep Gold Mine RPSA. The regulatory framework is defined by a combination of national regulatory requirements and guidance, supplemented with principles, requirements, and guidance from international organisations concerned with radiation protection and the management of radioactive waste.

The section is structured as follows. Section 2.2 provides an overview of the international framework for radiation protection and radioactive waste management, while Section 2.3 provides an overview of the national regulatory framework. The international framework demonstrates a strong basis to protect human health and the environment from exposure to ionizing radiation.

2.2 International Framework

2.2.1 General

The international framework for radiation protection in the nuclear, medical, and mining industries is well established and recognised. 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) (IAEA, 2004a).

The UNSCEAR mandate, established by the General Assembly of the United Nations in 1955, is to assess and report the levels and effects of exposure to ionizing radiation. Governments and organizations throughout the world rely on the Committee's estimates as the scientific basis for evaluating radiation risk and for establishing protective measures. Consequently, UNSCEAR published many informative documents (see Table B 1 in Appendix B). Some of these publications and reports may not be directly applicable to the mining and mineral processing industry but contribute to the overall framework for the protection of human health and the environment from exposure to ionizing radiation.

2.2.2 The International Commission on Radiological Protection (ICRP) System of Radiological Protection

The ICRP is a non-governmental, independent, scientific organization founded in 1928, following recommendations at the first International Congress of Radiology (ICR) held in London in 1925 to establish international protection standards (ICRP, 2009a). The ICRP has more than two hundred volunteer members from approximately thirty countries across six continents, who represent the world's leading scientists and policymakers in the field of radiological protection. The ICRP is a not-for-profit organisation registered as a charity in the United Kingdom and

currently has its scientific secretariat in Ottawa, Canada. They publish recommendations for protection against ionizing radiation regularly (<https://www.icrp.org/>). The ICRP authority derives from the scientific standing of its members and the merit of its recommendations.

Historically, the primary aim of the ICRP System of Radiological Protection is to provide an appropriate standard of protection for human beings without unduly limiting beneficial practices derived from radiological materials (ICRP, 1991). To achieve this objective, the ICRP 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 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, the ICRP recognises three types of exposure situations that are intended to cover the entire range of possible exposures situations (ICRP, 2007). These are:

- *Planned Exposure Situations:* Planned exposure situations involve the deliberate introduction and operation of sources. This 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.

The principles of *justification* and *optimisation* apply to all three exposure situations, whereas the principle of *application of dose limits* applies only for doses expected to be incurred with certainty because of planned exposure situations. The principle of *justification* requires that the net benefit of any action involving radiation be positive.

Planned exposure situations are normally within the scope of regulatory requirements for radiological protection. The concepts of exclusion, exemption, and clearance may, therefore, be used to justify and optimise regulatory control by avoiding the application of unamenable and unwarranted regulatory measures (ICRP, 2007).

The South Deep Gold Mine represents a combination of existing and planned exposure situations. Many of the facilities that are included in the scope of CoR-57 and CoR-228 are historical facilities, dating back to the 1940s at a time when the regulatory framework was not defined or in place (i.e., *existing exposure situation*). However, the structure of the South Deep Gold Mine and their daily activities falls within the category of a *planned exposure situation*.

2.2.3 International Atomic Energy Agency (IAEA) Safety Standard Series

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of human health and minimization of danger to life and property, and to provide for their application.

The IAEA safety standards provide a robust framework of fundamental principles, requirements, and guidance to ensure safety. The standards are developed through an open and transparent process of gathering, integrating, and sharing the knowledge and experience gained from the actual use of technologies, as well as from the application of the safety standards, including emerging trends and issues of regulatory importance. The standards contribute to the establishment of a harmonized high level of safety worldwide by serving as the global reference for protecting people and the environment from the harmful effects of ionizing radiation.

The safety standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material, and the management of radioactive waste. They are issued in the IAEA Safety Standards Series as Safety Fundamentals, Safety Requirements, and Safety Guides (see Figure 2.1).

As the primary publication in the Safety Standards Series, the *Fundamental Safety Principles* establishes the fundamental safety objective and principles of protection and safety. The fundamental safety objective is *to protect people and the environment from the harmful effects of ionizing radiation*. This fundamental safety objective of protecting people, both individually and collectively, as well as the environment, has to be achieved without unduly limiting the operation of facilities or the conduct of activities that give rise to radiation risks (IAEA, 2006).

The fundamental safety objective applies for all facilities and activities and all stages of the lifetime of a facility or radiation source including planning; siting; design; manufacturing; construction; commissioning and operation; transport of radioactive material and management of radioactive waste; decommissioning; and closure. Ten safety principles have been formulated, based on which safety requirements are developed and safety measures are to be implemented to achieve the fundamental safety objective (IAEA, 2006).

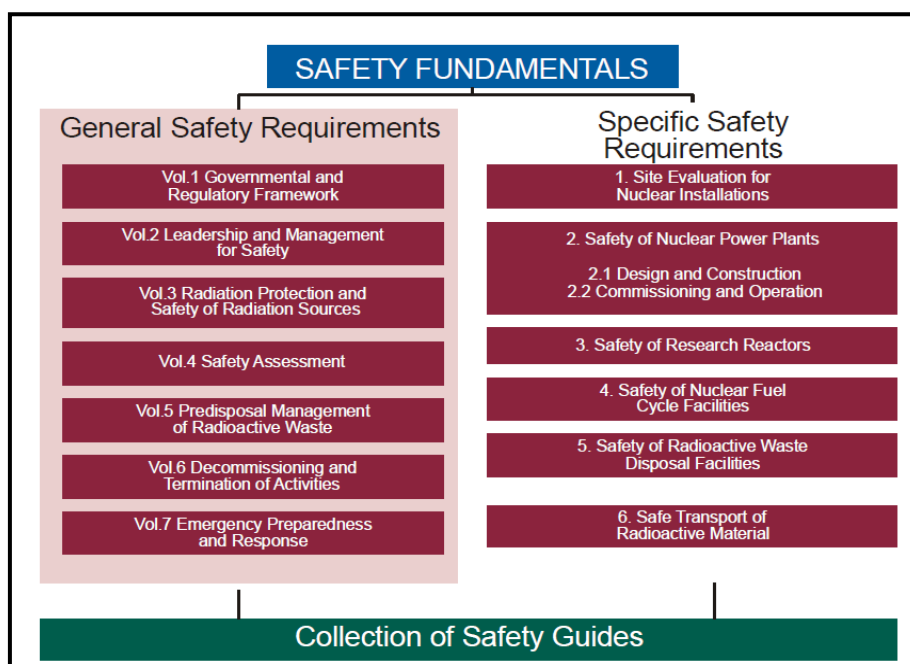


Figure 2.1 The long-term structure of the IAEA Safety Standards (IAEA, 2011).

An integrated and consistent set of *Safety Requirements* establish the requirements that must be met to ensure the protection of people and the environment, both now, and in the future. The requirements are governed by the objectives and principles of the Safety Fundamentals. If they are not met, measures must be taken to reach or restore the required level of safety. The format and style of the *Safety Requirements* facilitate use by the Member States for the establishment, in a harmonized manner, of their respective national regulatory frameworks. Requirements, including several ‘overarching’ requirements, are expressed as ‘shall’ statements.

Safety Guides provide recommendations and guidance on how to comply with the requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

A summary of the safety requirements and safety guides applicable to the mining and mineral processing industry, in general, is presented in Table B 2 in Appendix B. These publications are used and referenced as appropriate and justified.

2.2.4 Revised IAEA Basic Safety Standards (GSR Part 3) (IAEA, 2014)

The Basic Safety Standards (BSS) published in 1996 was a cornerstone of the IAEA safety standards for many years (IAEA, 1996). However, “*Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards*” (GSR Part 3) (IAEA, 2014) in the General Safety Requirement series (see Figure 2.1) superseded the BSS. The overall objective of GSR Part 3 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.

Section 1 of GSR Part 3 does not constitute requirements but explains the context, concepts and principles for the requirements presented in the remainder of the document. These include (amongst others) the following:

- The *System of Protection and Safety* that is based on the IAEA Fundamental Safety Principles outlines in IAEA (2006);
- The *Types of Exposure Situations* that in their definition is consistent with the ICRP exposure situations (ICRP, 2007) introduced in Section 2.2.2;
- An explanation of the concepts of *Dose Constraints and Reference Levels*. Both concepts are used for the optimization of protection and safety, the intended outcome of which is that all exposures are controlled to levels that are as low as reasonably achievable (ALARA), economic, societal and environmental factors being considered;
- *Protection of the Environment* that recognised the protection of the environment as an issue necessitating assessment, while allowing for flexibility in incorporating into decision-making processes the results of environmental assessments that are commensurate with the radiation risks; and
- *The Interface between Safety and Security*, both of which have in common the aim of protecting human life and health and the environment. Also, safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

Requirements specified in Section 2 to Section 5 of GSR Part 3 make a distinction between the three types of exposure situations, with a further distinction between occupational exposure, public exposure and medical exposure.

2.2.5 Safety Standards for the Protection of the Public

To avoid severely inequitable outcomes of the optimisation procedure, restrictions should be imposed on the doses or risks to individuals from a source. The regulatory tools that can be used to achieve a reduction of risks 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 reasonably achievable (ALARA) with 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 in a year.
- In special circumstances, an effective dose of 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 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.

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 *dose constraint is not a dose limit; exceeding a dose constraint does not represent non-compliance with regulatory requirements*, but could result in follow-up actions as required by the regulatory body (IAEA, 2014).

2.3 National Legislation and Standards

2.3.1 Legislation

2.3.1.1 *The National Nuclear Regulator Act (NNRA) (Act 47 of 1999)*

The NNRA is the leading national legislation for the protection of human health and the environment from adverse effects associated with exposure to ionizing radiation. The NNR is the statutory body responsible for, amongst others, regulating mining and mineral processing facilities that carry out activities and operations involving NORM. In terms of its mandate, the NNR must publish requirements, guidelines, and standards for the protection of persons, property, and the environment against ionizing radiation exposure. Two such documents that apply to the safety assessment of mining and mineral processing operations are:

- Regulation No. 388 (dated 28 April 2006), which defines regulations regarding safety standards and regulatory practices; and
- Regulatory Guide RG-002 (NNR, 2013), which provide CoR holders with guidelines to perform radiological public safety assessments for NORM associated facilities and activities.

2.3.1.2 The Nuclear Energy Act (NEA) (Act 46 of 1999)

In terms of the NEA, the authority regulating the disposal of radioactive waste and irradiated fuel waste is the Minister of Energy. In 2005, the Department of Energy (DOE) published the National Radioactive Waste Management Policy and Strategy (NRWMP) (DME, 2005). The purpose of the NRWMP 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 the appropriate solution for the management of radioactive waste.

2.3.1.3 The National Radioactive Waste Disposal Institute Act (NRWDIA) (Act 53 of 2008)

The government promulgated the National Radioactive Waste Disposal Institute Act in 2008. By way of the NRWDIA, the government gave effect to its undertaking in the NRWMP to establish the National Radioactive Waste Disposal Institute (NRWDI) for managing radioactive waste disposal on a national basis.

2.3.2 Safety Standards and Regulatory Practices (Regulation No. 388)

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. The regulations are broadly defined, focus largely on operational issues and do not necessarily recognise the unique and complex issues associated with mining and mineral processing operations.

Annexure 2 of Regulation No. 388 provides dose limits for occupational exposure, exposure of visitors and non-occupationally exposed workers at nuclear sites, and public exposure. The latter states the following:

The annual effective dose limit for visitors to the sites and those not deemed to be occupationally exposed is 1 mSv. The annual dose equivalent limit for individual organs and tissues of such persons is 10 mSv.

In terms of public exposure, the annual effective dose limits for members of the public from all authorised actions is thus 1 mSv. In terms of this regulation, no action may be authorised that would give rise to any member of the public receiving a radiation dose from all authorised actions exceeding 1 mSv in a year. The regulation makes provision for the application of a dose constraint for authorised actions to ensure optimisation of radiation protection. The following is stated:

“Where applicable in terms of the prior safety assessment, the optimisation of protection must be subject to dose constraints specific to the authorised action, which must not exceed values that can cause the relevant dose limits to be exceeded and which ensure as far as practicable that doses are restricted by application of the ALARA principle on a source-specific basis rather than by dose limits (Section 4.5.2.1).”

“For members of the public, the dose constraint applicable to the average member of the critical group within the exposure population is 0.25 mSv per year specific to the authorised action unless otherwise agreed by the Regulator on a case-by-case basis, taking into account the dose limit specified for exposure of members of the public from all sources (Section 4.5.2.2)”.

This means that the criteria adopted nationally for the protection of the public as stated in Regulation No. 388 are consistent with the ICRP and IAEA recommendations. The public dose constraint of 0.25 mSv in a year per CoR holder as stipulated in Regulation No. 388 is within the range proposed by the ICRP (see Section 2.2.5).

Other than specifying the requirement that prior or operational safety assessment must be conducted (Section 3.3, Section 4.1.1 to Section 4.1.3), Regulation No. 388 does not provide specific requirements for how these assessments must be conducted. Nor does it provide any requirements for post-operational safety assessments. However, some of the principles mentioned may be applied in a broad general sense in the safety assessment process (e.g. the principles of good engineering practices, quality management, and defence in depth).

Regulation No. 388 recognises the application of the graded approach (IAEA, 2009a), insofar that it recognises that the application of the radiation protection and nuclear safety requirements should be commensurate with the characteristics of the action and with the magnitude and likelihood of the exposure, as determined by the safety assessment (Section 3.11).

2.3.3 Safety Assessment of Radiation Hazards to Members of the Public from NORM Activities: RG-002 (NNR, 2013)

A broad set of guiding principles are required for radiological public safety assessments, especially in terms of an assessment approach and philosophy, the treatment of uncertainties, human behaviour, long-term (post-operational) issues, timescales, and the treatment of non-human biota, for example. The national guidance currently available is RG-002 (NNR, 2013) on “*Safety Assessment of Radiation Hazards to Members of the Public from NORM Activities*”, published in 2013.

RG-002 provides guidelines to holders and prospective holders of NNR authorisations on how to conduct prior and operational public safety assessments for NORM facilities. i.e., facilities that carry out activities and operations involving radioactive ore and minerals containing uranium, thorium and their progeny.

RG-002 starts with the definition of a few terms relevant to the safety assessment process. This is followed by a comprehensive overview of a proposed assessment methodology and addresses several specific issues of importance, such as:

- What should be included as part of a site description and characterisation section and the need for a process description in terms of all the facilities and activities that could serve as potential sources of radiation exposure to members of the public.

- Source terms and source term characterisation for the atmospheric and aquatic pathways, radioactive decay and the build-up of activity in the environment, and the different exposure pathways that might be of concern.
- The critical group concept, including guidelines to establish land use conditions, human habits, and the consideration of different age groups.
- The assessment criteria section provides an overview and summary of dose assessment criteria for (i) a screening level dose assessment and (ii) a site-specific assessment.
- Sampling and what should be the objectives of a monitoring programme, as well as what level of detail should be included in the sample analysis. For this purpose, the distinction is made between screening sample analysis and nuclide-specific sample analysis.
- The dose assessment section addresses several issues, which include scenario development, dose calculations, and input parameters for the different environmental pathway analysis, the use of manual methods (spreadsheets), codes and software, sensitivity and uncertainty analysis, and the interpretation of results.

The main part of RG-002 concludes with requirements in terms of the NNR submission. A few appendixes are attached that provides more information on the critical group concept, sampling and analysis, default parameter values for use in screening calculations, the use of an interaction matrix, and requirements for a site water balance.

2.3.4 National Radioactive Waste Management Policy and Strategy

One of the issues addressed in the NRWMP is options for managing radioactive waste generated through the nuclear industry, as well as waste containing un-concentrated natural occurring radioactive materials from the mining and minerals processing industries. In consideration of options for radioactive waste management, the document takes cognisance of the IAEA radioactive waste management principles (IAEA, 1995).

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 are 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 (1994) (unless deviations therefrom can be justified). Table 2.1 summarises the waste classification scheme adopted for this purpose. 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 (IAEA, 1994). The IAEA classification scheme has subsequently been revised and is presented in IAEA (2009b).

Table 2.1 Summary of the National Radioactive Waste Classification Scheme (DME, 2005).

Waste Class	Waste Description	Waste type / Origin	Waste Criteria	Generic waste treatment / conditioning requirements ⁽¹⁾	Disposal / Management Options
1 HLW	Heat generating radioactive waste with high long and short-lived radionuclide concentrations.	1 Used fuel declared as waste or used fuel recycling products 2 Sealed sources	1 Thermal power > 2 kW/m ³ . OR 2 Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels > levels specified for LILW-LL OR 3 Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) above 100 mSv per annum	Waste package suitable for handling, transport and storage (storage period in the order of 100 years). The waste form shall be solid with additional characteristics as prescribed for a specific repository.	1 (a) Regulated deep disposal (100's of metres). (b) Reprocessing, Conditioning and Recycling (c) Long Term Above Ground Storage
2 LILW-LL	Radioactive waste with low or intermediate short-lived radionuclide and intermediate long-lived radionuclide concentrations.	1 Irradiated uranium (isotope production). 2 Un-irradiated uranium (nuclear fuel production). 3 Fission and activation products (nuclear power generation and isotope production) 4 Sealed sources.	1 Thermal power (mainly due to short-lived radio nuclides ($T_{1/2} < 31 \text{ y}$) < 2 kW/m ³) AND 2 Long-lived radio nuclides ($T_{1/2} > 31 \text{ y}$) concentrations. ❖ Alpha: < 4000 Bq/g ❖ Beta and gamma: < 40000 Bq/g (Maximum per waste package up to 10x the concentration levels specified above). OR 3 Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) between 10 and 100 mSv per annum	Waste package suitable for handling, transport and storage (storage period in the order of 50 years). The waste form shall be solid with additional characteristics as for a specific repository.	1 Regulated medium depth disposal (10's of metres). 2 Managed as NORM-E waste (un-irradiated uranium)

Waste Class	Waste Description	Waste type / Origin	Waste Criteria	Generic waste treatment / conditioning requirements ⁽¹⁾	Disposal / Management Options
3 LILW-SL	Radioactive waste with low or intermediate short-lived radionuclide and / or low long-lived radionuclide concentrations.	- Un-irradiated uranium (nuclear fuel production). - Fission and activation products (nuclear power generation and isotope production). - Sealed sources.	- Thermal power (mainly due to short-lived radio nuclides ($T_{1/2} < 31 \text{ y}$) $< 2 \text{ kW/m}^3$. AND - Long-lived radio nuclide ($T_{1/2} > 31 \text{ y}$) concentrations. ❖ Alpha: $< 400 \text{ Bq/g}$ ❖ Beta and gamma: $< 4000 \text{ Bq/g}$ (Maximum per waste package up to 10x the concentration levels specified above). OR - Long-lived alpha, beta and gamma emitting radionuclides at activity concentration levels that could result in inherent intrusion dose (the intrusion dose assuming the radioactive waste is spread on the surface) below 10 mSv per annum	Waste package suitable for handling, transport and storage (storage period in the order of 10 years). The waste form shall be solid with additional characteristics as for a specific repository.	- Regulated near surface disposal ($< 10 \text{ metres}$). - Managed as NORM-E waste (un-irradiated uranium)
4 VLLW	Radioactive waste containing very low concentration of radioactivity.	Contaminated or slightly radioactive material originating from operation and decommissioning activities.	Clearance or authorised discharge or reuse criteria and levels approved by the relevant regulator.	Waste stream specific requirements and conditions.	- Clearance. - Authorized disposal, discharge or reuse
5 NORM-L (low activity)	Potential Radioactive waste containing low concentrations of NORM.	- Mining and minerals processing. - Fossil fuel electricity generation. - Bulk waste - un-irradiated uranium (Nuclear fuel production).	Long-lived radio nuclide concentration: $< 100 \text{ Bq/g}$.	Unpackaged waste in a miscible waste form.	- Re-use as underground backfill material in an underground area. - Extraction of any economically recoverable minerals, followed by disposal in any mine tailings dam or other sufficiently confined surface

Waste Class	Waste Description	Waste type / Origin	Waste Criteria	Generic waste treatment / conditioning requirements ⁽¹⁾	Disposal / Management Options
					impoundment 3 Authorised disposal 4 Clearance
6 NORM-E (enhanced activity)	Radioactive waste containing enhanced concentrations of NORM.	1 Scales 2 Soils contaminated with scales	1 Long-lived radio nuclide concentration: > 100 Bq/g.	Packaged or unpackaged waste in a miscible or solid form with additional characteristics for a specific repository.	1 Dilute and re-use as underground backfill material in an identified underground area. 2 3 Extraction of any economically recoverable minerals, followed by dilution and disposal in an identified mine tailings dam or other sufficiently confined surface impoundment Regulated deep or medium depth disposal.

⁽¹⁾ Treatment and conditioning requirements are mainly dependant on specific waste type in a waste class.

Note that at the time (in 2005) when the Policy and Strategy were drafted, the waste classification scheme was in line with the IAEA waste classification scheme (IAEA, 1994). The IAEA classification scheme has subsequently been revised (IAEA, 2009b).

The NRWMP 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 2.2 summarises the available management options for each of these classes of NORM waste.

Table 2.2 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)
Re-use 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	

2.3.5 Waste Categorisation for Mining and Mineral Processing Facilities

The waste categorisation scheme for mining and mineral processing facilities distinguishes between *non-process waste* (waste for which it is considered unlikely that any radioactive contamination of the waste could have occurred) and *process waste*. For *process waste*, the potential exists that the waste may have become radioactively contaminated, either directly through being involved in a process known for the presence of radioactivity, or indirectly by being near known or potentially radioactively contaminated waste. *Homogeneous Process Waste* refers to *process waste* that is in bulk or homogeneous form and may include material such as tailings, pyrite, baddeleyite and calcine. Table 2.3 summarises the categorisation of homogenous process waste and associated management options.

Table 2.3 The categorisation of homogenous process waste and associated management options.

Category	Description	Disposal/Storage Option
Category I	Waste with a specific alpha activity (U-238, U-234, Th-230, Ra-226, Po-210, Th-232, and Th-228) not exceeding 100 Bq.g ⁻¹	- Released to a licensed facility - Stored on site - Placed directly on TSFs or WRDs
Category II	Waste with a specific alpha activity (U-238, U-234, Th-230, Ra-226, Po-210, Th-232, and Th-228) exceeding 100 Bq.g ⁻¹ , but not exceeding 1,000 Bq.g ⁻¹	- Released to a licensed facility - Stored on site - Placed directly on a TSFs or WRDs following a process of dilution of at least 1:10
Category III	Waste with a specific alpha activity (U-238, U-234, Th-230, Ra-226, Po-210, Th-232, and Th-228) exceeding 1,000 Bq.g ⁻¹	Stored on a licensed site in an approved storage facility

Note that storage or disposal of Category I material with activity concentrations higher than 0.5 Bq.g⁻¹ may render the waste rock dump unsuitable for other uses (e.g. road construction). Also, note that the proposed management strategy of Category III waste (more than 1,000 Bq.g⁻¹) is still storage on a licensed site in an approved storage facility. This is because a long-term (permanent) solution for the management of this waste (i.e. high-level waste) is not available in South Africa at present.

3 Technical Basis of the Assessment

3.1 General

The purpose of this section is to define the technical basis of the 2020 South Deep Gold Mine RPSA, which is largely defined by the purpose, scope and focus of the assessment, but *inter alia* by the spatial and temporal boundary conditions and associated assessment endpoints.

Throughout the lifecycle of a mining and mineral processing operation, the radiological public safety assessment concept can be used for different purposes as part of the overall management of the operation. As the operation moves from the pre-operational to the post-closure phase, the purpose, scope and focus of these assessments will change. For example:

- Before commissioning a new facility or operation, a pre-operational safety assessment is performed on a *prospective basis* to assess whether the proposed facility or operations pose a radiological risk to members of the public above the regulatory compliance criteria. During the same period, the safety assessment concept can be used to design and refine facilities used for the management of radioactive waste and other residue materials.
- Once commissioned, it is viewed as a good radiation protection practice to revise and update the safety assessment on a 3 to 5-year basis. The purpose of these revisions is to reflect any operational changes and their impact on safety since the previous assessment and to incorporate updated knowledge and methods into the assessment (see Section 1.1).
- As an operation moves towards closure, the safety assessment is used to evaluate closure alternatives and assess the potential radiological impact of the operations to members of the public for the period following closure.
- For an existing facility or operation, the safety assessment may be used to design and select remedial action options and alternatives in case of existing environmental contamination.

A radiological public safety assessment is generally undertaken to provide confidence to stakeholders that a mining and mineral processing operation does not pose a radiological risk to exposure groups, particularly members of the public. The section consequently commences with a definition of the stakeholders (or target audience) for the assessment in Section 3.2. This is followed in Section 3.3 by the definition of the purpose and objective of the 2020 South Deep Gold Mine RPSA, while the scope and focus of the assessment are defined in Section 3.4. Section 3.5 defines the assessment or calculational endpoints that are consistent with the purpose, scope and focus of the assessment, while Section 3.6 is devoted to the definition of the spatial and temporal boundary conditions applicable to the assessment.

3.2 Stakeholders (Target Audience)

Stakeholders, as used here, are groups or individuals with an interest in the radiological safety of an existing or proposed operation. 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 is justified. Generally, the stakeholders include management and technical staff responsible for the mining and mineral processing operation, as well as regulatory authorities, workers, members of the public and environmental interest groups.

One can assume that local, provincial and national government departments and regulatory authorities such as the NNR serve as the main target audience for the 2020 South Deep Gold Mine RPSA, while other stakeholders that may have an interest in the assessment include:

- Gold Fields management and staff, particularly those persons involved in or responsible for the management and execution of the South Deep Gold Mine;
- Gold Fields workers that are responsible for the daily operational activities of the South Deep Gold Mine;
- The public near the South Deep Gold Mine, including ward councillors, labour unions, business and commerce, farmers, and landowners;
- Mining and industry in general, but in particular the interested and affected mines and industries near the South Deep Gold Mine; and
- Technical, scientific, and environmental interest groups that might have an interest in the approach being followed and the subsequent assessment results.

3.3 Purpose and Objective of the Assessment

Any Company endeavouring to develop or operate a mine or mineral processing facility must undergo a rigorous environmental authorization process 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, or 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) and its impact, where the performance measure is radiological safety to members of the public (IAEA, 2007b). This definition is consistent with Regulation No. 388 (see Section 2.3.2).

The regulatory framework (see Section 2) is clear on the need to perform the radiological public safety assessment to ensure the protection of human health and the environment over the timescales of concern (IAEA, 2009a; ICRP, 2000) for all facilities and activities, including mining and mineral processing operations. Within this framework, the operator (i.e., GFL) remains responsible for the public and operational safety of the South Deep Gold Mine.

The first comprehensive radiological public safety assessment for the South Deep Gold Mine dates back to 2002 (Van Blerk, 2002), while further iterations and updates were prepared and submitted to the NNR in 2012 and 2017 (Gold Fields, 2012; Van Blerk and Potgieter, 2017). Some operational changes took place at the South Deep Gold Mine since 2017, while additional data and information are available that can be used to improve and update the South Deep Gold Mine RPSA.

Viewed from this perspective, the *purpose* of the 2020 South Deep Gold Mine RPSA can be defined as follows:

To assess the radiological safety to members of the public from conditions induced by the South Deep Gold Mine in a comprehensive, systematic, and transparent manner that is consistent with the NNRA and NEA, as well as with NNR requirements, guidance, and regulations.

The main objective of the assessment is to confidently demonstrate to the NNR and other stakeholders that members of the public residing near the South Deep Gold Mine are not exposed to levels of ionizing radiation-induced by the South Deep Gold Mine above the regulatory compliance criteria set for public exposure as defined in Section 2.2.5. Specific objectives identified for the assessment include the following:

- To assess the radiological impact to members of the public induced by the South Deep Gold Mine within a systematic, structured, and transparent methodological safety assessment framework;
- To comprehensively describe the operational, environmental and associated human behavioural conditions relevant to the South Deep Gold Mine, including any relevant changes that may have occurred in recent years, as well as any new information and data that may have become available;
- To develop and justify a discrete set of public exposure conditions using a systematic approach that are representative of the operational and prevailing environmental conditions, but also the associated human behavioural conditions observed near the South Deep Gold Mine;
- Using the current understanding of the total system, to comprehensive assesses the radiological consequence of the discrete set of public exposure conditions, based on appropriate and well justified environmental *Process Level* modelling results, supplemented with appropriate *System Level* modelling and dose assessment results;
- To use the outcome and results of the radiological public safety assessment to revise the public Radiation Protection Programme (RPP), with the purpose to ensure that members of the public are protected from radiation exposure induced by the South Deep Gold Mine; and
- To compile a *safety case* of the South Deep Gold Mine, aimed at integrating all safety-related arguments into a confident statement of the safety of the South Deep Gold Mine to members of the public.

3.4 Scope and Focus of the Assessment

3.4.1 Natural Background Radiation

Many radioactive isotopes (or radionuclides) occur naturally throughout the Earth's crust and are present in most 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, which is not members of any of the four-decay series, include isotopes of potassium (K-40) and rubidium (Rb-87). These isotopes are of interest because of their presence in environmental media and their contribution to human exposure (Martin, 2006).

In undisturbed environmental conditions, these naturally occurring radionuclides form part of the natural background radiation to which all humans are daily exposed 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 dose, average over the population of the world, is about 2.8 mSv in total. As indicated in Figure 3.1, over 85% of this total is from natural sources, with about half coming from radon decay products in the home (2.4 mSv). 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 industry — account for less than 1% of the total value. Other natural background radiation sources include cosmic radiation, gamma radiation, and internal radiation in our bodies (IAEA, 2004a).

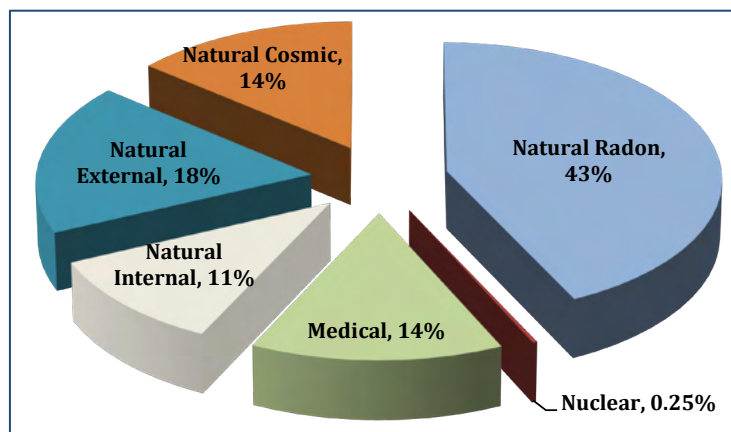


Figure 3.1 Distribution of the background radiation contribution as a percentage of the annual dose, average over the population of the world [Reproduced from IAEA (2004a)].

In addition to the natural background radiation, anthropogenic activities that exploit the earth's resources may enhance the potential for human exposure to naturally occurring radionuclides in their products, by-products, residues and wastes. As eluded in Section 1.1, mining and mineral processing operations have the potential to alter the natural background radiation.

Nationally and internationally, the contribution of natural background radiation is not amenable to regulatory control. The focus of the 2020 South Deep Gold Mine RPSA is, therefore, on the contribution of the South Deep Gold Mine to public ionizing radiation exposure conditions *above natural background radiation* (i.e. complementary exposure). The main approach that is followed

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.

for this purpose is to measure, calculate or assume a release rate of radioactivity to the environment from sources associated with the South Deep Gold Mine, the dispersion of the released radioactivity into the environment, and the subsequent interaction of members of the public with the affected environmental media. This approach is suitable for new or proposed operations with no historical releases to the environment. However, it is also suitable for existing operations and provides the opportunity to assess the contribution of a facility or activity since operations commence.

Where necessary and justified, this approach is complemented with actual environmental measurements (e.g., soil, water, sediment, crops, etc.) and observation to quantify the contribution to the annual effective dose received by members of the public. However, these environmental measurements most likely include a contribution of natural background radiation.

3.4.2 Site-Specific Assessment

The 2020 South Deep Gold Mine RPSA is based on site-specific data as far as practically possible and justified. However, in the absence of site-specific data and information, appropriate and justified values from literature are used to supplement the available data and information. RG-002 (NNR, 2013) in particular, is extensively used to supplement site-specific data. All assumptions and conditions used in the assessment are documented accordingly.

3.4.3 Cumulative Effect

The ICRP principles and 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 or sources near the South Deep Gold Mine.

The focus of the assessment is on the contribution of the South Deep Gold Mine to the annual effective dose to members of the public. Other potential sources of radiation exposure to members of the public include operational and historic gold mining activities located near the South Deep Gold Mine. These operations, especially the Sibanye Ezulwini and Kloof Operations, have the potential to influence the ambient concentration of radionuclides in the environment and thus the radiological impact on members of the public. 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 their potential contribution from these and other operations to a total effective dose through the application of the regulatory dose constraint.

3.4.4 Periods of Concern

The mining and mineral processing operation lifecycle makes a distinction between a pre-operational period, an operational period, and a post-operational period. An additional active or passive institutional control period may be associated with the post-operational periods. The NNR regulations (Regulation No. 388) or guidance (RG-002) do not provide any guidance on the period or conditions to assume for the institutional control periods. Therefore, the potential impact of these periods is often treated as an uncertain parameter in the safety assessment.

Furthermore, RG-002 is limited to considerations of the pre-operational and operation periods. While the post-operational period is explicitly excluded, RG-002 requires due consideration be given to the potential radiological impact of longer-lived radionuclides, which extend into the post-operational period. The operational period (Life of Mine) for the South Deep Gold Mine is assumed to be in the order of 73 years (2092). While the post-operational period is explicitly excluded, RG-002 does require that due consideration be given to the potential radiological impact of longer-lived radionuclides, which extend into the post-operational period.

Note that pre-operational and operational safety assessments can be performed with a greater level of certainty since the actual conditions are better known. Conditions during the post-operational period are more uncertain. These uncertainties are addressed in the assessment to the extent necessary and justified.

3.4.5 Surface Operations

The South Deep Gold Mine can be divided into underground operations, which is responsible for the mining and abstraction of ore to the surface, and the associated surface operations, which are responsible for the processing of ore. The latter also includes the reprocessing of historical TSFs to extract residual gold from tailings material. Furthermore, the surface operations also include the management of liquid and solid residue material generated as part of the mining and mineral processing operation, which may include water, tailings and waste rock.

The downcast shafts and the associated underground mining operations do not have any direct impact on the radiological exposure and impact to members of the public. The scope of the 2020 South Deep Gold Mine RPSA is therefore limited to the associated surface operations.

3.4.6 Sources of Radiation Exposure

Mineral processing operations such as the South Deep Gold Mine have the potential to include several features that may serve as sources of radiation exposure to members of the public and that must be considered in an integrated manner as part of the radiological public safety assessment. These sources include releases to the atmospheric and aquatic environment from the mineral processing plant stacks, material handling, (e.g. crushing, milling, and screening), ventilation shafts, stockpile facilities, residue management facilities (e.g., WRDs and TSFs), and various water management facilities (e.g., return water dams and storage pond).

The scope and focus of the 2020 South Deep Gold Mine RPSA are to all the facilities and activities associated with the South Deep Gold Mine that may serve as potential primary source of radiation exposure to members of the public during the operational life of the operation, as well as the secondary sources induced by natural environmental pathways. However, the scope of the assessment excludes secondary sources of radiation exposure induced by disruptive events outside the normal operating conditions. These events, normally associated with accidents and incidents such as pipeline bursts or overflowing of return water dams following excessive rainfall, is best addressed through the procedure set out in the NNR approved emergency preparedness and associated procedures for the South Deep Gold Mine.

3.4.7 Contaminants of Concern

Mining and mineral processing facilities may pose hazards to humans or the environment not only from the presence of radioactivity, but also from toxic and inorganic elements and compounds present in their reagents and chemicals, products, by-products, residue materials, and wastes.

The scope of the 2020 South Deep Gold Mine RPSA is limited to radiation exposures induced by naturally occurring radionuclides and excludes any safety considerations that may arise due to non-radioactive substances or any other mine health and safety aspect. The contaminants of concern are therefore those radionuclides associated with the U-238, Th-232 and U-235 decay series. These decay series and their radiological properties are listed in Table A 1 to Table A 3 and illustrated schematically in Figure A 1 in 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 naturally occurs 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. Table 3.1 lists the radionuclides explicitly considered in the 2020 South Deep Gold Mine RPSA.

Table 3.1 List of α and β emitting radionuclides explicitly considered in the 2020 South Deep Gold Mine RPSA.

Long-lived Alpha (α) Radiation Emitters	Beta (β) Radiation Emitters
U-238, U-234, Th-230, Ra-226, Po-210	Pb-210
U-235, Pa-231, Ra-223	Ac-227
Th-232, Th-228, Ra-224	Ra-228

Where applicable, radioactive decay and in-growth of daughter products are taken into consideration in the assessment. This serves the dual purpose of avoiding overly conservative results, in the case of slower transport processes, as well as accounting for impacts related to the radioactive decay products. Note that the radiological properties of some of the associated radioisotopes are such that they will remain a concern for periods of thousands of years. Secular

equilibrium is assumed between parent and daughter products in cases where analytical 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.

3.4.8 Worker Safety Assessment

The NNRA and associated national safety standards make provision for the protection of both workers (occupational exposure) and members of the public from exposure to ionizing radiation. For this purpose, both worker and public safety assessments must be submitted to the NNR. The scope of the 2020 South Deep Gold Mine RPSA is limited to the assessment of the radiological impact on members of the public. A radiological assessment for worker exposures at the South Deep Gold Mine is documented and submitted to the NNR as a separate report.

3.4.9 Human Behavioural Conditions and Age Groups

The 2020 South Deep Gold Mine RPSA considers site-specific human behavioural conditions observed near the South Deep Gold Mine to the extent possible and justified through the definition of a discrete set of public exposure conditions (see Section 4.5), for all relevant age groups. Consistent with the guidance provided in RG-002 (NNR, 2013), the assessment considers the age groups and ranges of age groups listed in Table 3.2.

Table 3.2 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	Age Group Used in the Assessment
New-born	From 0 to 1 year of age	0 to 2 years
1 Year	From 1 year to 2 years	
5 Year	More than 2 years to 7 years	2 years to 7 years
10 Year	More than 7 years to 12 years	7 years to 12 years
15 Year	More than 12 years to 17 years	12 years to 17 years
Adult	More than 17 years	Adults

3.4.10 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, 2009b), but no specific guidance about dose limits or an assessment framework for practical application has been developed. A major challenge is the complexity and variability of the natural environment. Also, 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 Southern Africa countries.

Furthermore, neither the NNR nor Regulation No. 388 requires at present that the impact to non-human biota be addressed as part of the assessment process. Radiological impact assessment on

non-human biota is thus excluded from the scope of this assessment. The principle applied here is to assume that if individual humans are adequately protected, then non-human biota is also be protected, at least at the species level (ICRP, 1991).

3.5 Assessment Endpoint

3.5.1 General

Assessment (or calculational) endpoints for a safety assessment is largely determined by the national regulatory framework, but also by the purpose, scope, and focus of the assessment. In some cases, the stakeholders or target audience (see Section 3.2) may also 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.

3.5.2 Radiological Public Safety Assessment Endpoints

Consistent with the ICRP System of Protection defined in Section 2.2, the primary assessment endpoint is the annual individual 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 members of the public). This is consistent with the NNR requirements for the radiological protection of members of the public and adopted in Regulation No. 388.

It follows from Section 3.3 that the purpose of the assessment is the radiological impact on members of the public induced by the South Deep Gold Mine. More specifically, the focus of the 2020 South Deep Gold Mine RPSA is the release and distribution of radioactivity into and through environment media, and the subsequent interaction of members of the public with these environmental media to pose an annual individual effective radiation dose.

3.5.3 Complimentary Assessment Endpoints

A radiological public safety assessment should not rely on an evaluation of a single assessment endpoint, such as an individual effective dose rate (IAEA, 1997; 2004b). Multiple lines of reasoning may be useful and sometimes of significant importance, since regulatory bodies and other stakeholders may use and require a wide range of arguments and endpoints to help determine the adequacy of a public safety assessment.

Viewed from this perspective, activity concentrations in environmental media may serve as a complementary assessment endpoint. While it may not be necessary from a regulatory compliance perspective, reporting these endpoints contributes to the overall transparency of the assessment. Therefore, radionuclide concentrations in environmental media can be used as complementary safety indicators to the dose criterion. These may be compared with natural background concentrations in environmental media as observed near the site. Activity concentrations in the following environmental media may thus be reported in addition to the annual individual effective dose:

- Airborne dust activity concentration in units of $\text{Bq}\cdot\text{m}^{-3}$ for PM_{10} (or less than 10 microns);
- Dust fallout or deposition rate in units of $\text{Bq}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ for Total Suspended Particulates (TSP);

- Airborne radon (or thoron) concentration in units of Bq.m⁻³;
- Activity concentration in surface water or groundwater in units of Bq.m⁻³ or Bq.L⁻¹; and
- Activity concentration in surface soils in units of Bq.kg⁻¹.

When evaluating the performance of a facility or an individual component of the total system, the release rate of radioactivity from the facility into the wider environment also serves as a useful criterion, especially if containment of radioactivity is of importance. These results could be used as feedback into the design process, to reduce the release rate if required.

3.6 Spatial and Temporal Boundary Conditions

3.6.1 Spatial Domain of Concern

The spatial domain used in the safety assessment models is largely dictated by an understanding of the processes governing the movement of radionuclides through the environmental media and relevant exposure pathways for the potentially exposed or critical groups. While physical boundaries cannot be applied rigorously to some of these processes, a radius of 5 km around the physical extent of the South Deep Gold Mine (see Section 1.1) defines the area in which environmental pathways are considered in the assessment.

Once a better understanding of the processes governing the movement of radionuclides is developed, a wider study area may be defined and justified to accommodate processes governing the movement of radionuclides beyond these boundaries. However, the spatial scale is likely to be limited by the selected exposure conditions. Since the intent of the analysis is to evaluate critical groups, the receptor locations to be evaluated are likely to be near the sources.

As part of communication to stakeholders, there may be an interest to evaluate the public radiological impact at greater distances than would be considered from a purely regulatory standpoint. That is, the critical group for comparison with regulatory criteria may be nearby the South Deep Gold Mine, but more distant locations may be of interest to members of the public living further away, even though they are at lower risk than the critical group. The decision to include these broader conditions, and associated larger spatial scales, is taken as needed as part of the development of public exposure conditions and the assessment process in general.

3.6.2 Assessment Timescales

The main period of concern for this assessment is the operational period of the South Deep Gold Mine (see Section 3.4.4). While the post-operational period is not explicitly included in the assessment, RG-002 (NNR, 2013) requires consideration of the potential radiological impact of longer-lived radionuclides that might extend into the post-operational period, especially since some of the radiation exposure sources will remain at the surface following closure.

Properties of U-238, U-235 and Th-232 (e.g. half-life) and their associated decay products suggest that some of the remaining radiation sources may be hazardous indefinitely. Furthermore, for decay chains that are not currently in secular equilibrium, there is the potential for the hazard of the waste to increase as time increases. This effect is of concern for the U-238 decay chain when U-238 is in disequilibrium with Ra-226. As time increases, Ra-226, and its radiotoxic progeny

(i.e., Rn-222, Pb-210, and Po-210) can be expected to increase, and this increase continues over timescales exceeding one million years. The implication is that there is no natural timescale, at which the safety assessment analysis can be truncated using the argument that the peak hazard has been evaluated. Also, one must recognise that over these almost indefinite timescales, natural processes such as wind and water erosion has the potential to spread and disperse surface area sources into the wider environment.

No prescribed period is specified in current national regulations and guidelines that must be considered regarding assessing the radiological impact on members of the public, other than to determine peak doses. Considering approaches in the international literature (Kozak, 2011), the following approach is adopted for evaluating the long-term safety of the South Deep Gold Mine.

Doses calculated in the safety assessment are quantitatively compared to regulatory performance objectives for the first 10,000 years. It is considered that for times later than 10,000 years, geological, morphological, and critical group uncertainties increase to the point that quantitative comparisons to the regulations are of limited use.

There may be circumstances where analyses may need to be carried out for longer periods, but the results of such calculations should only be considered qualitatively, and for the sake of providing information to stakeholders. The results should not be regarded as meaningful for quantitative comparison with the performance objectives specified in Regulation No. 388.



4 Assessment Framework

4.1 General

The purpose of this section is to describe the safety assessment framework used to perform the 2020 South Deep Gold Mine RPSA. The framework, schematically illustrated in Figure 4.1, resembles the IAEA ISAM methodology developed for the safety assessment of near-surface radioactive waste disposal facilities (IAEA, 2004b). Conceptual variations were introduced to make the framework more suitable for mining and mineral processing operations. The revised framework is still systematic and structured and provides for the continual improvement of the total system through an iterative process.

As illustrated in Figure 4.1, the assessment framework consists of several interrelated elements. The extent to which each element is incorporated into the assessment depends on the technical basis of the assessment (see Section 3) and the assessment philosophy (see Section 5). Reference to the ISAM methodology and how each element is applied is made as appropriate. IAEA (2004b) provides a more detailed description of each element for the interested reader.

The use of models and the application of modelling approaches forms an integral part of the assessment framework. Section 4.2 is consequently devoted to a brief overview of the modelling approach adopted and how it is applied in the assessment framework. The first element in Figure 4.1 is the definition of the assessment context, which is the purpose of this document. The assessment context is consequently not elaborated upon further, while Section 4.3 to Section 4.8 summarise each of the remaining elements of the assessment framework.

4.2 Modelling Approach

4.2.1 General

Various modelling approaches can be used to establish a comprehensive and defensible safety case for the mining and mineral processing operations. These approaches vary from scoping (screening) calculations to sophisticated three-dimensional modelling of environmental processes and media. What is important within the assessment framework is to ensure that the approaches used are appropriate and consistent with the purpose and objectives of the assessment (see Section 3.3).

The use of models (e.g. conceptual, mathematical, and computer models) and associated modelling approaches are an integral part of the assessment framework. Figure 4.1 makes a distinction between *Process Level* modelling and *System Level* modelling.

4.2.2 Process Level Modelling

Process Level modelling of major environmental pathways is performed to develop an understanding of the release and subsequent migration of contaminants into and through the environment. This applies to the atmospheric and aquatic (surface water and groundwater)

pathways. For the atmospheric pathway, the focus is on the release and dispersion of airborne particulates (PM₁₀ and TSP) and gases (e.g., radon and thoron). For the aquatic pathways, the focus is on the surface water and groundwater flow regimes and the subsequent release and migration (i.e., advection, adsorption, dispersion and diffusion) of contaminants through the aquatic environment.

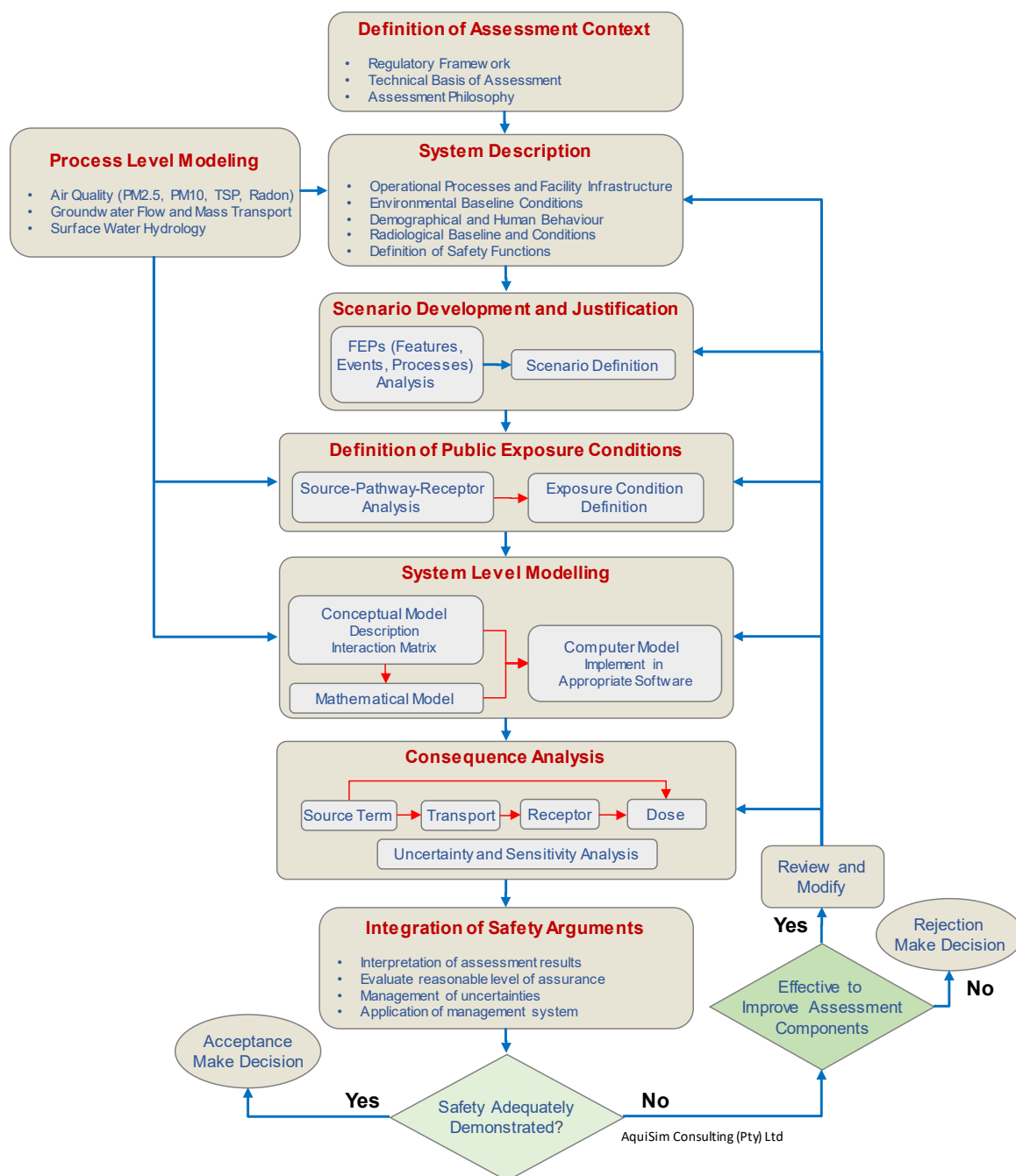


Figure 4.1 Schematic illustration of the safety assessment framework, within which the 2020 South Deep Gold Mine RPSA is performed.

Process Level modelling is often performed in much more detail than *System Level* modelling and is thus often performed by specialists using sophisticated two or three-dimensional numerical models to simulate the spatial and temporal migration of particulate matter or contaminants

through the environment media. While this enables a detailed consideration of environmental processes, it also requires considerable resources to develop and execute these models. Consequently, it is often not viable to use *Process Level* models in integrated radiological safety assessment analysis.

Within the assessment framework, *Process Level* modelling is alternatively used to provide an overall understanding of system behaviour and the nature of the underlying processes and to inform *System Level* modelling. It serves as input into the system description but also serves as the basis for the definition and justification of scenarios (see Section 4.4) and public exposure conditions (see Section 4.5).

4.2.3 System-Level Model Development

System Level modelling often requires the abstraction and use of relevant information from the *Process Level* models to represent an integrated system. In other words, the potential coupling of different processes to represent the total contribution from all pathways. For this purpose, modelling results are abstracted from the detailed atmospheric pathway modelling results. Or the groundwater flow and mass transport modelling results are simplified from three dimensions to one dimension, for example.

Compartmental models are often used to represent the migration and fate of contaminants in the environment in a simplified manner. However, the use of a compartmental model places two main constraints on the mathematical representation of a system (Little *et al.*, 2003):

- The first constraint is that the system must be discretized into a series of compartments. Using the compartment modelling approach, the system is represented by breaking it down into compartments, which correspond to the components identified in the conceptual model. It is assumed that as soon as a contaminant enters a compartment, instantaneous mixing occurs so that there is a uniform concentration over the whole compartment. Each compartment must be chosen to represent a system component for which this assumption is reasonable.
- The second constraint is that processes resulting in the transfer of contaminants from one compartment to another need to be expressed as transfer coefficients that represent the fraction of the activity in a compartment transferred from that compartment to another one per unit time. The mathematical representation of the inter-compartmental transfer processes takes the form of a matrix of transfer coefficients that allow the compartmental amounts to be represented as a set of first-order linear differential equations.

System-Level modelling as part of the 2020 South Deep Gold Mine RPSA is performed using Ecolego® Version 7 (<https://www.ecolego.se/>), a commercial software package for creating dynamic models and perform deterministic and probabilistic simulations. Ecolego® uses a compartment model approach to represent the migration and fate of contaminants in environmental systems. The system is discretized into a series of compartments and sub-compartments that correspond to the components identified in the conceptual model. It is assumed that, as soon as a contaminant enters a compartment, instantaneous mixing occurs so that there is a uniform concentration over the whole compartment.

4.2.4 Source Pathway Receptor Analysis

Consistent with the assessment framework presented in Figure 4.1, a Source-Pathway-Receptor (SPR) analysis approach provides input into the definition of public exposure conditions (see Section 4.5). This approach is inherently systematic, traceable, and transparent. The SPR analysis as a modelling approach is well known and applied extensively in environmental and radiological risk assessment (Till and Grogan, 2008).

First, all historic, current and potential (future) sources of radiation exposure are identified, with the *source(s)* referring to any feature that contains and releases radioactivity into the environment in concentrations significant enough to pose a potential radiological risk to humans. The sources are characterised in terms of their unique composition (i.e., specific radioactive substances present or emitted) and their characteristics, which determine how contaminants may be distributed in the environment.

Next, all relevant pathways and routes of exposure that relate to the identified sources are identified. In this context, *pathway* refers to the means, by which radionuclides may be dispersed or transferred within or between media of the total environmental system, to a point where humans interact with the media. *Route* refers to the route of entry into the human body, such as through ingestion or inhalation.

Finally, *Receptors* are defined and characterised, where receptors as used here refer to human beings (i.e., members of the public) that may potentially be subject to radiation exposure (i.e. a radiation dose) from the applicable sources and through the exposure pathways of concern.

4.3 System Description

Mining and mineral processing operations can be complex, consisting of various interrelated features and processes that must be considered in an integrated manner with prevailing environmental site conditions. Furthermore, quantifying the potential radiological impact on human beings requires knowledge about their behavioural characteristics.

The mining and mineral processing operation (process), associated facilities, the waste or any residue materials generated as part of the process, the prevailing environmental conditions, and the nearby human behavioural conditions are collectively viewed as an *integrated system*.

The purpose of the system description in the assessment framework is to describe the components and subcomponents of the integrated system. The level of detail to include in the system description should be proportionate to the information needed for the safety assessment. That is, the system description is intended to provide a clear representation of the features, events, and processes of the system relevant to the overall safety of the operation. However, applying the graded approach implies that it is not necessarily required to provide a comprehensive, detailed description of every component and subcomponent of the integrated system. The emphasis of the system description is to present the current understanding of the system, based on currently available data and information. As illustrated in Figure 4.1, the system description may be improved during subsequent iterations of the overall safety assessment process.

4.4 Scenario Development and Justification

The purpose of scenario development and justification within the ISAM safety assessment methodology (IAEA, 2004b) is to address uncertainties in the future evolution of the system (future uncertainties). Given the long periods that radiological contaminants can stay active in the environment and the slow progress of environmental migration, uncertainties in the post-closure conditions must be considered. Scenario development and justification are thus applied in the same context as for near-surface radioactive waste disposal facilities. Viewed from this perspective, a scenario is defined as follows (IAEA, 2004b):

A scenario is one member in a set of hypothetical Features, Events, and Processes (FEPs), devised to rationalise the future behaviour of a disposal system in a safety assessment.

The definition of scenarios forms just one part of the representation of the overall uncertainty, with the other forms of uncertainty that must also be accounted for represented by conceptual model uncertainty and parameter uncertainty (see Figure 5.1).

Different scenario development approaches have been developed over the years for near-surface and geological disposal systems. None of them can be considered the single approach to development and justification of scenarios. A common element in most of these approaches is the use of a comprehensive list of features, events and processes or FEPs list. Normally, this process results in the definition of a scenario that is related to the current understanding of how the operation or site or facility evolve (often referred to as the Normal Evolution Scenario, Reference Scenario, Base Case Scenario, etc.), and a set of alternative evolution scenarios. The latter is often related to external factors induced by changes in climate, geology, or human behaviour that may influence the normal evolution of the system. IAEA (2004b) presents a detailed description of these methodologies and a generic FEP list that can be used.

4.5 Definition of Public Exposure Conditions

While scenario development and justification are concerned with uncertainty in the future evolution of the system, it is recognised that for a specific scenario, members of the public might be exposed to radioactivity released from the total system in different ways, mainly as a function of sources, pathways, and receptors. For this reason, the concept of an exposure condition was introduced, which may be defined as follows:

An exposure condition is a sequence of features, events, and processes (FEPs) and is one of a set devised to illustrate normal or potential situations of radiation exposure to receptors.

Exposure conditions can be derived using a SPR analysis approach, a FEPs analysis approach, or a combination of the two. Whatever the approach followed, it should be inherently systematic, traceable, and transparent. A key point of interest relates to the potential for changes in exposure conditions from current receptors to potential future receptors. Current receptors and exposure pathways leading to their exposure are relatively straightforward to identify and justify since they are based on currently observable behaviour at the site.

When potential future exposures are considered, the location and behaviour of members of the public may become more speculative. It is thus important to keep assumptions about future human behaviour reasonable and within the bounds of what can be expected at the site. As discussed in Section 3.6.2, long timescales may need to be considered, in which case a broader set of exposure conditions may become increasingly likely.

Depending on the periods and associated timescales of concern, future human behavioural conditions must be considered in the definition of exposure conditions, e.g., it may be necessary to consider the potential for people to move onto the site. When such exposure conditions are considered, additional exposure pathways and contaminants of concern are expected to become important.

4.6 Model Development

A “model” is defined in the National Research Council’s *Science and Decisions: Advancing Risk Assessment* (2009) as a “simplification of reality that is constructed to gain insights into select attributes of a particular physical, biologic, economic, or social system. Mathematical models express simplification in quantitative terms.

As illustrated in Figure 4.1, the model development comprises the development of conceptual models (for each scenario and associated exposure conditions), the formulation of mathematical models necessary to evaluate the radiological consequences of each scenario and exposure condition, and the combined implementation of the conceptual model and mathematical model in an appropriate computer model.

A conceptual model per definition is a representation of the real-world system and is an important step in the process of quantifying radiological consequences of the facility or operation. Various approaches to conceptual model development (e.g. descriptions, flow diagrams, and interaction matrixes) can be used to increase the transparency and traceability of the assessment results.

The time-dependent movement and distribution of radioactive contaminants within the system are evaluated with mathematical models formulated to estimate the quantity of radioactivity transferred from sources *via* exposure pathways to receptors. The mathematical model development includes a description of the mathematical equations or expressions, as well as a definition and justification of the parameter values associated with each conceptual model and as required by the different mathematical models. Implementation of the conceptual and mathematical models in an appropriate computer model is consistent with the *System Level* modelling approach adopted for the assessment (see Section 4.2.3).

4.7 Consequence Analysis

The conceptual and mathematical models are combined in an appropriate computer model that is used to perform an analysis of the system and determine the radiological consequence of each scenario and for each exposure condition. System evaluation includes the following:

- *Source term analysis*: The source term analysis is done for each exposure pathway, notably the atmospheric and aquatic pathways, for both point and diffusive sources as appropriate;
- *Pathways analysis*: A *Process Level* modelling approach is followed for the pathway analysis to quantify the activity concentration in environmental media. This applies in particular to the atmospheric, surface water and groundwater pathways;
- *Dose assessment*: The *System Level* modelling integrates the dose assessment and the outcome of the source term and *Process Level* modelling to quantify the potential radiological safety to members of the public in terms of dose compliance criteria for each exposure condition; and
- *Uncertainty and sensitivity analysis*: Various approaches are applied as part of the uncertainty and sensitivity analysis, with the selection of the approach based on a judgment about which approach the best increase the confidence in the assessment results for the specific safety assessment. These analyses include addressing model uncertainties, parameter uncertainties, and subjective uncertainties as appropriate.

4.8 Interpretation and Presentation of Results

The final step in the assessment framework is the integration of the assessment results. As illustrated in Figure 4.1, this is done in terms of the conditions and criteria specified in the assessment context. The emphasis is to integrate all safety arguments from a reasonable assurance of safety perspective.

Various approaches can be adapted to present safety assessment results. These approaches might differ depending on the target audience and the assessment endpoints. If the results are to be presented to the wider community, for example, there may be an increased focus on the presentation of the types of results, which can be readily understood by a less technical audience. It may also be necessary to address the interests of local people with particular behaviour patterns, who wish to see the implications of those behaviour patterns addressed, whether they are included in a critical group, or not.

The main target audience for the safety assessment is the NNR and the South Deep Gold Mine management. The results are presented to facilitate the NNR decision-making process. However, viewed from a secondary objective, there may be an interest from the public and environmental interest groups. The technical report may, therefore, be complemented with a less technical presentation of the assessment results if required.



5 Assessment Philosophy

5.1 General

The purpose of this section is to define the *assessment philosophy*, which refers to the use of reason, arguments, and assumptions to establish a comprehensive and defensible safety case as part of the 2020 South Deep Gold Mine RPSA. The assessment philosophy adopted for a safety assessment largely determines the assessment and modelling approaches to follow, the treatment and management of uncertainties, future human behaviour assumptions, the performance of sensitivity analysis and establishing confidence in the overall assessment.

Before these elements are defined in more detail in Section 5.3 to Section 5.6, Section 5.2 is devoted to a brief statement on normal (exact) science and the safety assessment process.

5.2 Normal (Exact) Science and Safety Assessments

The methodology applied in a safety assessment cannot be described as an *exact science*². The classical “exact science” approach to a problem is to establish a working hypothesis, identify a set of observations or experiments to test the hypothesis and to verify or reject the hypothesis based on the results of the experiments. As noted by the philosopher of science Karl Popper, a key feature of science is the ability to prove the hypothesis as false based on empirical information (Personal communication between Dr Matt Kozak and AquSim Consulting, February 2005).

The safety assessment process draws from the fundamental principles of exact sciences and parts of the assessment methodology are sometimes amenable to “normal” scientific approaches³. However, the time scales, spatial scales, uncertainties in boundary conditions and uncertainties in future human behaviour make it impossible to test and verify (or falsify) the overall assessment. The inherent nature of the assessment methodology - from the release of radioactive contaminants, the migration of these contaminants into the environment, and the subsequent uptake of radionuclides into the human body to pose a radiological exposure - is not an exact science.

The safety assessment process can instead be described as a process to develop an understanding of the limits of potential radiological exposure to members of the public for an assumed set of conditions and parameter values. By examining a range of potential conditions of concern, it is possible to develop confidence that the public is protected from radiation exposure, even though exact statements about future exposures cannot generally be made.

² An exact science is any field of science capable of accurate, quantitative expression or precise predictions and rigorous methods of testing hypotheses, especially reproducible experiments involving quantifiable predictions and measurements. Reference: Exact science, http://en.wikipedia.org/w/index.php?title=Exact_science&oldid=330413677 The Web page states that “[Mathematics](#), [physics](#), [chemistry](#), as well as parts of [biology](#), [psychology](#), and the [social sciences](#) can be considered as exact sciences in this sense.” (last visited Feb. 4, 2010).

³ Thomas Kuhn denoted this process “normal science,” in which ordinary hypotheses and experiments lead to incremental changes in understanding of the science, to contrast this process with situations when revolutionary changes in understanding occur. Reference: Demarcation problem, http://en.wikipedia.org/wiki/Demarcation_problem (last visited Feb. 5, 2010).

5.3 Assessment Approach

Various approaches exist that can be incorporated into the safety assessment framework to enhance the overall safety case for a mining and mineral processing operation. The following approaches can be adopted for the safety assessment:

- *Graded Approach:* The graded approach ensures that the safety case and the supporting safety assessment are based on an appropriate level of understanding of the total system and its potential behaviour and that all safety-related aspects are considered and addressed. However, the resources devoted to ensuring safety have to be commensurate with the magnitude of the possible radiation risks and their amenability to control, as well as the stage of development of the facility (IAEA, 2012);
- *Iterative:* The safety assessment methodology presented in Section 4 is iterative, aimed at continual improvement of the safety case. This implies that generally, one can expect a safety assessment to go through two or more consecutive iterations (IAEA, 2004b). This assessment is not the first iteration that is performed within the comprehensive assessment framework. One can thus expect that safety arguments can be refined and improved through what is learnt during the assessment process, thereby enhancing confidence in the assessment;
- *Systematic:* The safety assessment methodology presented in Section 4 is systematic. This ensures that each stage of the assessment process and its associated decisions are appropriately documented and are rigorously based on methods that are scientifically and technically justifiable (IAEA, 2004b);
- *Reasonable Assurance:* The safety assessment process is not an exact procedure (see Section 5.2). The assessment must reach defensible decisions and determine the conditions for which reasonable assurance of compliance with safety objectives and regulatory criteria can be demonstrated;
- *Cautious vs. Realistic Assumptions:* In undertaking a safety assessment, various assumptions must be adopted. Realistic assumptions are physically possible and quite likely to occur but may be difficult to justify from existing information. Cautious assumptions are not necessarily realistic but ensure that assessment end-point(s) is not being underestimated. A balance is sought between realistic and cautious assumptions for the assessment;
- *Transparency:* A transparent assessment approach ensures that all assumptions made within the assessment and constraints and conditions imposed on the assessment are communicated to all stakeholders. Examples of measures that can be implemented to enhance transparency include:
 - Follow a transparent scenario and exposure condition development approach, including the documentation and handling of expert judgement;
 - Justify and document all assumptions and constraints imposed on model development;
 - Follow a transparent approach to treat subjective uncertainties; and
 - Justify and document all input parameter values used in the model development process.

- *Multiple Lines of Reasoning*: A single line of reasoning is not necessarily sufficient to establish confidence in a safety case. Multiple lines of reasoning refer to a set of complementary arguments that use different approaches or sources of evidence to build confidence in the safety case. Some of these arguments may be more qualitative than quantitative; and
- *Defence in Depth*: This principle implies that the safety of the facility or operation should not be unduly dependent on a single safety function. Safety functions are elements of a facility, such as a physical or chemical property of part of the system, or a process or combination of processes, that contribute to containment and isolation of the waste and associated radionuclides (IAEA, 2012).

5.4 Management of Uncertainty

Uncertainties arise from three related sources (NEA, 1997), namely scenario (or future) uncertainties, model uncertainty (in terms of conceptual and mathematical model development), and data/parameter uncertainties (in terms of conceptual and mathematical model development). Subjective uncertainty is often added as a separate category of uncertainty. However, subjective uncertainty is inherent within each of the categories of uncertainty and arises from the need to rely on professional judgment and expert elicitation⁴ due to lack of data, lack of knowledge concerning future conditions, conceptual models and parameter values (and distributions), or any aspects of the system under study that are not currently well understood (IAEA, 2004b).

It is not possible to draw rigid boundaries between these categories (see Figure 5.1). These uncertainties are inherent in any assessment of an environmental system; even more so if long-term (post-operational) timescales must be considered. Of the many judgments that need to be made during a safety assessment, a number are not amenable to quantitative evaluation and it is, therefore, necessary to deal with both qualitative and quantitative components of uncertainty. Management of uncertainties can be viewed with four main components (Savage, 1995):

- *Awareness*: Uncertainties cannot be managed if they are unknown. A safety case and safety assessment need to identify all major potential sources of uncertainty.
- *Importance*: Some uncertainties have significant effects on the safety case, while many others are unimportant. Before attempting to reduce uncertainties, it is first necessary to determine whether the uncertainty has a significant effect on the overall outcome and conclusions of the safety assessment. This can involve the use of scoping calculations and sensitivity analysis.
- *Reduction*: Having ascertained the importance of uncertainties, measures can be undertaken to reduce them. The focus of this approach is to manage and reduce uncertainties.
- *Quantification*: The effect of uncertainties in the final safety assessment needs to be addressed as part of the documentation. Some uncertainties are more difficult to quantify than others, but it is helpful to have some quantitative consideration of key uncertainties (sensitivity and/or uncertainty analysis).

⁴ Elicitation is the practice of collecting the requirements of a system from users, customers and other stakeholders.

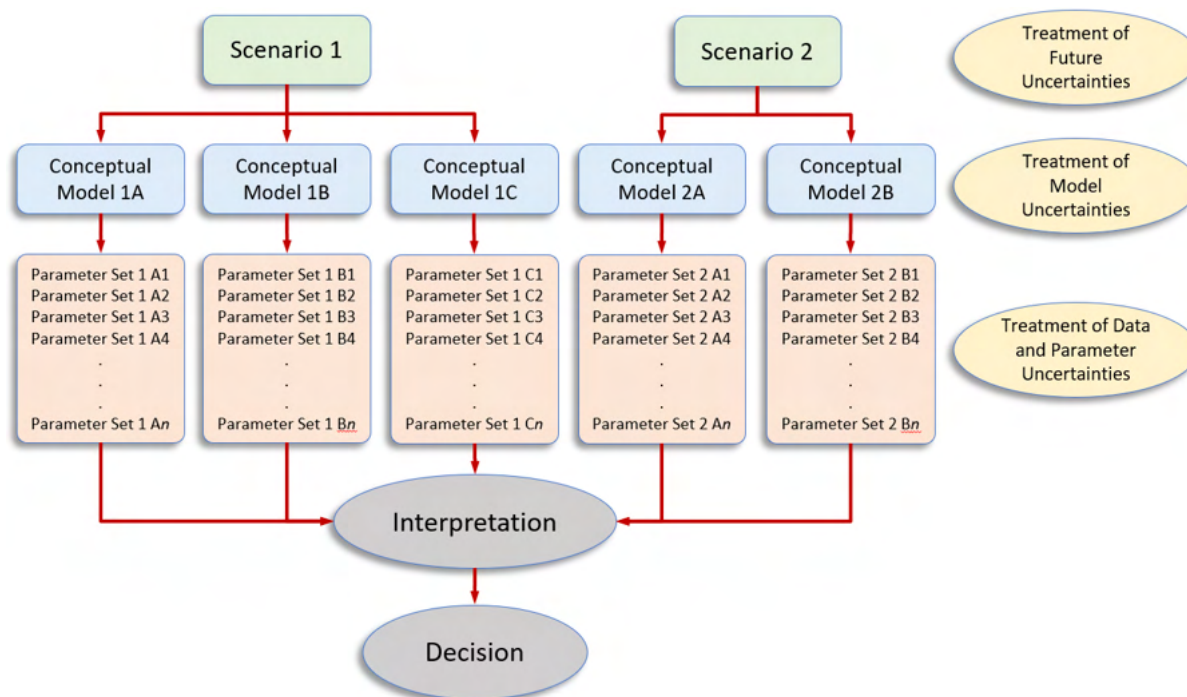


Figure 5.1 Structure of the uncertainty analysis, showing the relationship of scenario, conceptual model, and parameter uncertainty [taken from (Kozak, 1994)].

As with other aspects of the safety assessment, it is important to ensure that an appropriate level of effort is given to the management of uncertainties through the application of the graded approach. Furthermore, a strategy for uncertainty management should include consideration of building confidence for a variety of specific stakeholders, including technical reviewers, regulators, and the public.

A qualitative approach explicitly states all assumptions adopted in the assessment, establishing a corresponding audit trail with justifications for the decisions and choices that are made. A quantitative approach can encompass a range of different methods but is ultimately influenced by the stage of development of the available models as well as the quality and relevance of information available to support the analyses.

The task is not to completely remove all uncertainties, which is impossible, but rather to manage the uncertainties in such a way as to understand their impacts on the outcome of the assessment so that they can be taken into account in the development of the safety case (BNFL, 2002). Uncertainties in the safety assessment can be addressed and minimised using the following approaches:

- Documenting the assessment team's understanding of how components of the system interact;
- Using formalised procedures to record uncertainties in conceptual models and input parameters, and to document the reasoning and judgements about how these uncertainties are addressed in the assessment calculations;
- Mapping the flow of information through the assessment;

- Systematic scenario and exposure condition definition and justification approaches;
- Sensitivity and uncertainty analysis;
- Peer review of safety assessment process and documentation; and
- The use of site-specific information or information from reputable literature sources, and sufficiently cautious assumptions to ensure that assessment end-point(s) is not being underestimated.

By understanding the possible influence that uncertain data can have on the assessment endpoints, professional judgement can be utilised to manage the uncertainty and determine an appropriate course of action.

5.5 Human Behavioural Conditions

5.5.1 Present Human Behavioural Conditions

Defining the receptor population around or at an operation is a fundamental element of the radiological public safety assessment process. For this reason, the characterisation and description of the human behavioural conditions observed near the operation are included in the system description (see Section 4.3). However, not all members of a population would be exposed to radiation in the same manner, which is the main reason for the definition of a discrete set of public exposure conditions (see Section 4.5).

Variation within an exposure condition may also be expected, especially among different age groups (see Section 3.4.10). Not only are different human behavioural characteristics possible (e.g. ingestion or inhalation rates, time spent indoors or outdoors), but different dose conversion factors for ingestion and inhalation are associated with the different age groups.

5.5.2 Future Human Behavioural Conditions

The potentially long timescales that must be considered in the safety assessment (see Section 3.4.4) requires that assumptions be made regarding the future behaviour of potentially exposed population groups. These assumptions are fundamental to the definition of scenarios and exposure conditions.

Consistent with the guidance in ICRP *Publication 81* (ICRP, 1998), it is not helpful to speculate on future developments in human society and their future behaviour. Therefore, the safety assessment is based on assumptions consistent with observed human habits, activities, and behaviour. Land use conditions consistent with the rural location are assumed for defining the characteristics of potential future communities near the study area.

Where appropriate and justified, site-specific data may be supplemented with hypothetical conditions to define a critical group for the assessment. The ICRP recently introduced the concept of a *Representative Person* (ICRP, 2007) as an individual receiving a dose that is representative of the more highly exposed individuals in the population.

The *Representative Person* may be hypothetical, but it is important that the habits (e.g.,

consumption of foodstuffs, breathing rate, location, usage of local resources, etc.) which characterises the *Representative Person* are typical habits of a small number of individuals, representative of those most highly exposed and not the extreme habits of a single member of the population. Consideration may be given to some extreme or unusual habits, but they should not dictate the characteristics of the *Representative Persons* considered. While the exposure conditions defined for the assessment in all likelihood include the *Representative Person*, it is important to note that it is not necessarily the only receptor groups considered in an assessment. More than one receptor groups can be defined, leading to potentially different exposure conditions.

The following two approaches can be applied in the safety assessment to consider future human behavioural conditions, as appropriate:

- In the *a priori* approach, the assumed characteristics and habits of candidate critical groups are fixed before performing the exposure calculation, and the highest resulting dose then serves as a representative indicator of the maximum potential exposure.
- A *posteriori* approach adopts the premise that it is only possible to determine which particular combination of characteristics of human behaviour would cause an individual to be among those incurring a given exposure range (e.g. among the highest exposures) after each pathway has been assessed quantitatively.

5.6 Confidence Building

5.6.1 General

Findings of a safety assessment are generally used to provide confidence to stakeholders that the radiological impact on members of the public by the mining and mineral processing operation will not have adverse effects on human health.

It is recognised that dose assessment calculations alone are not sufficient to demonstrate a reasonable level of assurance that the mining and mineral processing operations do not pose unnecessary radiological risks to members of the public. To improve confidence in the safety of the operation, it is necessary to develop a broader set of arguments covering more aspects of the potential operational influences on the public. The combination of these arguments is commonly referred to as the *safety case* for the mining and mineral processing operation.

5.6.2 Confidence Building in Safety Assessment

NEA (1999) defines confidence as a positive judgement that a given set of conclusions are well-supported. It is from this perspective that confidence-building has become an integral part of safety assessment. It can be considered as both internal and external to the safety assessment:

- Internal confidence refers to the confidence the people performing the safety assessment have in their results, that the analysis and the results are appropriate, and that the uncertainties are identified and minimised where possible, and
- External confidence refers to the confidence stakeholders have in the assessment, in

particular, the regulatory authorities and the public, providing an acceptable level of justification that the safety assessment is suitable for supporting a decision, whether by technical or non-technical decision-makers.

A variety of approaches can be followed to build confidence in the safety assessment, most of which are qualitative and falls outside the calculations assessment process. These approaches are used to develop a defensible safety case and managing uncertainties. Examples of these approaches include:

- | | |
|-----------------------------------|--|
| ■ Use of Management Systems | ■ Scientific and Technical / Engineering Principles |
| ■ Stakeholder Involvement | ■ Understanding the Disposal System |
| ■ Discussion of Options | ■ Monitoring |
| ■ Passive Safety | ■ Independent Peer Review |
| ■ Defence in Depth | ■ Completeness of the Safety Case |
| ■ Robustness | ■ Traceability and Transparency |
| ■ Complimentary Safety Indicators | ■ Plans for Addressing Significant Unresolved Issues |
| ■ Multiple Lines of Reasoning | |

5.6.3 Quality Assurance and Control (QA/QC)

Maintaining appropriate quality control/quality assurance measures during the safety assessment is integral to building confidence in the assessment. QA/QC measures that are applied include keeping a system of records of decisions, justifying and documenting parameter values used in the assessment, peer-reviewing reports and where applicable, validated, verified and calibrated computer models.

Traceability of reports and documents prepared for the safety assessment is assured using a simple system of numbering successive document revisions.



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Appendix A: Radionuclide and Element Dependent Data

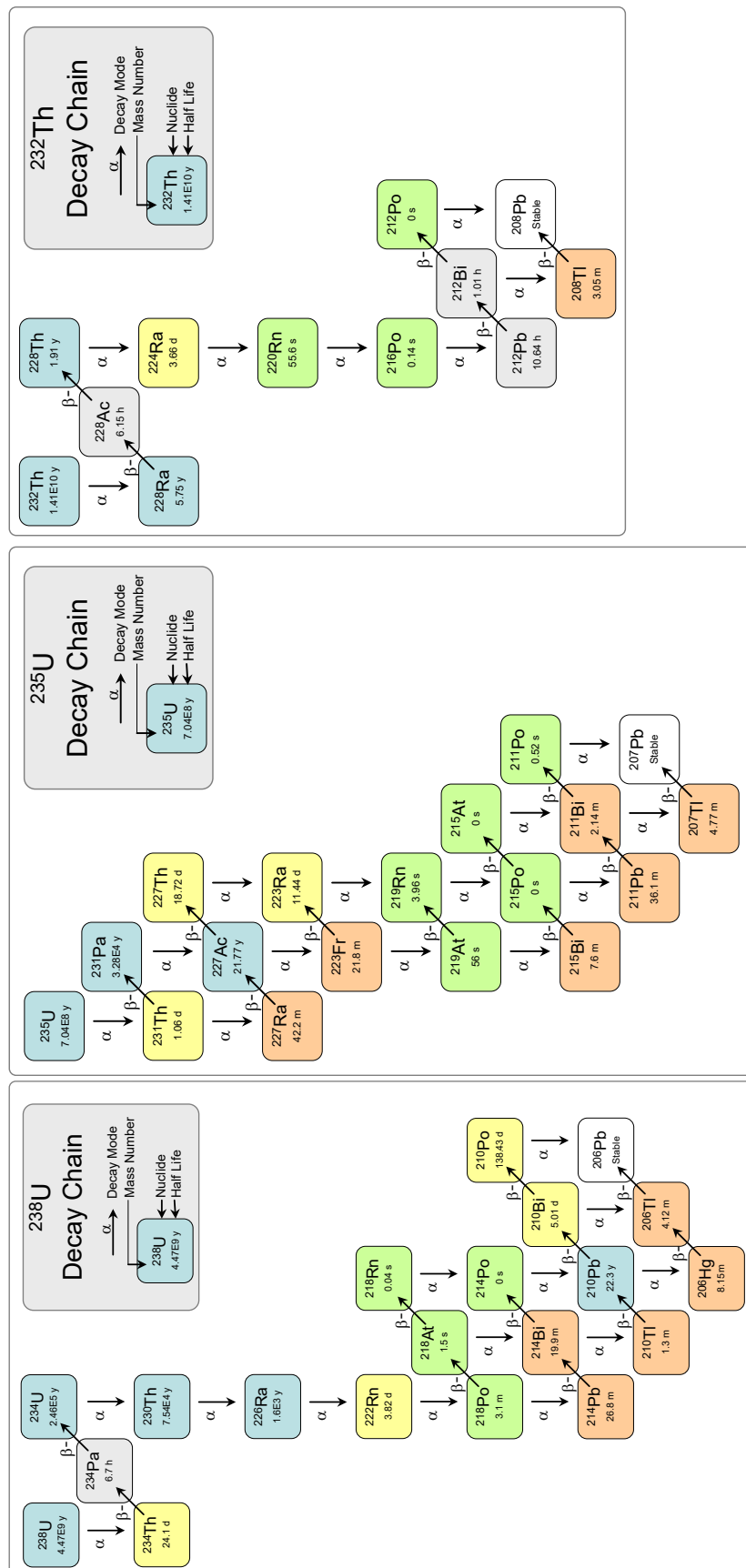


Figure A 1 Schematic illustrations of the U-238, U-235, and Th-232 decay chains.

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: Reports and Publications that Contributes to the Definition of the International Radiation Protection Framework for the Nuclear, Medical, and Mining Industries

Table B 1 Summary of the more recent UNSCEAR publications and the reports attached as annexures.

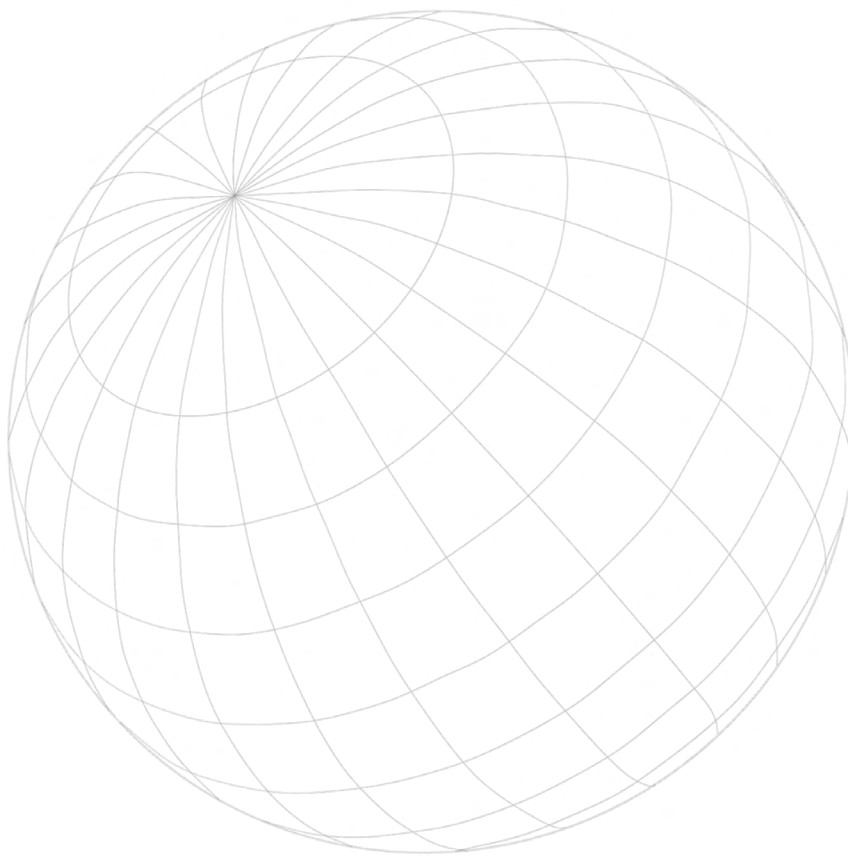
UNSCEAR 2000 Report: Sources and Effects of Ionizing Radiation	
Annex A	Dose assessment methodologies
Annexe B	Exposures from natural radiation sources
Annexe C	Exposures from man-made sources of radiation
Annexe D	Medical radiation exposures
Annexe E	Occupational radiation exposures
Annexe F	DNA repair and mutagenesis
Annexe G	Biological effects at low radiation doses
Annex H	Combined effects of radiation and other agents
Annexe I	Epidemiological evaluation of radiation-induced cancer
Annex J	Exposures and effects of the Chernobyl accident
UNSCEAR 2001 Report: Hereditary Effects of Radiation	
UNSCEAR 2006 Report: Effects of ionizing radiation	
Annex A	Epidemiological studies of radiation and cancer
Annexe B	Epidemiological evaluation of cardiovascular disease and other non-cancer diseases following radiation exposure
Annexe C	Non-targeted and delayed effects of exposure to ionizing radiation
Annexe D	Effects of ionizing radiation on the immune system
Annexe E	Sources-to-effects assessment for radon in homes and workplaces
UNSCEAR 2008 Report: Sources and Effects of Ionizing Radiation	
Annex A	Medical radiation exposures
Annexe B	Exposures of the public and workers from various sources of radiation
Annexe C	Radiation exposures in accidents
Annexe D	Health effects due to radiation from the Chernobyl accident
Annexe E	Effects of ionizing radiation on non-human biota
UNSCEAR 2010 Report: Summary of low-dose radiation effects on health	

Table B 2 Summary of IAEA General Safety Requirements, General Safety Guides, and Specific Safety Guides applicable to the mining and mineral processing industry.

A	General Safety Requirements	
1	Preparedness and Response for a Nuclear or Radiological Emergency Safety Requirements	Series No. GS-R-2
2	The Management System for Facilities and Activities Safety Requirements	Series No. GS-R-3
3	Governmental, Legal and Regulatory Framework for Safety General Safety Requirements Part 1	Series No. GSR Part 1
4	Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards – Interim General Safety Requirements Part 3	Series No. GSR Part 3
5	Safety Assessment for Facilities and Activities General Safety Requirements Part 4	Series No. GSR Part 4
6	Predisposal Management of Radioactive Waste General Safety Requirements Part 5	Series No. GSR Part 5
7	Decommissioning of Facilities Using Radioactive Material Safety Requirements	Series No. WS-R-5
B	General Safety Guides	
1	Arrangements for Preparedness for a Nuclear or Radiological Emergency Safety Guide	Series No. GS-G-2.1
2	Application of the Management System for Facilities and Activities Safety Guide	Series No. GS-G-3.1
3	The Management System for Technical Services in Radiation Safety Guide	Series No. GS-G-3.2
4	The Management System for the Processing, Handling and Storage of Radioactive Waste Safety Guide	Series No. GS-G-3.3
5	Classification of Radioactive Waste General Safety Guide	Series No. GSG-1
6	Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency General Safety Guide	Series No. GSG-2
7	Occupational Radiation Protection Safety Guide	Series No. RS-G-1.1
8	Assessment of Occupational Exposure Due to Intakes of Radionuclides Safety Guide	Series No. RS-G-1.2
9	Assessment of Occupational Exposure Due to External Sources of Radiation Safety Guide	Series No. RS-G-1.3
10	Building Competence in Radiation Protection and the Safe Use of Radiation Sources Safety Guide -	Series No. RS-G-1.4
11	Environmental and Source Monitoring for Purposes of Radiation Protection Safety Guide	Series No. RS-G-1.8
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14	Predisposal Management of Low and Intermediate Level Radioactive Waste Safety Guide	Series No. WS-G-2.5
15	Predisposal Management of High-Level Radioactive Waste Safety Guide	Series No. WS-G-2.6
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17	Release of Sites from Regulatory Control on Termination of Practices Safety Guide	Series No. WS-G-5.1
18	Safety Assessment for the Decommissioning of Facilities Using Radioactive Material Safety Guide	Series No. WS-G-5.2
19	Storage of Radioactive Waste Safety Guide	Series No. WS-G-6.1
C	Specific Safety Guides	
1	Occupational Radiation Protection in the Mining and Processing of Raw Materials Safety Guide	Series No. RS-G-1.6
2	Management of Radioactive Waste from the Mining and Milling of Ores Safety Guide	Series No. WS-G-1.2

2020 Radiological Public Safety Assessment of the Gold Fields South Deep Gold Mine:

System Description



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Technical Report



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REVISION TABLE

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LIST OF ACRONYMS

ALARA	As Low As Reasonably Achievable
BBBEE	Broad Based Black Economic Empowerment
Bq	Becquerel
CIL	Carbon in Leach
CIP	Carbon in Pulp
CM	Current Mine
CoR	Certificate of Registration
GFI	Gold Fields Limited
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LLα	Long-Lived Radioactive Dust (Alpha)
LoM	Life of Mine
LM	Local Municipality
MAP	Mean Annual Precipitation
MPRD Act	Minerals and Petroleum Resources Development Act
mSv	millisievert
NEA	Nuclear Energy Act (Act No. 46 of 1999)
NoW	North of Wrench
NNR	National Nuclear Regulator
NNRA	National Nuclear Regulator Act (Act 47 of 1999)
NORM	Naturally Occurring Radioactive Materials
PM ₁₀	Particulate matter less than 10 micron in size
RG	Regulatory Guide
RGMs	Radon Gas Monitors
RPP	Radiation Protection Programme
RPS	Radiation Protection Specialist
RPSA	Radiological Public Safety Assessment
RWD	Return Water Dam
SoW	South of Wrench
SPR	Source-Pathway-Receptor
TSFs	Tailings Storage Facilities
TSP	Total Suspended Particles
VCR	Ventersdorp Contact Reefs
WAL	Western Areas Gold Mining Company Limited
WMA	Water Management Area
WRD	Waste Rock Dump

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1 Introduction

1.1 Background

Gold Fields has operated in South Africa since 1887 when Cecil John Rhodes and Charles Rudd formed Gold Fields of South Africa. In 1932, the company began mining the mineral-rich West Rand, where it discovered high-yielding gold deposits. A merger between Gold Fields of South Africa and Gencor in 1998 led to the formation of Gold Fields Limited (GFI). Today, GFI is an unhedged, globally diversified producer of gold that has built on its South African reserves and resources, with a portfolio of eight operating assets and several exploration projects grouped into four regions, namely Australia, Ghana, Peru and South Africa. Gold Fields has a primary listing on the Johannesburg Stock Exchange, with secondary listings on the New York Stock Exchange and the Swiss Exchange.

The only remaining GFI mining operation in South Africa is the South Deep Gold Mine, which conducts gold mining and processing operations in a lease area comprising approximately 4,268 hectares. All required authorisations have been obtained and are in good standing. The conversion of the old order mining right to a new order mining right, as required in terms of the Minerals and Petroleum Resources Development Act (MPRD Act) (Act 28 of 2002) was approved in July 2010.

The South Deep Gold Mine has extensive underground workings and surface production facilities, with associated infrastructure that are used to access and extract gold-bearing ore from the Ventersdorp Contact Reefs (VCR) and the Upper Elsburg formation conglomerates of the Witwatersrand Basin. The surface production facilities and associated infrastructure include a gold processing plant, backfill and water treatment plants, access and ventilation shaft complexes, tailings storage facilities (TSFs), waste rock dumps (WRDs), return water dams (RWDs), transfer pipelines for water and tailings, and offices.

1.2 Naturally Occurring Radionuclides

Naturally occurring radionuclides associated with the uranium, thorium and actinium decay series are associated in varying degrees with the gold-bearing reefs of the Witwatersrand Basin. These naturally occurring radionuclides are present in ore brought to the surface for processing and consequently was carried through to the mineral processing residues that are now stored on the surface as tailings or sand facilities. These materials and residues that contain naturally occurring radionuclides are generally referred to as Naturally Occurring Radioactive Materials (NORM) (IAEA, 2007).

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). 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 other wastes.

Industries such as NORM generating mining and mineral processing operations and associated facilities and activities thus have the potential to alter the natural background radiation, and potentially increase radiation exposure to human beings and the environment, by:

- Moving naturally occurring radionuclides from inaccessible locations to locations where humans are present and can be exposed;
- Concentrating naturally occurring 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).

1.3 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 safety 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”.

Gold Fields holds a Certificate of Registration (CoR-18) granted by the NNR in terms of Section 22 of the NNRA for the South Deep Gold Mine. Under the regulatory process administered by the NNR and in line with internationally accepted radiation protection and management practices, a CoR holder must submit an updated Radiological Public Safety Assessment (RPSA) regularly (every 3 to 5 years) to retain the nuclear authorisation. The purpose of these revisions is to reflect on regulatory and operational changes incurred during this period and to assess the radiological consequences of these changes to members of the public. At the same time, new information that became available on the current operation can be incorporated into the RPSA and the associated public Radiation Protection Programme (RPP) can be revised and updated accordingly. Collectively, this ensures that the protection of members of the public against exposure to ionizing radiation-induced by facilities and activities incorporated within the scope of the CoR is in line with the national safety standards.

The current radiological public safety assessment for the South Deep Gold Mine was performed and submitted to the NNR in 2017 (Van Blerk and Potgieter, 2017). AquiSim Consulting (Pty) Ltd (AquiSim) was appointed as Radiation Protection Specialist (RPS) to update the 2017 Radiological Public Safety Assessment of the South Deep Gold Mine in accordance with the provision, requirements, and guidelines provided by the NNR (hereafter referred to as the 2020 South Deep Gold Mine RPSA).

1.4 Purpose of the Report

Mining and mineral processing operations can be complex, consisting of various interrelated features and processes that must be considered in an integrated manner with prevailing environmental site conditions. Furthermore, quantifying the potential radiological impact on human beings requires knowledge about their behavioural characteristics. The mining and mineral processing operation (process), associated facilities, the waste or any residue materials generated as part of the process, the prevailing environmental conditions, and the nearby human behavioural conditions are collectively viewed as an *integrated system*.

The purpose of the system description in the assessment framework is to describe the components and subcomponents of the integrated system. The level of detail to include in the system description should be proportionate to the information needed for the safety assessment. That is, the system description is intended to provide a clear representation of the features, events, and processes of the system relevant to the overall safety of the operation. However, applying the graded approach implies that it is not necessarily required to provide a comprehensive, detailed description of every components and subcomponent of the integrated system.

Viewed from this perspective and consistent with the assessment methodology and technical approaches therein (see Figure 1.1), the purpose of this report is to provide a summary description of the South Deep Gold Mine including the surface infrastructure and associated activities, the residue materials generated as part of the operation, associated environmental and human behavioural characteristics, as well as the measured and observed radiological conditions associated with the South Deep Gold Mine.

Consistent with one of the objectives of the 2020 South Deep Gold Mine RPSA as presented in the *Assessment Context* report (Aquisim, 2020a), this includes any relevant changes that may have occurred the past 3 years, as well as any new information and data that may have become available since the 2017 South Deep Gold Mine RPSA, as presented in Van Blerk and Potgieter (2017).

1.5 Scope and Structure of the Document

The objective of the assessment is to confidently demonstrate to the NNR and other stakeholders that nearby members of the public are not exposed to levels of ionizing radiation induced by the South Deep Gold Mine above the regulatory compliance criteria set for public exposure.

Consistent with the *Assessment Context* report (Aquisim, 2020a) and regulatory guidance provided by the NNR (NNR, 2013), the focus of the assessment is the operational period of the South Deep Gold Mine. Viewed from this perspective, the purpose of the 2020 South Deep Gold Mine RPSA was defined as follows (Aquisim, 2020a):

To assess the radiological safety to members of the public from conditions induced by the South Deep Gold Mine in a comprehensive, systematic, and transparent manner that is consistent with the NNRA and NEA, as well as with NNR requirements, guidance, and regulations.

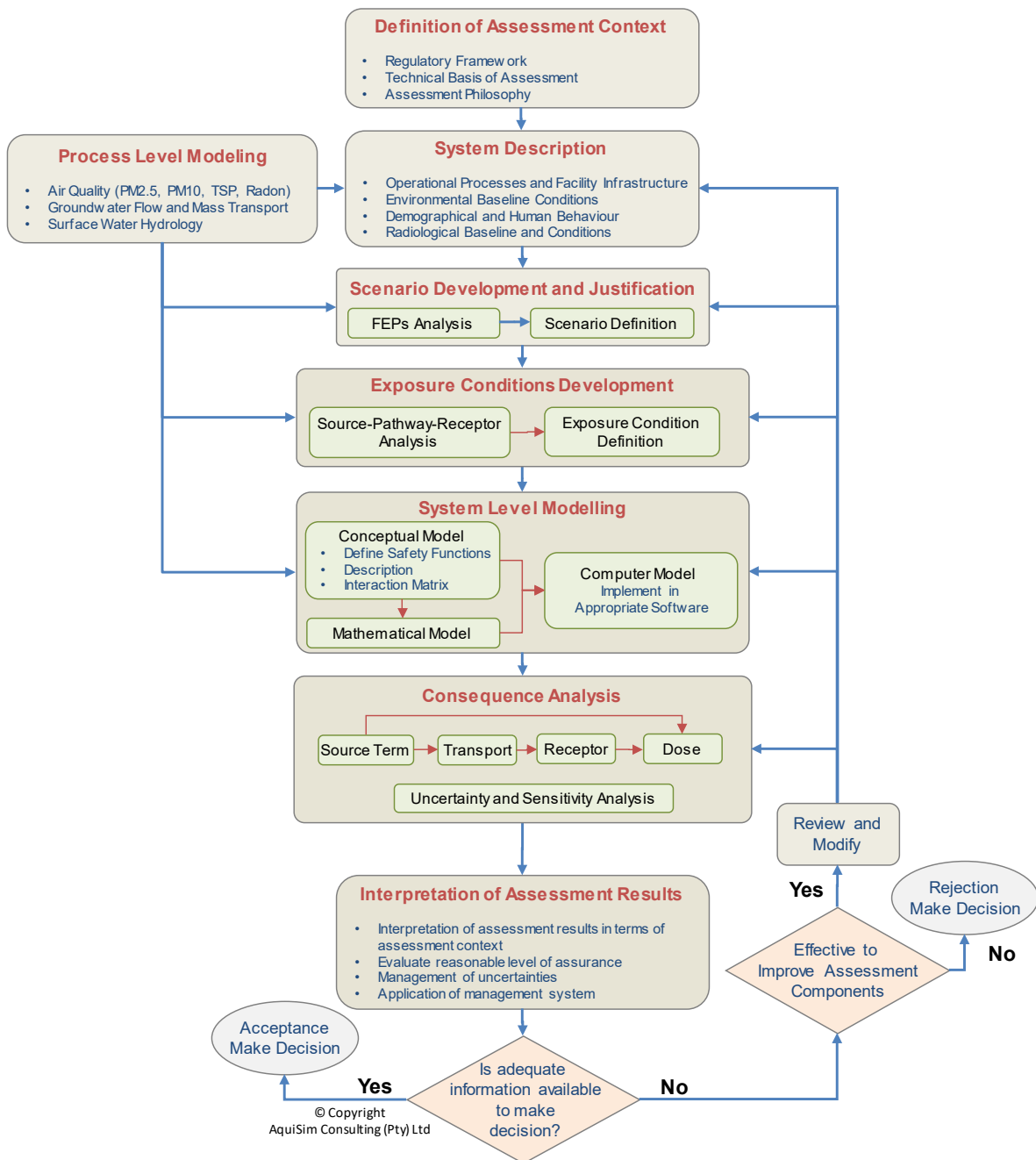


Figure 1.1 Schematic illustration of the safety assessment framework, within which the 2020 South Deep Gold Mine RPSA is performed (Aquisim, 2020a).

The methodology used for this purpose is based on a general framework developed in the international community to conduct post-closure radiological safety assessments of near-surface radioactive waste disposal facilities (IAEA, 2004). As illustrated in Figure 1.1, the definition of the assessment context and system description is the first steps in the process and provides the basis for the definition and justification of scenarios and public exposure conditions as subsequent steps. The latter is documented in the *Development and Justification of Public Exposure Conditions* report (Aquisim, 2020b) for the 2020 South Deep Gold Mine RPSA.

The nature of mining and mineral processing operations is such that some of the associated facilities and activities may serve as sources of radiation exposure from the time they are commissioned. Others will cease to serve as sources following decommissioning, while facilities such as tailings storage facilities that remain at the surface will continue to serve as a source of radiation exposure long after operations ceased. Incidents or accidents outside normal operational conditions (e.g., spillages or controlled or uncontrolled releases of water or tailings) may serve as additional sources of radiation exposure to members of the public. It is thus important that the system description reflect this time-varying aspect to the extent possible.

The report is structured as follows:

- Section 2 provides a summary description of the mining and mineral processing surface infrastructure associated with the South Deep Gold Mine, as well as conditions as it is perceived to be during the post-operational period;
- Section 3 provides a summary description of the environmental baseline conditions as observed near the South Deep Gold Mine;
- Section 4 describes the land use and human behavioural conditions near the South Deep Gold Mine; and
- Section 5 summarises the radiological properties and conditions associated with the South Deep Gold Mine, including baseline environmental radiological conditions as observed in the area.



2 Description of the South Deep Gold Mine and Associated Surface Infrastructure

2.1 General

It follows from Section 1.1 that surface production facilities and associated infrastructure include a gold processing plant, backfill and water treatment plants, access and ventilation shaft complexes, TSFs, WRDs, RWDs, transfer pipelines for water and tailings, and offices. However, all these facilities and activities are not equally important from a radiological public safety assessment perspective. The purpose of this section is to provide a summary description of the South Deep Gold Mine and associated surface infrastructure, with specific emphasis on the information needed for the safety assessment.

Within the conceptual assessment framework presented in Figure 1.1, the description of the South Deep Gold Mine and associated infrastructure serves as input into the source characterisation (and associated source term analysis), which in turn provides input into the development of the environmental process and system level models, as well as the development of public radiation exposure conditions.

The section is structured as follows. Section 2.2 provides an overview of the regional and local setting of the South Deep Gold Mine, while Section 2.3 provides a general overview of the South Deep Gold Mine. Section 2.4 describes the surface infrastructure associated with the South Deep Gold Mine, including a description of the management of mining and mineral processing waste, as well as water usage and management practices. Section 2.5 describes the operational features and associated surface infrastructure associated with the South Deep Gold Mine that is of relevance to the 2020 South Deep Gold Mine RPSA.

2.2 Geographic Setting

Figure 2.1 shows that the South Deep Gold Mine is located in the Gauteng Province of South Africa in the magisterial districts of Westonaria and Vanderbijlpark, near the border with North West Province. The mine is located between the N12 and N1, some 45 kilometres south-west of Johannesburg and can be accessed *via* the R28 provincial road between Randfontein and Vereeniging.

Neighbouring towns include Westonaria, which is situated 15 km to the north of the South Deep Gold Mine, Fochville situated 25 km to the west, Randfontein situated 30 km to the north, Carletonville situated about 35 km to the north-west, and Vereeniging situated 40 km to the south-east of the mine. Neighbouring mining operations include the Sibanye-Stillwater Kloof and Cooke 4 (Ezulwini) Operations. Figure 2.2 shows the South Deep Gold Mine relative to major nearby towns and other mining operations, while Figure 2.3 shows that the current underground Mining Right Area of the South Deep Gold Mine is situated on the farms Modderfontein 345 IQ and Doornpoort 347 IQ.

Gauteng Province of South Africa.

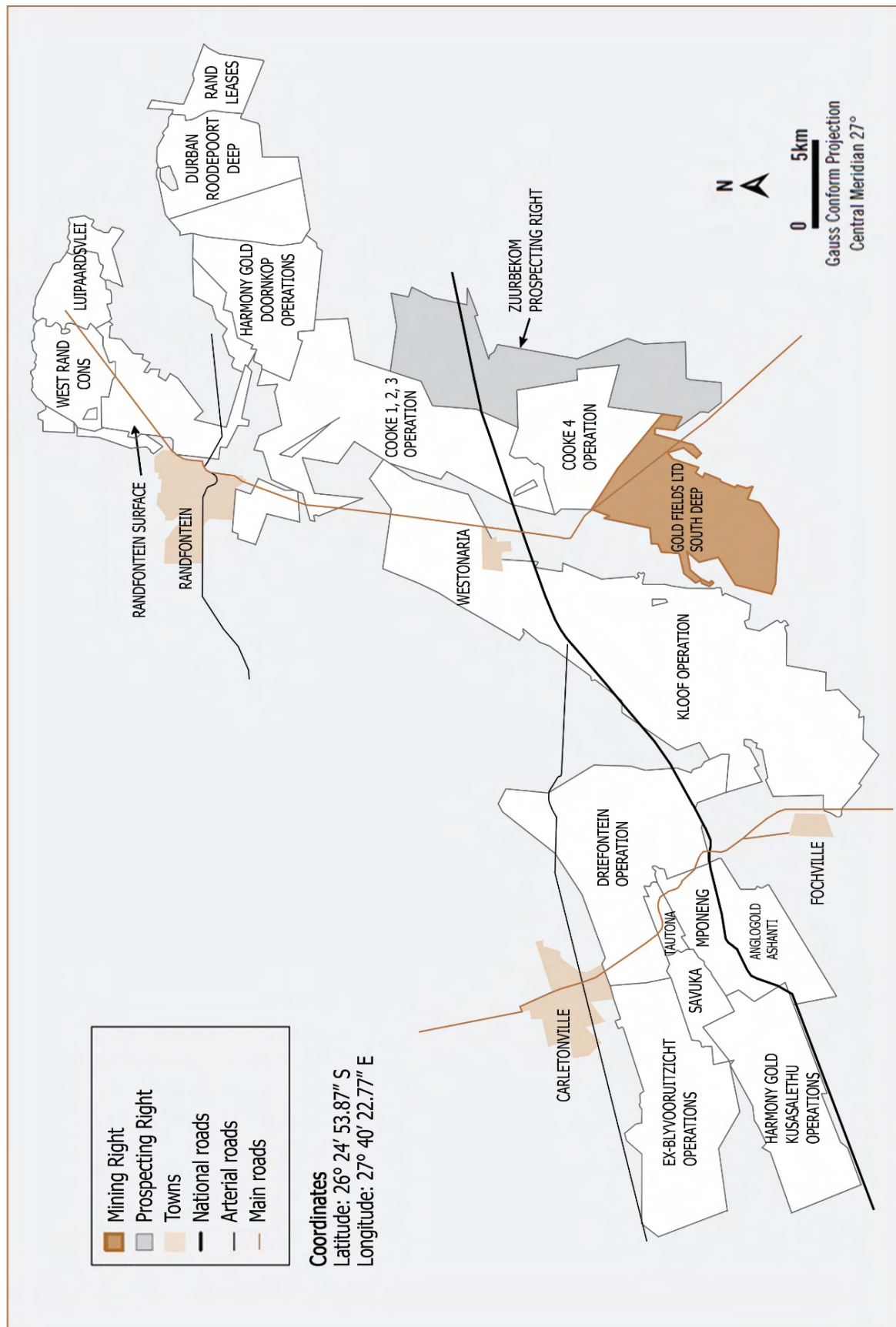


Figure 2.2 Map showing the South Deep Gold Mine relative to major towns and other mining operations.

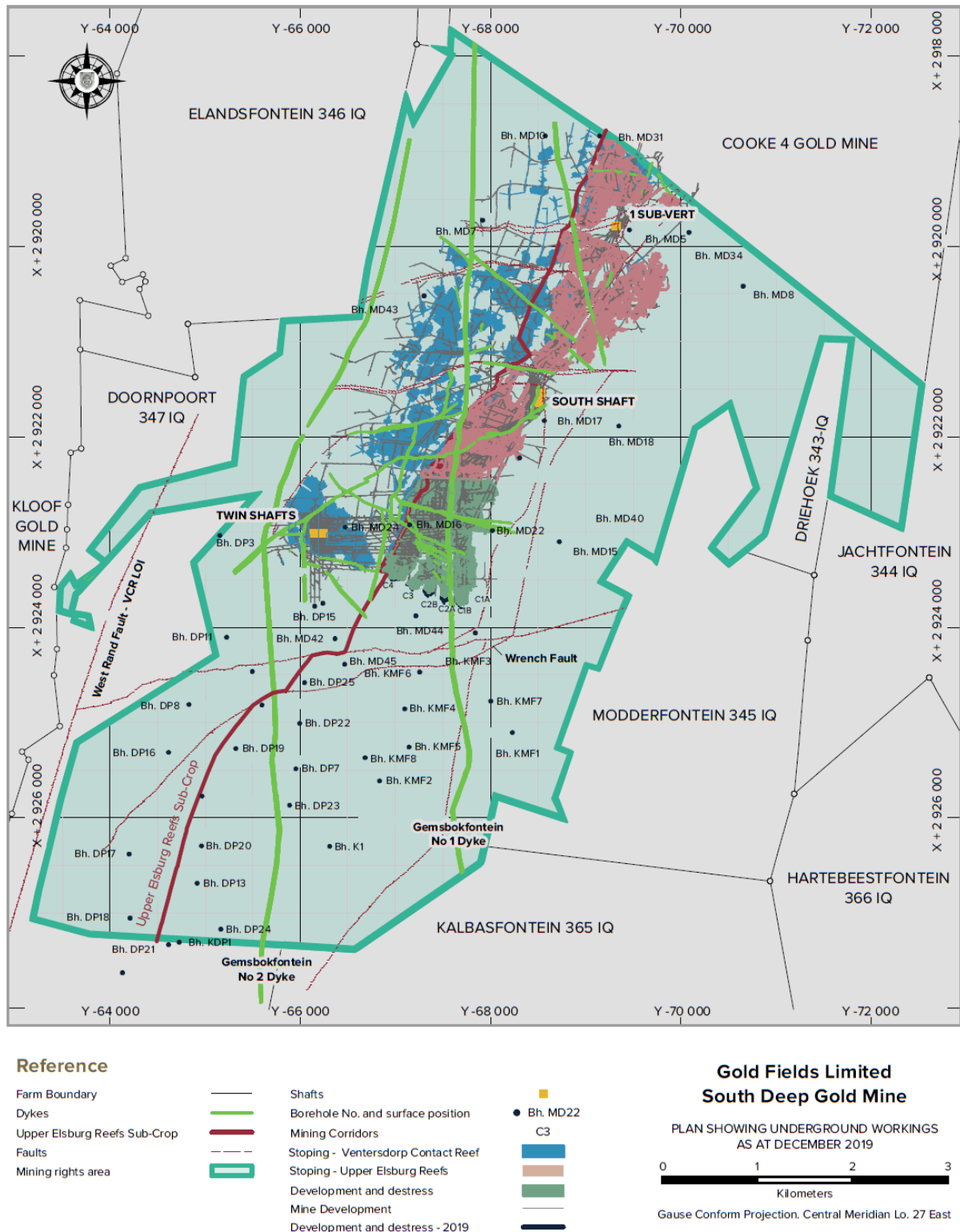


Figure 2.3 Map showing the present Mining Right Area and scope of the South Deep Gold Mine Operations.

2.3 General Overview of the South Deep Gold Mine Mining Operations

2.3.1 General

The South Deep Gold Mine has been built to extract one of the largest undeveloped gold ore bodies in the world. The underground workings are accessed from the surface at two shaft complexes, namely the Twin Shaft Complex and the South Shaft Complex. These underground operations are complemented by limited surface operations that extract gold from historical TSFs on the surface. Presented here is an overview of the historic and present South Deep Gold Mine operations.

2.3.2 Historical Perspective

Historically, South Africa has been the largest producer of gold in the world, with 98% of the country's gold believed to have been produced from the goldfields located in the Witwatersrand Basin. The gold is recovered from ancient sedimentary conglomerate bands or "reefs" found mainly in the Central Rand Group of the upper Witwatersrand Basin.

The South Deep Gold Mine is located in an area referred to as the West Rand Goldfields, which is one of the areas in South Africa where the gold resources of the Witwatersrand Basin are actively mined (see Figure 3.1). The Witwatersrand Basin is a conglomerate deposit that accounts for some 35% of the world's total known historical gold production. As indicated in Figure 3.1, the West Rand Goldfields are located between the Potchefstroom Goldfields, situated just northeast of Potchefstroom and the Central Rand Goldfields located at Johannesburg.

It follows from Section 1.1 that Gold Fields of South Africa dates back to 1887, while the company began mining the mineral-rich West Rand in 1932, where it discovered high-yielding gold deposits. Commercial production of the Western Areas Gold Mine commenced in September 1951. In 1990, Western Areas Gold Mining Company Limited (WAL) shareholders approved the transfer, cession and assignment of certain land and mineral rights to South Deep Exploration Company Limited in exchange for its shares. WAL and South Deep Exploration Company Limited merged on 1 January 1995. Development of 95 Level across to the planned collar position of the Twin Shaft commenced. A merger between Gold Fields of South Africa and Gencor in 1998 led to the formation of Gold Fields Limited.

On 1 April 1999, the Placer Dome/Western Areas joint venture was formed, while in February 2000, the name of the mine was changed to South Deep Gold Mine. The sinking of the ventilation shaft was completed to 95 Level in 2001 and the main shaft to 110 Level in 2002, concurrently a 7,200 tons per day capacity mill was commissioned. The Twin Shaft Complex was officially opened on 4 February 2005.

Barrick Gold Corporation acquired a majority interest in Placer Dome Inc. on 20 January 2006 and Gold Fields acquired Barrick's 50% joint venture interest in the Placer Dome/Western Areas joint venture on 1 December 2006. In April 2007, Gold Fields acquired all remaining WAL shares and consequently owned 100% of South Deep Gold Mine at that time. Between 2008 and 2009, all conventional mining was stopped and low-profile mechanised destress mining was initiated following a pre-feasibility study, the ventilation shaft was deepened to 110 Level that was commissioned in 2012.

A new-order mining right was granted to the South Deep Gold Mine in 2010, including the area known as Uncle Harry's. In 2011, Newshelf 899 (Proprietary) Limited (Newshelf) was established, which holds a 100% interest in South Deep Gold Mine. Newshelf is a 90% subsidiary of GFI and the remaining 10% is held by outside shareholders as part of a Broad Based Black Economic Empowerment (BBBEE) transaction.

In 2017, the high-profile destress method successfully implemented and the Rebase Plan was initiated. In 2018, a major restructuring of the South Deep Gold Mine was initiated in support of a new operating model designed to improve operational efficiency, reduce operating costs and leverage cash flow. The restructuring plan was embedded in 2019, which incorporated a reduced workforce and mobile equipment levels aligned to overall mining activity that increased focus on the core productivity process and supported a recalibration of the cost base.

The new Life of Mine (LoM) plan addresses the previous disconnects between mine plan and execution and encompasses the revised strategy and new operating model. It remains anchored by the Rebase Plan design and fundamentals, with a specific renewed focus on improved operational efficiency and execution. The new plan sets out the foundation and installs the key enablers required to fully convert the mine to a fully mechanised bulk-efficient operation with an effective organisational culture supportive of mechanised operations. The anticipated levels of production have been achieved quarter-on-quarter during 2019.

2.3.3 Underground Workings

The South Deep Gold Mine is an intermediate to deep-level mechanised gold mine exploiting auriferous palaeoplacers (reefs), or more specifically the conglomerates that comprise the Upper Elsburg Reefs of the Mondeor Formation at a depth greater than 2,000 m below surface. Historically the Ventersdorp Contact Reef (VCR) of the Venterspost Formation has been exploited using conventional mining methods (see Figure 2.3).

The underground workings are accessed from the surface through two shafts. The Twin Shaft Complex provides access to 110A Level, of which the main shaft comprises a single drop to a depth of 2,998 m and the ventilation shaft at Level 110 to 2,947 m. The South Shaft Complex is a sub-vertical system to 95 Level at a depth of 2,786 m. The underground workings have been subdivided into three main areas.

- Current Mine (CM) characterised by selective mining methods scattered over a large area originally exploited using conventional tabular mining. CM is accessed from four active levels (90, 93 and 95) from both the South Shaft and Twin Shaft complexes;
- The North of Wrench (NoW) area, directly south of CM, comprises six mining corridors separated by regional pillars that extend southwards to the Wrench fault. A bulk non-selective mining method is applied here resulting in a higher Resource to Reserve conversion ratio; and
- South of Wrench (SoW) East and West situated south of NoW, which will be mined in the same manner as NoW.

2.3.4 Tailings Storage Facilities

The Doornpoort TSF is the only operating active TSF at the South Deep Gold Mine, in addition to two historical dormant TSF Complexes that are undergoing re-mining using hydraulic mining methods. TSF 1, consisting of two compartments, was commissioned in 1968 and is an upstream raised paddock dam as is typical in South African gold mines. This TSF Complex covers a combined footprint of 70 ha and has a maximum height of 47 m. TSF 2, also consisting of two compartments, was commissioned in 1982 and are also an upstream raised paddock dam. This TSF Complex covers a combined footprint of 100 ha and has a maximum height of 41 m. Deposition on both these TSFs Complexes ceased in 2011.

The Doornpoort TSF, with a footprint area of 260 ha, was commissioned in April 2011 and three upstream wall raises have been constructed. The current height is in the order of 25 m, with a planned final height of 62.2 m. The deposition rate in 2012 initially started at 160,000 tpm of plant tailings with 80-90% passing 75 μm with a planned deposition rate of 230,000 tpm of plant tailings with 80-90% passing 75 μm . The specific gravity of the tailings material deposited on the Doornpoort TSF ranges between 1.30 and 1.40 with backfill material removed before deposition. The TSF incorporates a gravity decant system with drainage structures placed beneath the tailings themselves. This Doornpoort TSF has a remaining LoM storage capacity of ~149 Mt (Phase 2).

2.3.5 Surface Operations

The surface operations at present are limited to the extraction of residual gold from historical TSFs on the surface, with the additional purpose to supply backfill material for the worked-out areas of the underground workings. Combined, Gold Fields stores more than 50 million tons of tailings within these 2 TSF Complexes. The TSFs consist of tailings material containing varying amounts of gold, uranium, base metals and sulphur. Through the reprocessing (re-mining / reclamation) activities, gold, uranium, base metals and sulphur can be extracted. Table 2.1 summarises the estimate reserves for the reprocessing of the historical TSFs (as in 2016).

Table 2.1 Summary of the estimated reserves for the reprocessing of the historical TSFs (as in 2016) (Golder Associates, 2016).

Tailings Storage Facility	Tonnes (mt)	Gold Grade (g.t ⁻¹)	U ₃ O ₈ Grade (g.t ⁻¹)
TSF 1	21.3	0.22	85
TSF 2	26.2	0.26	85

The tailings are reclaimed using several hydraulic (high-pressure water) monitoring cannons to deliver water at pressure, typically 27 to 30 bar. The tailings material is reclaimed by blasting the TSF face with the high-pressure water, resulting in the slurry gravitating towards pumping stations. These monitoring guns can be positioned to selectively reclaim required areas from the TSFs. Bench heights are constrained by the force delivered from the monitoring gun nozzle and safety constraints. With sufficient pressure, face lengths of up to 25 m can be reclaimed. The reclamation strategy is aimed at processing the higher-grade TSFs first. The pump stations are located at the lowest point of the TSFs to ensure that the slurry from the TSF will gravitate towards the pump station from where the slurry is pumped to the gold processing plant (see Figure 2.4).



Figure 2.4 Photos showing the reclamation activities at the South Deep TSF 1 (Golder Associates, 2016).

2.3.6 Primary Products

The primary products produced at the South Deep Gold Mine is gold bullion and gold-bearing slag, both from the underground operations as well as the reprocessing of the historical TSFs as part of the surface operations. The product is sold directly to Rand Refinery.

2.3.7 Mining and Mineral Extraction Process

The metallurgical gold processing plant, with a design capacity of 330 ktpm, processes the ore brought from underground to recover gold and associated metal concentrates. Figure 2.5

presents a simplified depiction of a mining and mineral extraction process utilised at the South Deep Gold Mine. For the pre-processing of tailings, the processing plant also includes a tailings re-treatment gold recovery section, that consists of a thickener followed by a dedicated Carbon in Leach (CIL) circuit.

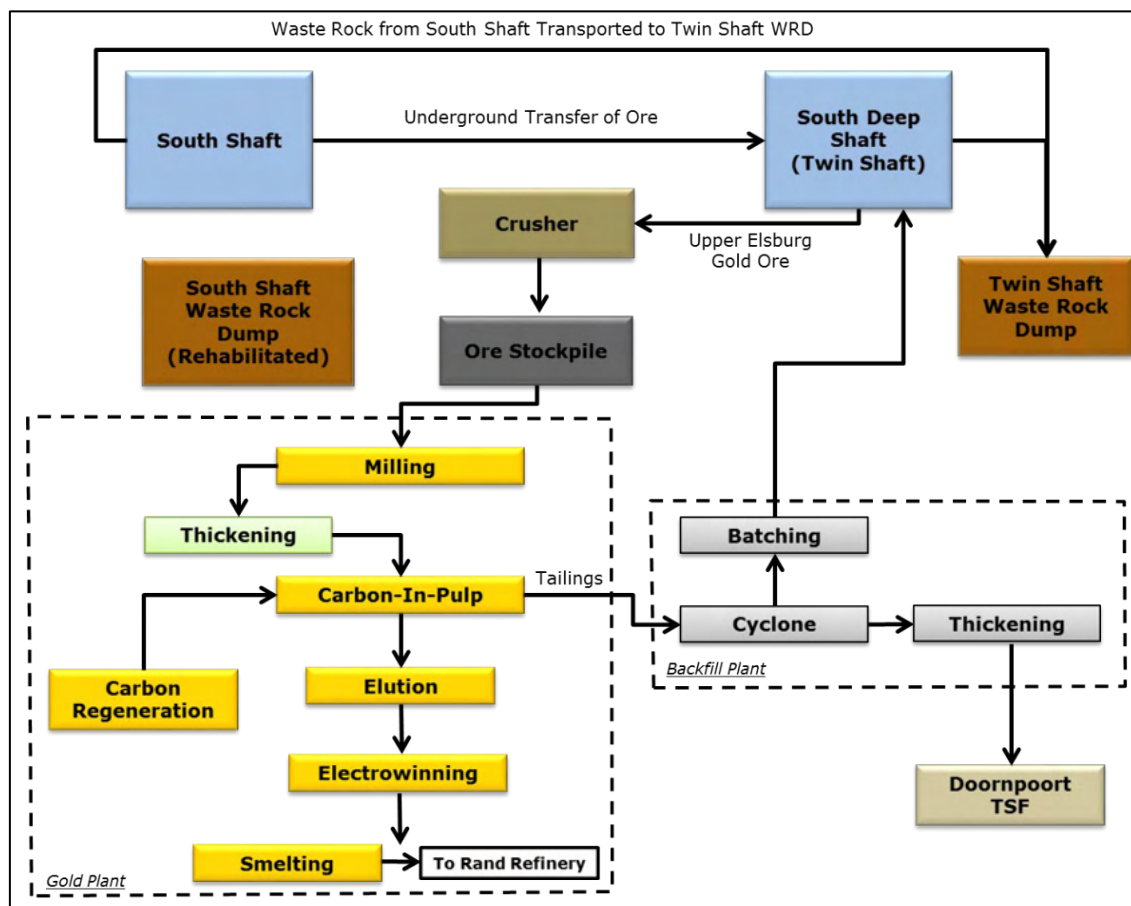


Figure 2.5 Simplified mining and metallurgical process utilised at the South Deep Gold Mine.

The underground mining activities involve the drilling of holes into the ore body, filling these holes with explosives and then blasting the rock face or 'stopes' to break the ore body into pieces that can be transported to the surface. Ore from the South Shaft is transferred to the Twin Shaft from where all ore is brought to the surface. The ore is crushed before being transferred directly to the metallurgical processing plant *via* conveyor belts. Rock that does not contain gold-bearing minerals that are brought to the surface during shaft sinking or underground developments, was disposed of in dedicated areas called waste rock dumps (WRDs). The waste rock at the South Shaft has been recovered and the WRD area has been rehabilitated, while the Twin Shaft WRD is currently dormant. The crushed ore is stored in an ore stockpile at the processing plant, from where it is fed to a milling plant for further size reduction. Water is utilised in the milling process thus minimising dust release.

The slurry discharged from the mill is thickened through settling aided by adding flocculant chemicals. Underflow from the thickeners is leached using a standard cyanide leach process, which recovers about 90 % of the gold present in the ore. The leach solution is separated from

the leached solids and transferred to the Carbon in Pulp (CIP) adsorption circuit where the dissolved gold is adsorbed onto activated carbon particles. During the gold production process, the ore is sent through leach tanks for leaching (removal of gold from ore), the resulting gold then goes through an elution process.

Solids from the leaching process are washed to remove gold and cyanide and then screened to recover loaded carbon before being transferred to a backfill plant where the slurry is dewatered and density classified by a cyclone. The cyclone underflow is transferred to a batching plant where stabilising agents are added before being pumped back to the underground workings for backfilling. The overflow is disposed of to the Doornpoort TSF. Loaded carbon from the processing plant is processed at an elution facility. Gold is stripped from the loaded carbon with a caustic liquid and the stripped carbon is regenerated in rotary kilns for reuse in the CIP circuit. The gold is recovered from the caustic eluent with electrochemical cells, followed by calcination and smelting.

2.3.8 Estimated Life of Mine

The South Deep Gold Mine has been built to extract one of the largest undeveloped gold ore bodies in the world, encompassing a ~32.8Moz mineral reserve. The planned production rate of rock hoisted is a steady build-up to 330,000 tons per month to the mill and the production of 700,000 ounces per year by 2016. The planned production life of the mine, based on the reserve and production rates, is estimated at 75 years (2093).

2.4 Surface Infrastructure

2.4.1 General

The South Deep Gold Mine consists of surface infrastructure and underground workings, each of which has its area of authorisation in terms of the GFI Mining Lease Area. The overview of the surface infrastructure relevant to the radiological public safety assessment as presented in this section is consistent with the current scope of CoR-18.

Material (ore) brought to the surface from the underground workings contains naturally occurring radionuclides and are classified as NORM (per definition). However, members of the public may only be exposed to these materials once it reaches the surface. The surface infrastructure where radioactive materials may exit the underground workings or may be distributed and deposited in the environment is thus of concern. The underground workings themselves, on the other hand, are not considered to contribute directly towards public radiation exposure and, therefore, is not considered further in this section.

Table 2.2 summarises the surface infrastructure that is of relevance to the 2020 South Deep Gold Mine RPSA, separated into categories according to their function. It includes the downcast shafts and associated mining infrastructure, the metallurgical processing plant, upcast ventilation shafts, TSFs, WRDs, backfill and water treatment plants, as well as process and stormwater dams. Figure 2.6 presents a map indicating the location of the mine shaft and services, as well as the major solid process waste management infrastructure relative to one another.

Table 2.2 Surface infrastructure at the South Deep Gold Mine relevant to the 2020 South Deep Gold Mine RPSA (see Figure 2.6 for the respective locations).

Category	Source Type	Coordinates		Status
		Latitude	Longitude	
Mining infrastructure	Downcast Shafts – South Shaft	-26.404558	27.685526	Operational
	Downcast Shafts – Twin Shaft	-26.417881	27.662728	Operational
	Ventilation shafts – South Shaft	-26.404455	27.684958	Operational
	Ventilation shafts – Twin Shaft	-26.418496	27.663661	Operational
Metallurgical plants	Metallurgical Gold Plant	-26.419116	27.658599	Operational
Solid process waste management	South Shaft Complex WRD	-26.402812	27.680693	Rehabilitated
	Twin Shaft Complex WRD	-26.421337	27.652479	Dormant
	South Deep TSF 1	-26.414660	27.676838	Dormant
	South Deep TSF 2	-26.418889	27.670166	
	Doornpoort TSF	-26.463579	27.644561	Operational
	Backfill Plant	-26.407167	27.687276	Operational
Process water management	South Deep RWD 1	-26.421019	27.679087	Operational
	South Deep RWD 2	-26.425322	27.671686	Operational
	Doornpoort RWD	-26.467629	27.639963	Operational
	Pollution Control Dams	-26.422504	27.418943	Operational
	Return Water Treatment	-26.405824	27.687779	Operational

The remainder of infrastructure including material management areas (e.g., scrap and salvage yards), offices, staff quarters and training facilities are not considered as potential sources of public radiation exposure and, therefore, will not be considered further in this section.

2.4.2 Mining Infrastructure

As already mentioned, the South Deep Gold Mine makes use of the Twin Shaft Complex and the South Shaft Complex to provide access for personnel, equipment and materials to the underground workings at the different horizontal development levels (see Figure 2.7). The shafts are further used to bring mined ore to the surface from where it is transferred to the metallurgical processing plant. However, ore from the South Shaft Complex is transferred to the Twin Shaft Complex, from where all ore is brought to the surface.

Natural ventilation is very rarely used in mines because the pressure differential between the surface and underground workings is usually not enough to create a sufficient and steady flow of air through the mine. With mechanical ventilation, large fans are used to create the pressure differential at specified points in the mine and force air movement in the underground working environment. The greater the pressure difference the fans create, the faster the flow of air is underground.

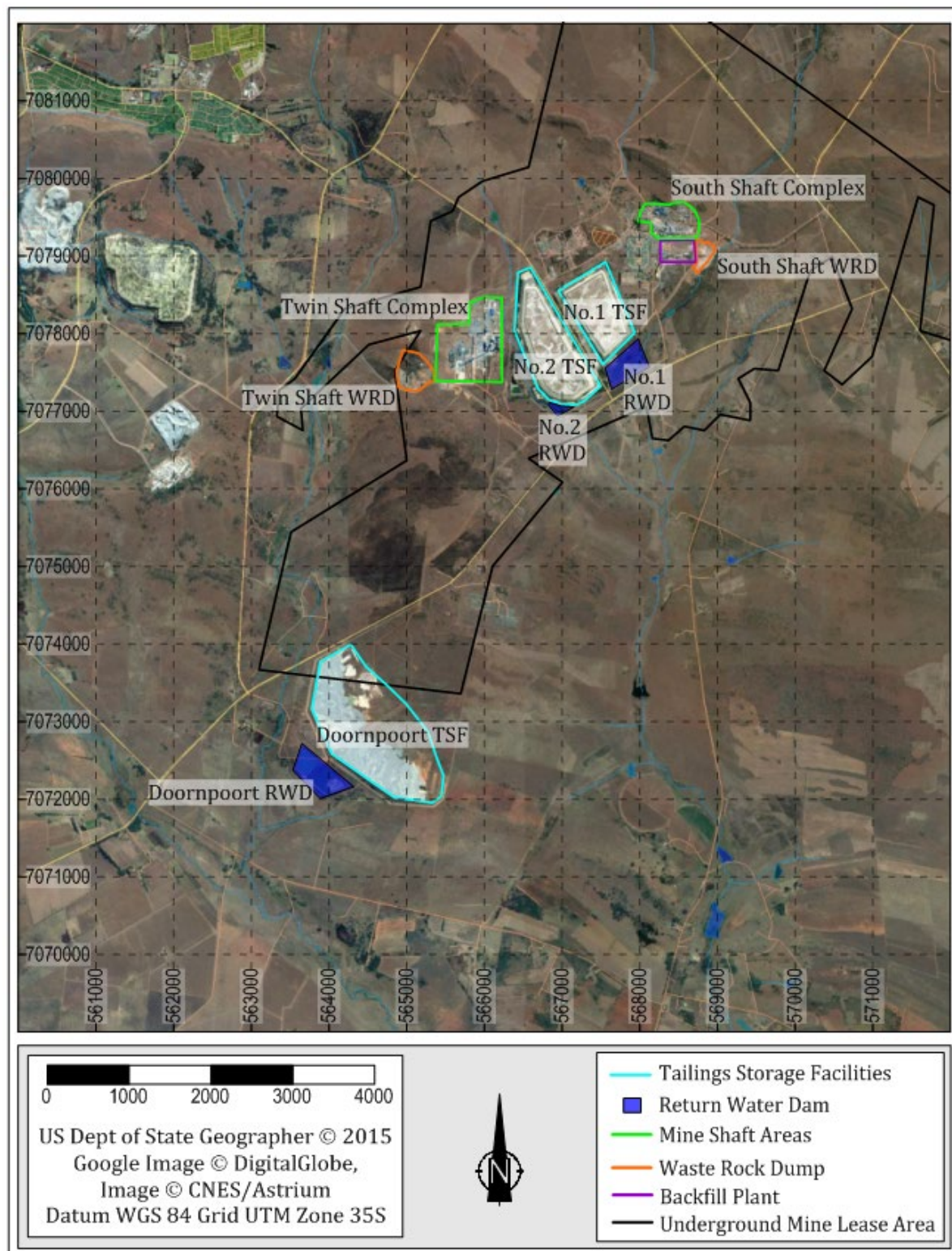


Figure 2.6 Layout of the surface infrastructure that is of importance for the 2020 South Deep Gold Mine RPSA (see Table 2.2).

The purpose of mine ventilation is to provide a volume of air sufficient to disperse and remove harmful gases, dust, smoke, and fumes, and to circulate adequate fresh air through the underground workings. The air vented from the mine (see Figure 2.8) contains radioactive (Radon) gases and particulates present in the underground working environment. The point on

the surface where the air from underground is vented to the atmosphere (generally referred to as an upcast ventilation shaft) thus present a potential source of radiation exposure to members of the public. The ventilation shafts are located close to the shaft bank area (see Figure 2.6).



Figure 2.7 View of the Twin Shaft Complex of the South Deep Gold Mine, with the South Shaft Complex in the distance.



Figure 2.8 Air released from the ventilation shafts at the surface at the Twin Shaft Complex of the South Deep Gold Mine.

2.4.3 Metallurgical Processing Plant

As described in Section 2.3.7, the South Deep Gold Mine gold recovery process consists of several distinct components, each with its function. Each of the components contains different materials with different concentrations of naturally occurring radionuclides. It is thus prudent to understand how each component of the process could contribute to the release of these radionuclides to the environment, if at all. Figure 2.9 is a detailed depiction of the metallurgical plant process. The primary process components and their functions are listed below:

- **Crushing, screening and milling:** Decreases the ore particle size to assist easier extraction of the gold;
- **Thickening and leaching:** Thickening removes most of the water from the ore that was introduced during milling. Leaching with Sodium Cyanide (NaCN) dissolves the gold from the thickened ore;
- **Carbon in pulp (CIP) adsorption:** Activated carbon collects the dissolved gold from the leach solution to separate it from other elements dissolved from the ore;
- **Elution:** Gold is recovered from the activated carbon and the carbon is regenerated for re-use;
- **Electrowinning:** Precipitates the metallic gold from the eluent solution; and
- **Smelting:** Metallic gold from the electrowinning cells is melted and cast into bars for further refining.

The purpose of the metallurgical processes is to produce the gold bars that represent the primary product of the South Deep Gold Mine. The components of the metallurgical processes can generate emissions or wastes that could contain radionuclides from the radioactive materials associated with the gold-bearing ore. Releases through these processes components are expected to occur as follows:

- **Crushing and screening:** The crushing and screening of the ore can release dust particulates as well as gaseous radioactive elements such as radon into the atmosphere. The crushing and screening are performed underwater sprays to prevent loss of gold-bearing minerals in the form of dust. Nevertheless, small releases of particulates to the atmosphere (in the order of $0.24 \text{ g}\cdot\text{s}^{-1}$) is possible at stacks serving the processing plant crusher and screens.
- **Thickening and leaching:** The solid residue that remains after the gold has been leached from the ore is commonly referred to as the 'tailings' and consist of fine (usually white) sand. At the South Deep Gold Mine, the tailings produced annually is managed either through the backfill plant or through disposal at the Doornpoort TSF. Most of the naturally occurring radionuclides associated with the ore remain in the tailings following the leaching of the gold. The areas where tailings are stored or handled, therefore, represent a potential source of public radiation exposure. These areas are discussed further in Section 2.4.4.2.
- **CIP Adsorption:** The leach solution, referred to as low-grade slurry, that remains after adsorption of the gold onto the activated carbon, contains some dissolved radioactive elements leached from the crushed ore. At the South Deep Gold Mine, this liquid is managed through disposal onto the Doornpoort TSF.

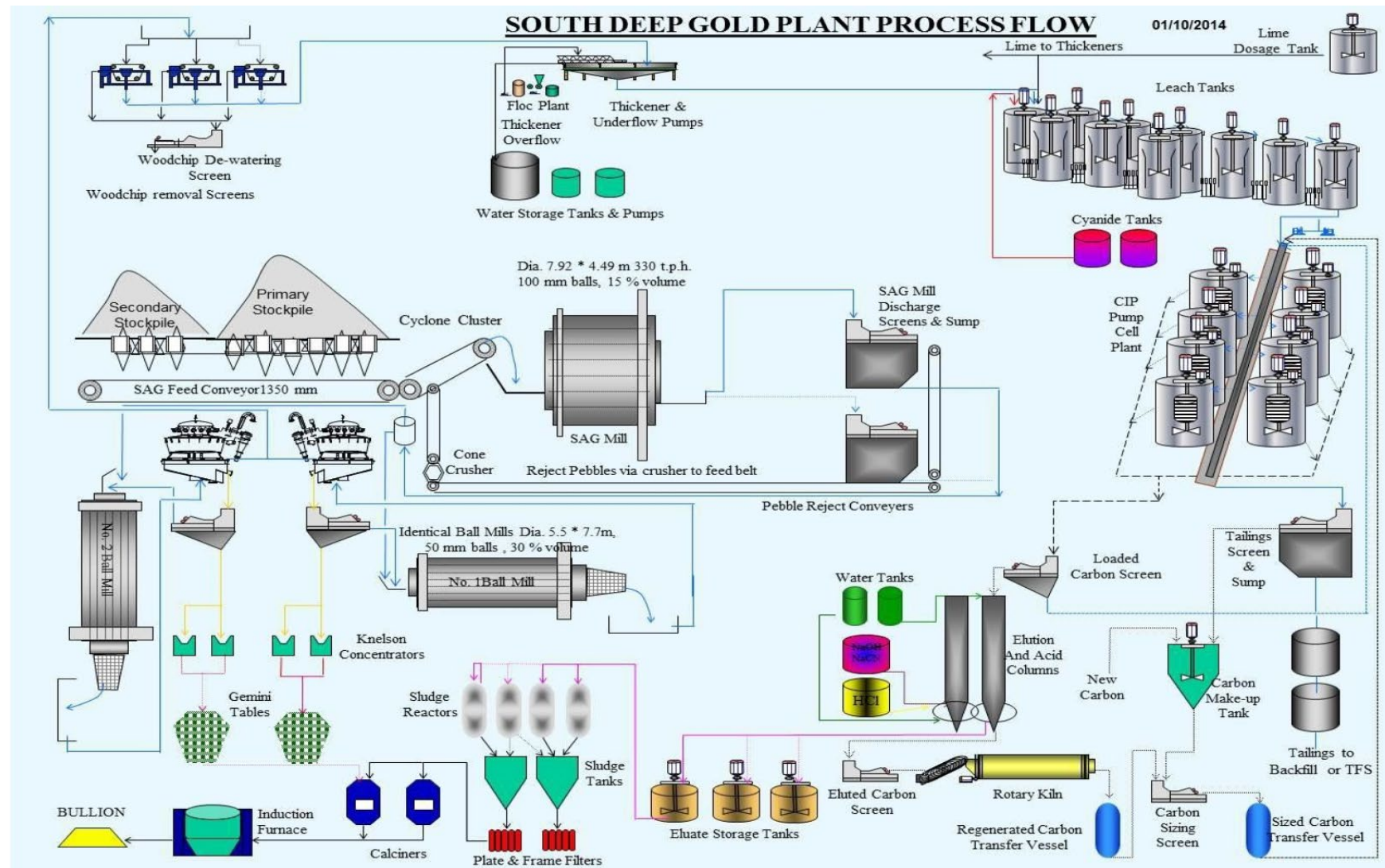


Figure 2.9 Conceptual diagram showing the South Deep Gold Mine gold processing plant process flow (Airshed, 2015).

The carbon particles used in the gold adsorption process are regenerated in a kiln at high temperature for re-use. The kiln drying process results in particulate emissions with values in the order of 8.5 mg.s^{-1} estimated for emissions from the stacks that serve the kilns. However, the particulates emitted from the carbon regeneration kilns are not expected to contain radionuclides as the source material (activated carbon and fuel) are not considered as NORM.

- **Smelting:** Gold smelting is another high-temperature process that releases small quantities of particulates into the atmosphere *via* a stack at the processing plant. However, the unrefined gold and flux or fuels used in the process are not expected to contain significant quantities of radionuclides. Particulate emissions from the smelting stack are thus excluded from further assessment.

2.4.4 Solid Process Waste Management

2.4.4.1 Waste Rock Dumps

As part of underground operations, shafts and tunnels that provide access to the ore body have to be developed. These developments involve the removal of large amounts of non-gold bearing rock from the underground workings and shafts. These rocks are generally deposited onto a heap near the shaft complex, referred to as a waste rock dump (WRD). As some of the rocks removed during development are from the same geological formations as the gold-bearing ore, these also contain naturally occurring radionuclides.

WRDs can contain a wide variety of minerals that are characteristic of the geology of the area and are frequently used for disposal of other inorganic wastes such as building rubble and scrap steel. The WRDs have the potential to leach various inorganic contaminants, including radionuclides, as a result of rainwater percolating through the waste heap. Small particulates disposed with the waste rock or produced through weathering of the waste rock may be transported off-site as airborne dust. This airborne dust may contain naturally occurring radionuclides and thus have the potential to expose members of the public living off-site to radioactive materials. There is no operational WRD associated with the South Deep Gold Mine at present.

The South Shaft Complex WRD (see Figure 2.6 and Figure 2.10), with a footprint area of about 15 ha, dates back to the 1950s with the sinking of the South Shaft. Waste rock from the subsequent mining process was also disposed of at the facility (Golder Associates, 2016). Figure 2.11 shows that the area is mostly rehabilitated and the material moved the Doornpoort TSF. Another area near the South Shaft Complex is an old industrial waste dump area but some waste rock was disposed of there as well, resulting in residual radiation observed in the area. The industrial waste site has been decommissioned and the wastes have been sorted according to waste streams. Removal of these wastes commenced in 2016. Rehabilitation of the site will commence after all the wastes have been removed from the site.

The WRD at the Twin Shaft Complex, with a footprint area of 20 ha, is dormant (see Figure 2.6 and Figure 2.10). Disposal of waste rock commenced in 1994 with the sinking of the Twin Shafts. This area will be rehabilitated as part of the mine closure (Golder Associates, 2016).



Figure 2.10 Google Earth views showing the two South Deep Gold Mine WRDs at the South Shaft and Twin Shaft.



Figure 2.11 Rehabilitation of the South Shaft WRD as of February 2016 (Golder Associates, 2016).

2.4.4.2 Tailings Storage Facilities

The South Deep Gold Mine has two dormant TSFs consisting of two units each, with the Doornpoort TSF the only operational TSF. The ore residue (tailings), from which the gold was extracted, is released from the processing plant as a slurry that is pumped through pipelines to the Doornpoort TSF or backfill plant.

The two dormant TSFs, South Deep TSF 1 and South Deep TSF 2 (see Figure 2.12), are located between the South Shaft Complex and the Twin Shaft Complex. The side walls are vegetated and partially covered with rock cladding and netting. Both TSFs are continuously re-vegetation, with irrigation as required (see Figure 2.13).



Figure 2.12 Google Earth view showing the two South Deep Gold Mine dormant TSFs, associated Return Water Dams, and the nearby-pollution control dam.

The South Deep TSF 1 (70 ha and a maximum height of 47 m) drainage system comprises toe and elevator underdrains, while that of the South Deep TSF 2 (100 ha and a maximum height of 41 m) consists of toe and blanket underdrains around the base of the TSF. Both TSFs have toe paddocks around the perimeter of the dam. Seepage from the underdrains is released into a trench system, which feeds into cascade ponds. Runoff from the TSF is collected in toe paddocks from where it gravitates to the cascade pond RWDs.

The Doornpoort TSF (see Figure 2.14) was developed as a two-paddock system and has been operational since 2007. The TSF is designed to accommodate a total volume of 200 million tons of tailings (*in situ* dry density 1.35 ton.m⁻³). Tailings are deposited using a spigot at a production rate of 233,000 tons per month. The TSF design includes an underdrainage system comprising of toe drains and inner blanket drains, both draining to a concrete-lined solution trench around the perimeter of the TSF. The solution trench channels the water to a dedicated and lined RWD.



Figure 2.13 Netting, re-vegetation, and irrigation systems implemented at the two South Deep Gold Mine dormant TSFs.

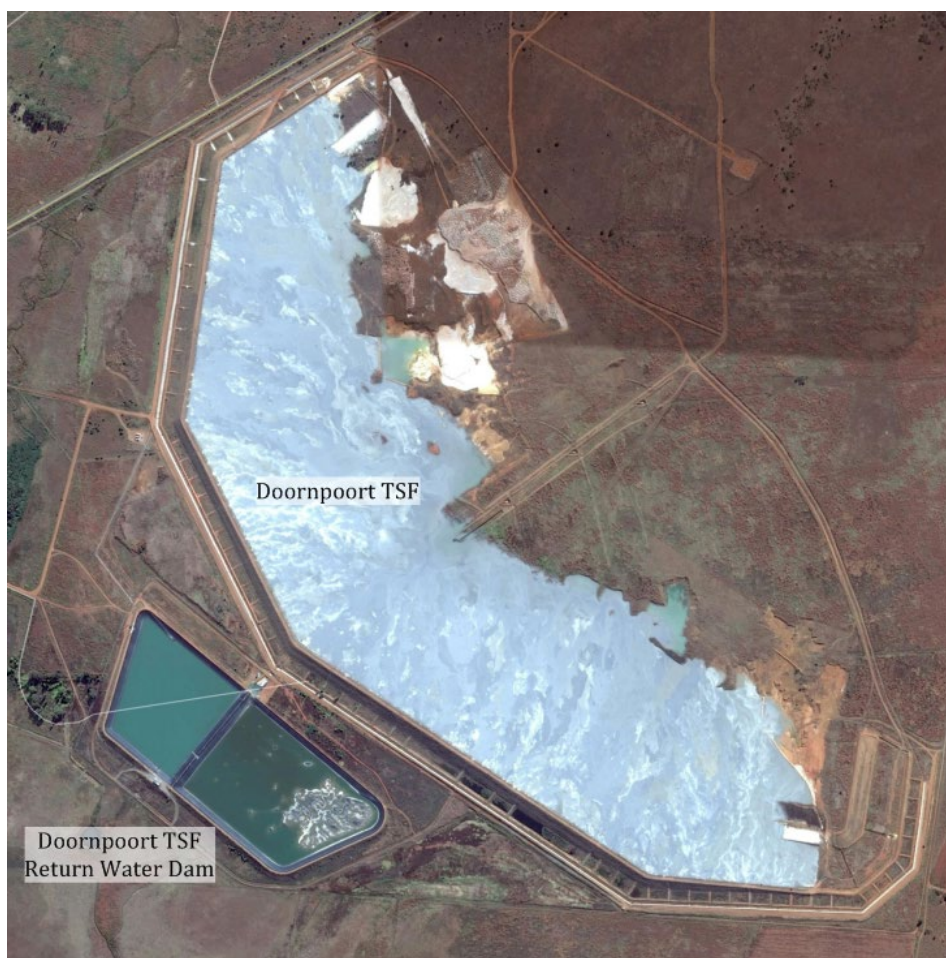


Figure 2.14 Google Earth view showing the operational Doornpoort TSF and associated Return Water Dams.

There are also scavenger wells and a seepage cut-off curtain-drain downgradient of the Doornpoort TSF to collect any seepage moving underneath the solution trench. Table 2.3 lists some of the physical characteristics of the South Deep Gold Mine TSFs.

Table 2.3 Characteristics of the South Deep Operations TSFs (EcoPartners, 2011).

Parameter	South Deep TSF 1	South Deep TSF 2	Doornpoort TSF
Status	Dormant	Dormant	Active
Footprint Area	70 ha	100 ha	386 ha
Height	47 m (Maximum)	41 m (Maximum)	62.2 m (Maximum)
Lining	None	None	0.5 m residual andesitic material

2.4.4.3 Backfill Plant

As indicated in Figure 2.9, a proportion of the tailings slurry produced at the metallurgical processing plant is sent to a backfill plant, where it is prepared to be disposed of underground. The balance of the tailings mass is sent to the TSFs. The volume of material generated from the underground operations is supplemented with tailings material generated as part of the reclamation operations at the South Deep TSF 1.

The backfill plant uses a series of thickeners and cyclones to produce a paste backfill material, which is sent underground to the mine workings. The backfill plant requires water of potable water quality to endure the seal in the pumping equipment moving the material underground.

The thickening of the influent slurry stream to produce the backfill paste results in the backfill plant producing excess water. The excess water is either used for flushing the backfill piping system or sent to the existing RWD or directly to the metallurgical processing plant.

2.4.5 Other Solid Waste Management Facilities

Smaller volumes of domestic, industrial and hazardous waste streams are formally managed at the South Deep Gold Mine. Although radioactivity is not necessarily associated with these wastes, the management thereof is covered in the South Deep Gold Mine Waste Management Procedure as part of the CoR-18 requirements. The following can be noted:

- The general (domestic) waste generated by the shaft, plant, offices and residences is collected daily from waste bins and collection points and transported for temporary storage (± 1 week) to containers located at the mine's industrial waste site. Here recyclable waste is sorted by a local SMME contractor. The sorted waste is then removed by the Westonaria Local Council to a permitted general landfill site in Westonaria.
- The solid industrial waste from underground, the metallurgical plants, and the workshops are collected at the respective salvage yards. The material arriving at the salvage yards is sorted by a private contractor. Reusable or recyclable items are removed, and either sold or returned to the mining process while unusable waste is removed by hazardous waste contractors and disposed of off-site at approved waste disposal sites.

2.5 Water Usage and Management

2.5.1 General

The South Deep Gold Mine includes both surface and underground infrastructure specifically for the management of contaminated mine and process water and potentially contaminated stormwater runoff. The information presented is summarised from the Integrated Water and Waste Management Plan for South Deep Gold Mine prepared by Golder Associates Africa (2013) in support of a water use licence application. The purpose of this section is to highlight the efforts employed at the South Deep Gold Mine to prevent contamination of surface water and groundwater and conserve natural resources through the re-use of contaminated water.

2.5.2 Water Use

The largest use of water at the South Deep Gold Mine is as material conveying medium in the metallurgical extraction and tailings disposal processes. Other uses for water include:

- Solution water in the gold plant.
- Conveyance medium for backfill.
- Dust suppression during percussion drilling, watering down airways and as a wetting agent after blasting operations.
- Irrigation of the dormant TSF to suppress dust formation (see Figure 2.13).
- In cooling systems, both in the condenser and evaporation circuits.
- Washing of underground mining equipment and surfaces.
- Independent drinking water supply to the underground workforce, which ultimately ends up the main return water drain system.

From all processes, water is lost through evaporation. In the underground workings, water vapour is entrained in the air vented through the main exhaust ventilation shafts and ultimately split to join the main drainage system or rejected to the atmosphere via the main ventilation fans on the surface.

Ultimately, all the process water from the underground workings drain to the underground water treatment facilities. Underground facilities comprise settling ponds and mine water reservoirs located on most levels. Fissure water (groundwater leaking into the underground mine workings) and recycled underground water are pumped to the underground settling ponds. Settled water from the ponds is pumped to the mine water dams on the surface. Silt from the maintenance of the facilities is pumped to the surface and processed through the gold plant. The mine water reservoirs are used to store cooled water from the refrigeration plant used for cooling air underground.

2.5.3 Polluted Water Holding Facilities

2.5.3.1 Metallurgical Processing Plant

At the metallurgical plant, water used in the mill circuit is collected from the thickeners and transferred to a storage tank for re-use in the mill circuit. Tanks storing water used in underground cooling as well as water used in the concentrator are all located within the gold plant. The water is used in the gold recovery process. All water is recycled in the process.

The gold plant settling ponds located within the gold plant area are used to collect dirty water runoff from the gold plant area, after which it is transferred to the Twin Shaft pollution control dams. Silt from the maintenance of the ponds is reprocessed through the gold plant. Water is recycled through the metallurgical processing plant.

2.5.3.2 Pollution Control Dams

The Twin Shaft pollution control dams (see Figure 2.12 and Figure 2.15) collect dirty stormwater runoff from the shaft complex and gold plant terraces. Water from the gold plant settling ponds is abstracted for use in the metallurgical processing plant before the balance report to the Twin Shaft pollution control dams.



Figure 2.15 View of the concrete-lined Twin Shaft Complex pollution control dam.

The Twin Shaft pollution control dams consist of two compartments, both of which are lined. The water collected is used to supply the mine, where it is used for dust suppression or used in the metallurgical processing plant. The water stored in the pollution control dam is only abstracted for use in the gold plant after the water available from the RWD and backfill plant is used. Spills from the pollution control dams report to the environment.

2.5.3.3 TSF Return Water

Decant water from South Deep TSF 1 collected at the penstock flows directly into the RWD located downgradient of the TSF. Penstock water that decants from South Deep TSF 2 gravitates to the cascade ponds located on the western side of South Deep TSF 1. Seepage from the underdrains at the South Deep TSF 1 flows into a solution trench located around the perimeter of the TSF, which feeds into the cascade ponds. Seepage water from the underdrains at South Deep TSF 2 is collected in the RWD located downgradient of the South Deep TSF 2 and pumped to the cascade ponds. The cascade ponds are used for cyanide degradation. From the cascade ponds the water flows (gravitates) to the South Deep TSF 1 RWD. The RWD is also used to collect stormwater from the South Shaft Complex *via* a trench. Water from the RWDs is recycled back to the plant water circuit.

The return water system of the Doornpoort TSF comprises a solution trench, collecting dirty water from the catchment paddocks, and a dosing pond, receiving seepage water from the underdrainage system and scavenger wells. Water from the solution trench contains suspended particulates and is consequently treated at a silt trap, which acts as a settling facility for the suspended particulates. Water collected in the dosing pond may be acidic and is treated with a neutralising agent (e.g., lime).

Water from both the silt trap and dosing pond is conveyed to the Doornpoort RWDs *via* a concrete-lined solution trench. The two RWDs are equipped with a liner comprising an *in situ* compacted clay layer covered with a 100 mm layer of filter sand, which act as a leakage detection system for the 1,500 µm HDPE liner. Water collected in the Doornpoort RWD is pumped back to the return water sump *via* the pump station at the RWD should water be required.

2.5.4 Wastewater and Polluted Water Treatment

Figure 2.16 gives an overview of the processes implemented in the ION2 Water Beneficiation Plants to produce SANS 241 compliant drinking water from the Doornpoort RWD source.

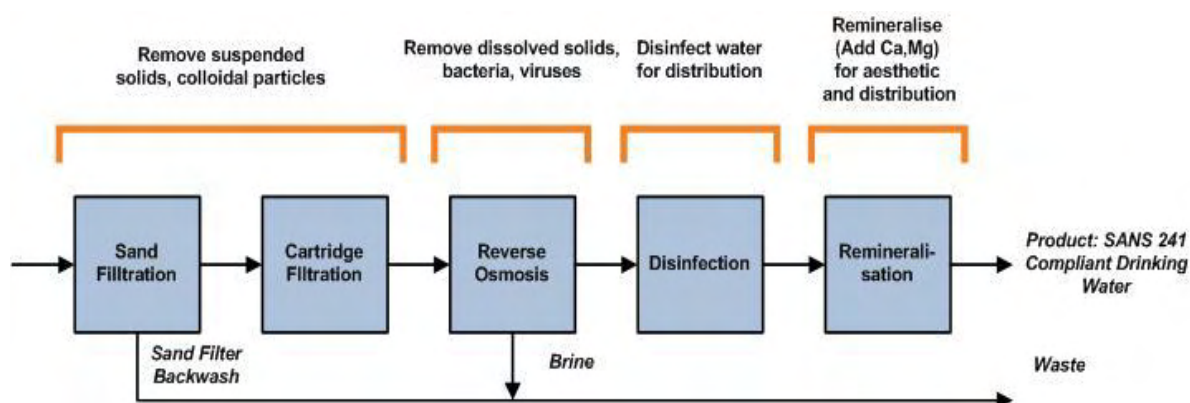


Figure 2.16 Overview of the processes implemented in the ION2 Water Beneficiation Plants to produce SANS 241 compliant drinking water from the Doornpoort RWD source.

Water treatment at the mine involves cyanide management, refrigeration plants (including chlorine plants - for cooling air and water used underground), and sewage treatment facilities. Apart from treated sewage effluent, which is discharged into the stream, all polluted water is recycled back into the process.

The South Deep Gold Mine has commissioned a reverse osmosis plant to treat process water from the Doornpoort RWD to replace the use of potable water obtained from Rand Water. An added benefit of re-using the return water is that it helps to create capacity in the RWD and prevent spillages during heavy rainfall.



3 Environmental Baseline Description

3.1 General

The purpose of this section is to provide a summary description of the environmental baseline conditions as observed near the South Deep Gold Mine. Within the conceptual assessment framework presented in Figure 1.1, the information presented here will provide input into understanding the distribution of radioactivity released from the South Deep Gold Mine into the wider environment and the subsequent accumulation of the radioactivity in associated environmental media.

Several specialist studies and reports prepared for the South Deep Gold Mine in recent years are available and were used as the basis for the description of the environmental conditions. Presented here is thus only a summary of the available information. Specific reports that were used as reference include:

- An Environmental Management Programme Report prepared for the South Deep Gold Mine by EcoPartners (EcoPartners, 2011) and a consolidated environmental management programme report prepared by Golder Associates Africa (Golder Associates, 2016);
- An Integrated Water and Waste Management Plan for South Deep Gold Mine prepared by Golder Associates Africa in support of a water use licence amendment application (Golder Associates Africa, 2013);
- An air impact report and air quality management plan prepared for the South Deep Gold Mine by Airshed Planning Professionals (Airshed, 2015) and Parc Scientific (Parc Scientific, 2020);
- Two numerical groundwater flow and mass transport models prepared for the South Deep Gold Mine by Metago Environmental Engineers (Metago, 2011) and Rison Groundwater Consulting (Rison Groundwater Consulting, 2014); and
- Human interaction with the environment study prepared for the South Deep Gold Mine by Equispectives Research and Consulting Services (Equispectives, 2016; 2020).

Other reports used in the description of the environmental baseline conditions are referenced as appropriate. The section is structured as follows. Section 3.2 provides an overview of the regional geological environment as well as the local geology in the vicinity of the South Deep Gold Mine. Section 3.3 is devoted to an overview of the topography and surface water drainage (hydrology) conditions, while Section 3.4 presents a description of the hydrogeological (groundwater) conditions. The description of the baseline environmental conditions is concluded in Section 3.5 with a description of the atmospheric (meteorological) conditions.

3.2 Geological Setting

3.2.1 Regional Geology

The South Deep Gold Mine is located in the Far West Rand Goldfield (West Wits Line), on the north-western rim of the geologically unique Witwatersrand Basin (see Figure 3.1).

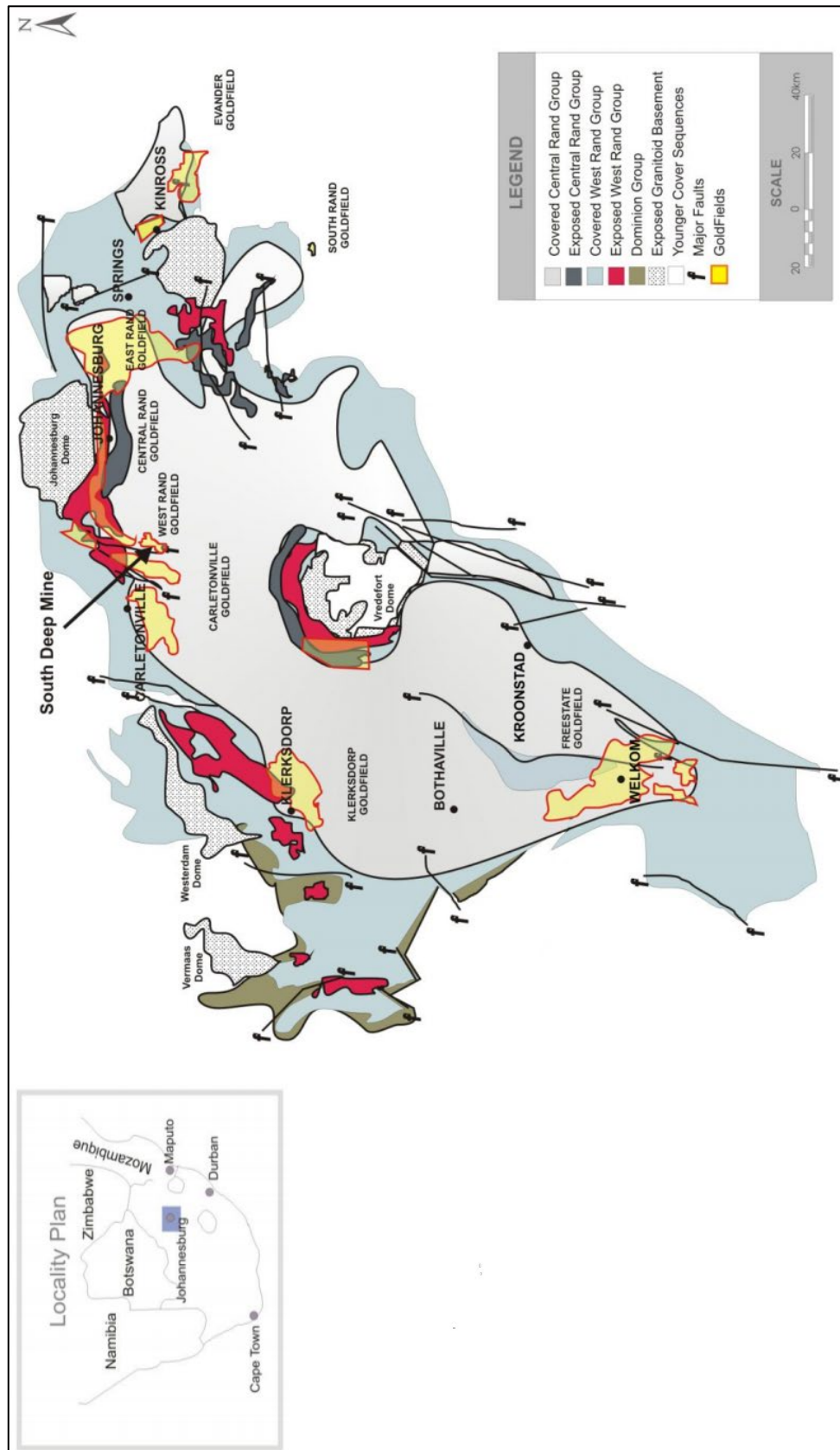


Figure 3.1 Regional geology, showing that the South Deep Gold Mine falls in the Far West Rand Goldfield (West Wits Line), on the north-western rim of the geologically unique owned Witwatersrand Basin (Minxcon, 2010).

The Witwatersrand Basin remains the greatest unmined source of gold in the world, and the deposits have now been worked for well over 100 years. Gold is produced from seven goldfields within the basin, mainly from conglomerate horizons of the Witwatersrand, Ventersdorp and Transvaal Supergroups. The gold mineralisation occurs within quartz pebble conglomerates, termed reefs, which occur within nine separate goldfields located along the eastern, northern and western margins of the basin.

The Witwatersrand Supergroup is underlain by an Archaean (>3.1 Ga) granite-greenstone basement and the 3.086 to 3.074 Ma Dominion Group. It is unconformably overlain by rocks of the Ventersdorp (2.7 Ga), Transvaal (2.6 Ga) and Karoo (302-180 Ma) Supergroups. The Witwatersrand Supergroup can be further divided into two groups, the West Rand Group and the Central Rand Groups.

The South Deep Gold Mine lies within the Central Rand Group of the Witwatersrand Supergroup. Most of the area is underlain by Transvaal Supergroup rocks of the Timeball Hill Formation, except for the topographically positive areas around Randfontein and Krugersdorp, where older rock types of the Ventersdorp and Witwatersrand Supergroup are exposed (EcoPartners, 2011).

3.2.2 Local Geology

Rison Groundwater Consulting (2014) describes the local geology underlying the South Deep Gold Mine as a rock of the Pretoria Group from Transvaal Supergroup. The mined reefs, known as the Upper Elsburg Reefs and the Ventersdorp Contact Reef (VCR) occur at a depth of 2,000 to 3,500 m below the surface. They are overlain by up to 1,200 m of Klipriviersberg lava and a 2,000 m succession of Transvaal Supergroup dolomites, quartzites, shales and lavas. The South Deep TSF complex is underlain by the Timeball Hill Formation (see Figure 3.2), consisting of mudrock, quartzite, shale and siltstone. The gentle sloping stratum dips at 10 to 20° to the south.

The rocks towards the south of the South Deep TSF complex and underlying the Doornpoort TSF consist of the younger Hekpoort andesite, Strubenkop shale, Daspoort quartzite and Silverton shale units of the Pretoria Group (see Figure 3.2). The weathering of the shale results in grey to dark grey silty sand and clay. Most of these rocks, especially in the lower-lying areas, are concealed beneath a cover of younger sedimentary rocks, residual soils and alluvium. There is also a significant accumulation of hillwash and transported sediments. The floodplains of the Leeu Spruit contain grey, silty to clayey soils.

The weathering of the Hekpoort Andesite results in a dark to reddish-brown silty sand. These can contain fragments of lava and quartz ranging from pebble to cobble size. The quicker erosion of the softer tuffaceous sediments, interbedded between the amygdaloidal lava flows is believed to be the cause of the topographical features. Extensive diabase sill intrusions are evident as intrusions in the Silverton shale and Timeball Hill siltstone-shale sequences.

3.2.3 Structural Geology

According to Rison Groundwater Consulting (2014), the most significant geological structures within the area are the two sub-parallel north-south oriented Gemsbokfontein dykes that cross-cut the Transvaal rocks. These are the Gemsbokfontein east and the Gemsbokfontein west dykes (see Figure 3.2).

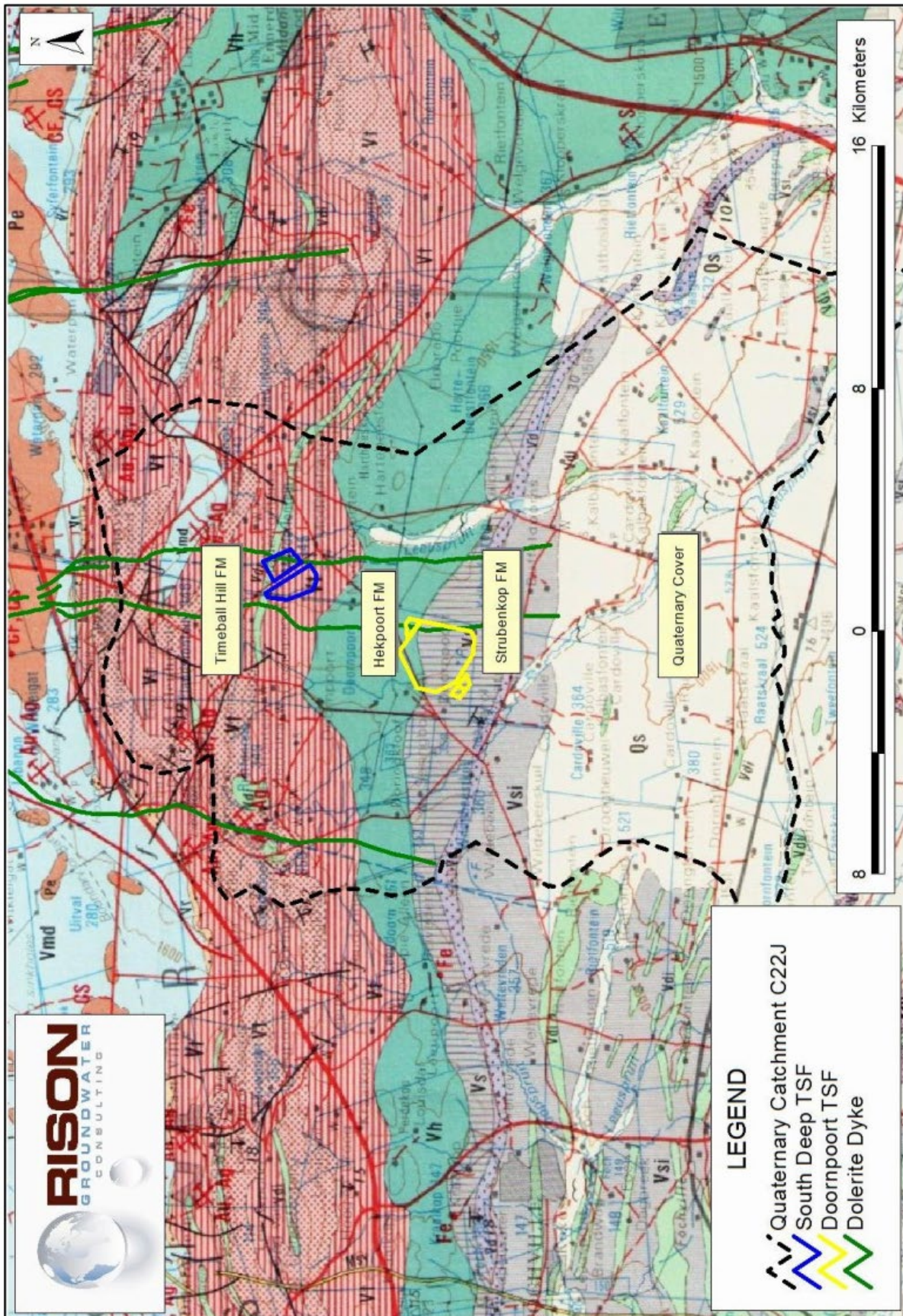


Figure 3.2 Map showing the local geology in the vicinity of the South Deep Gold Mine (Rison Groundwater Consulting, 2014).

The thickness of the dykes appears to be in the order of 10 to 30 m. These dykes cut through the underlying strata, including the dolomite formations, dividing the dolomites into different groundwater compartments further to the north in the Westonaria/Venterspost area. The dolomites, which have a thickness of approximately 1,200 m, are covered by some 500 m of impermeable Transvaal and Karoo sediments and will, therefore, not be affected by any activities on the surface. The geological structure of the region is dominated by north-south trending fault systems, which include the West Rand, Panvlakte and Waterpan Faults.

3.3 Topography and Hydrological Conditions

3.3.1 General

The hydrological conditions are strongly influenced by the topographical features of the areas. The South Deep Gold Mine is situated in a semi-rural area and is surrounded by a relatively natural environment that generally falls from north to south, with an east-west oriented ridge to the north of the mine. Figure 3.3 shows that the South Deep Gold Mine falls within the upper catchments of the Vaal Water Management Area (WMA) and more specifically the Leeu Spruit catchment forming part of the Rietspruit Quaternary Catchment (C22)).

3.3.2 Topography

The most dominant topographical feature in the area is the quartzite ridges Gatsrand, located immediately north of the South Deep Gold Mine, trending roughly east-west. Gatsrand forms the northern boundary of the Rietspruit Quaternary Catchment. From here the topography is gentle sloping in a southerly direction towards the Leeu Spruit confluence. The surface area of the mine is located within the elevation range of 1,550 m to 1,650 m above mean sea level (mamsl). The footprint elevation of the South Deep TSF Complex is at approximately 1,600 mamsl, while the Doornpoort TSF is located at approximately 1,560 mamsl.

3.3.3 Hydrological Conditions

The Leeu Spruit catchment as part of the Riet Spruit Quaternary Catchment encompasses several non-perennial streams, forming gently sloping, shallow valleys that drain in a southerly and south-westerly direction. The surface watercourses that drain the South Deep Gold Mine covers a total surface area of 77.3 km² (see Table 3.1).

Table 3.1 Catchment surface areas of South Deep Gold Mine (Golder Associates Africa, 2013).

Catchment	Surface Area (km ²)
Leeu Spruit	27.7
Kariega Spruit	9.6
Loop Spruit	40.0
Total Catchment Area	77.3

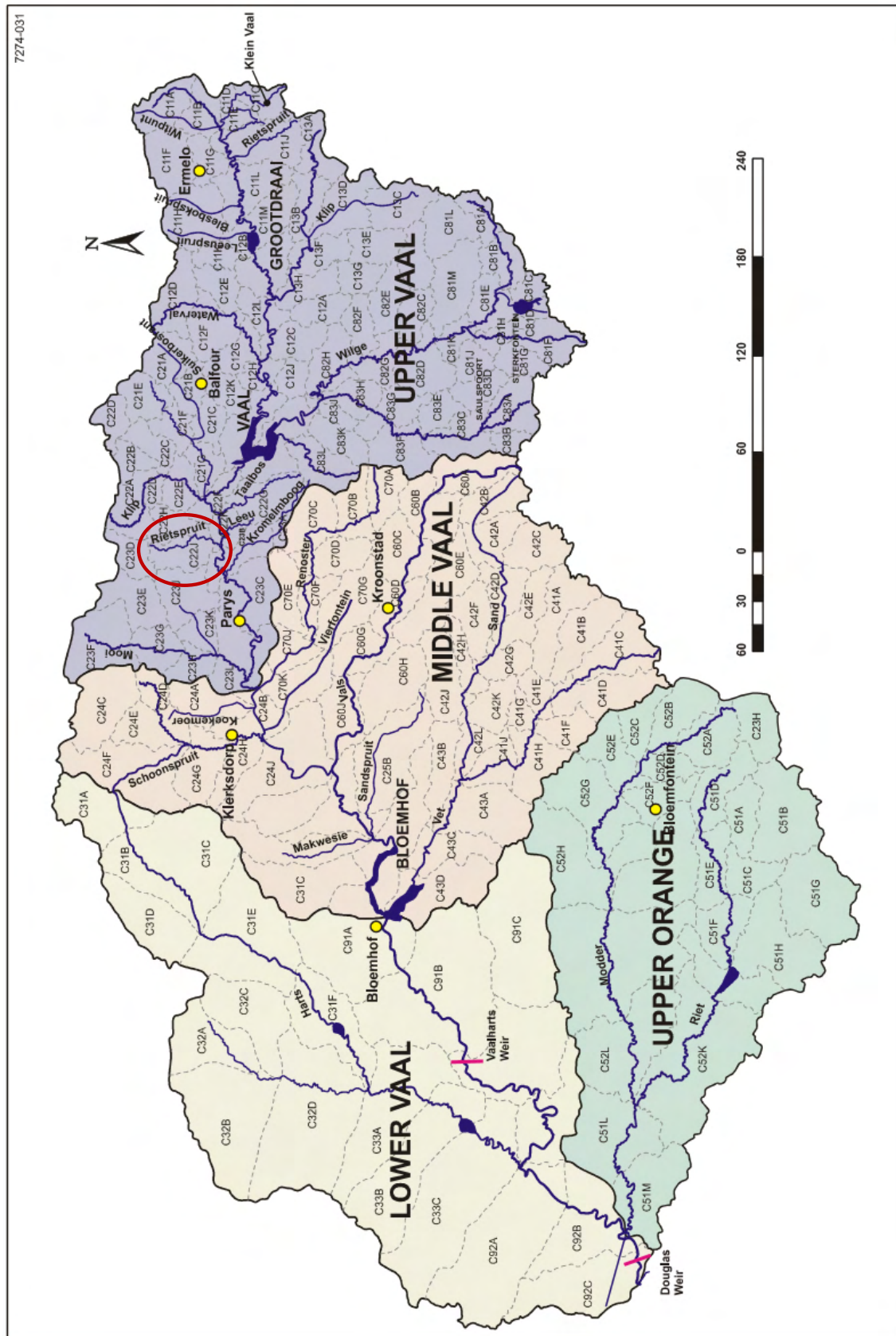


Figure 3.3 Map showing the South Deep Gold Mine is located in the upper catchments of the Vaal Water Management Area (WMA) and more specifically, the Rietspruit Quaternary Catchment (C22J) (Golder Associates Africa, 2013).

A distinction is made between the Leeu Spruit (east) and the Leeu Spruit (west). The confluence of these two streams is about 15 km downstream from the South Deep Gold Mine, and a further 12 km before the Leeu Spruit confluence with the Riet Spruit. The ultimately flows into the Vaal River *via* the Vaal Barrage, which is approximately 32.5 km downstream of the mine. The Leeu Spruit contributes about 4.8% of the flow to the Riet Spruit. Its contribution to the Vaal River is thus considered negligible.

The Leeu Spruit (east) originates northeast of the South Deep Gold Mine in Gatsrand ridges near the Sibanye-Stillwater Ezulwini Operations and flows in a southerly direction to the east of the South Shaft Complex. The Leeu Spruit (west) tributary originates immediately to the south of Glenharvie, passing through the Sibanye-Stillwater Kloof Operations and then flowing in a south and south-easterly direction about 2 km to the west of the Doornpoort TSF. The confluence of these two tributaries (Leeu Spruit east and west) of the Leeu Spruit occurs on the farm Kalbasfontein 529 IQ, after which the stream continues as the Leeu Spruit, in a southerly direction, up to its confluence with the Riet Spruit. The general flow direction in these catchments is southerly to south-easterly.

The Kariega Spruit, a non-perennial tributary of the Leeu Spruit, originates just north of the South Deep Gold Mine, flows in a south-easterly direction between the South Deep TSF 2 and the South Deep Twin Shaft complex to its confluence with the Leeu Spruit, 3 km south of the mine. South of the South Deep TSF Complex, the ground along the Kariega Spruit becomes marshy.

The South Deep Loop Spruit (so named to avoid it being confused with the “true” Loop Spruit that flows westwards from Kloof Gold Mine directly into the Mooi River) rises near Glenharvie (immediately to the north of this small township) and generally drains in a southerly direction less than 1 km to the west of the Doornpoort TSF to its confluence with the Leeu Spruit (west). The South Deep Twin Shafts, in particular its waste rock dump and parts of the haul road, falls within the drainage area of this stream. The confluence of this stream with the Leeu Spruit (west) occurs immediately south (and also downstream) from the Doornpoort TSF.

3.4 Hydrogeological Conditions

3.4.1 General

The purpose of this section is to provide a summary description of the hydrogeological conditions and aquifer characteristics observed in the area and the subsequent migration of contaminants from the main sources associated with the South Deep Gold Mine. A comprehensive and more discussion of the hydrogeological environment can be found in the specialist study reports prepared for the South Deep Gold Mine (Golder Associates Africa, 2013; Metago, 2011; Rison Groundwater Consulting, 2014).

3.4.2 Aquifer Description

The underlying aquifers developed in the region are associated with the Pretoria Group of sedimentary rocks and can be divided into two distinct aquifers consisting of three hydraulic zones, namely a shallow perched aquifer and a deep dolomitic aquifer. Figure 3.4 is a conceptual

cross-section diagram through the South Deep TSF complex from east to west, illustrating the aquifers relative to the mine, hydrological and geological features.

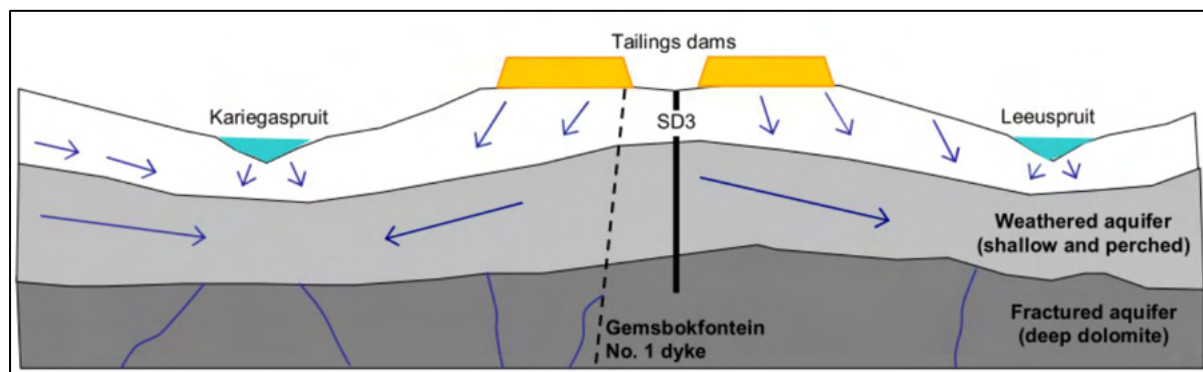


Figure 3.4 Cross-section through the South Deep TSF Complex from east to west illustrating the aquifers associated with the South Deep Gold Mine (EcoPartners, 2011).

According to EcoPartners (2011), the **shallow perched aquifer** consists of a shallow weathered zone in the Timeball Hill shale, varying from 0 to 30 m and a deeper fractured aquifer system to approximately 70 m. The weathered aquifer has low aquifer parameters (transmissivity and storativity) and groundwater movement is slow due to the nature of the weathered material, which consists mainly of silty sand and clay. This aquifer is the most vulnerable to contamination from surface sources. Underlying the weathered formations is a zone of fracturing, which may or may not be in hydraulic connection with the upper weathered aquifer. The water table in this aquifer varies between 0 and 56 m from the surface and is mainly restricted to faults and fractures. Some high-yielding boreholes are associated with this aquifer.

The shallow perched aquifer is separated from the underlying **deep dolomitic aquifer** by a thick succession of impermeable shale, some 400 m in thickness (EcoPartners, 2011). The dolomite aquifer is situated in the Malmani Dolomite with an approximate thickness of 1,200 m in the mine area. Before the deposition of the overlying Pretoria Group sediments, the dolomites were exposed to weathering of the upper 100 to 200 m, to the extent that significant storage capacity exists within this zone. During the shaft sinking operations at the South Deep Twin Shaft, large quantities of groundwater were intersected. Groundwater from this aquifer has an impact on the mining operations in the sense that groundwater inflow into the mine workings results in nuisance water that has to be sealed and/or pumped out. This aquifer is unaffected by contamination sources on the surface but water flowing into the South Deep Gold Mine is subjected to acid mine drainage (EcoPartners, 2011).

The geological and hydrogeological setting of the South Deep TSFs and Doornpoort TSF is not considered to impact on any major aquifers, as these minor aquifers are classified as low yielding (i.e., 0.5 to 2 L.s⁻¹) based on the Department of Water Affairs Geohydrological Map Series (1:500 000 Johannesburg) (Metago, 2011). The Pretoria Group sediments are characterised as an intergranular and fractured aquifer, i.e., the shales and quartzites provide primary porosity and storage capacity (especially in the zone of weathering) as well as a limited potential for groundwater movement, while secondary features like the dominant north-south trending fault

systems can enhance the potential for groundwater flow considerably. Figure 3.5 provides a simplified geological cross-section of the catchment from north to south.

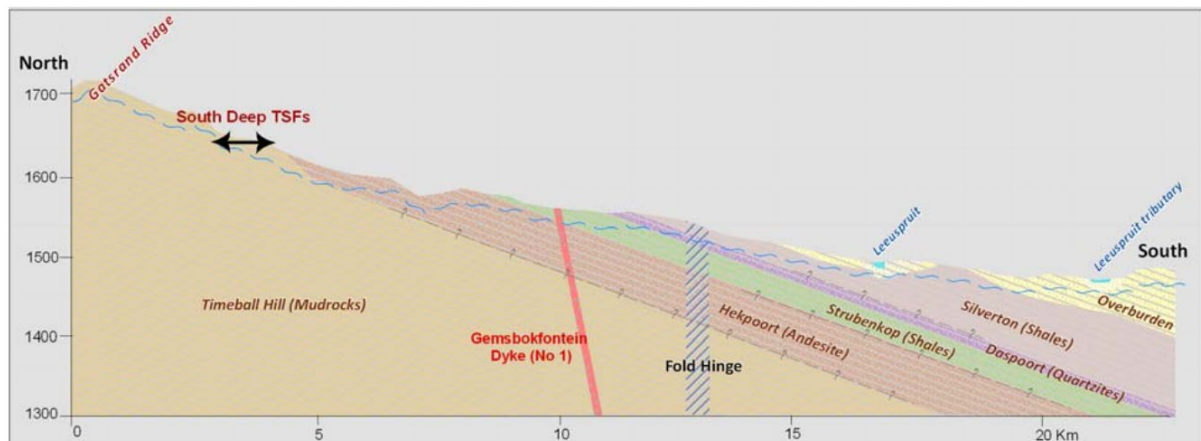


Figure 3.5 Cross-section of the area from north to south, considered in the development of the numerical groundwater flow models for the South Deep Gold Mine (Metago, 2011).

3.4.3 Hydraulic Parameters

A description of the hydraulic parameters available for the underlying strata is described in some detail in Metago (2011) and Rison Groundwater Consulting (2014), for the development of two consistent groundwater flow models in 2011 and 2014, respectively. Additional aquifer tests were performed on 2 boreholes (SD17 and SD18) in 2014 to supplement the conceptual model for groundwater flow in 2014 (Rison Groundwater Consulting, 2014).

The average hydraulic conductivities used for the different aquifers and geological features 0.005 m.day^{-1} for the Gembokfontein dykes, 1 m.day^{-1} for the fold hinge and between 0.03 and 0.13 m.day^{-1} for on the Pretoria Group stratigraphy. The vertical hydraulic conductivities were set at 10 % of the horizontal conductivities, while an effective porosity value of 0.1 was used over the entire model domain. *Note that porosity values affect only the transport model and do not influence the outcome of the steady-state flow model.* A recharge rate of 2% of the Mean Annual Precipitation (MAP) of 683 mm was assumed. Both models assumed a consistent 100 m aquifer thickness.

Figure 3.6 presents the hydraulic conductivity zones used in the development of the South Deep Gold Mine groundwater flow model in 2011, while Table 3.2 summarises the calibrated hydraulic conductivity zone values as determined for the groundwater flow models in 2011 and 2014. Note that the Doornpoort TSF lies partly over the K2 and K3 zones in Figure 3.6 (see Figure 3.2).

3.4.4 Groundwater Elevation and Flow Directions

Based on 34 monitoring boreholes used in the model development, Rison Groundwater Consulting (2014) reported that the average depth to groundwater is 5.29 m below ground level (mbgl), with a range of 0 mbgl to 23.45 mbgl. To increase the spatial distribution of the water levels measurements, Metago (2011) used the National Groundwater Database to increase the total number of groundwater level measurements to 78.

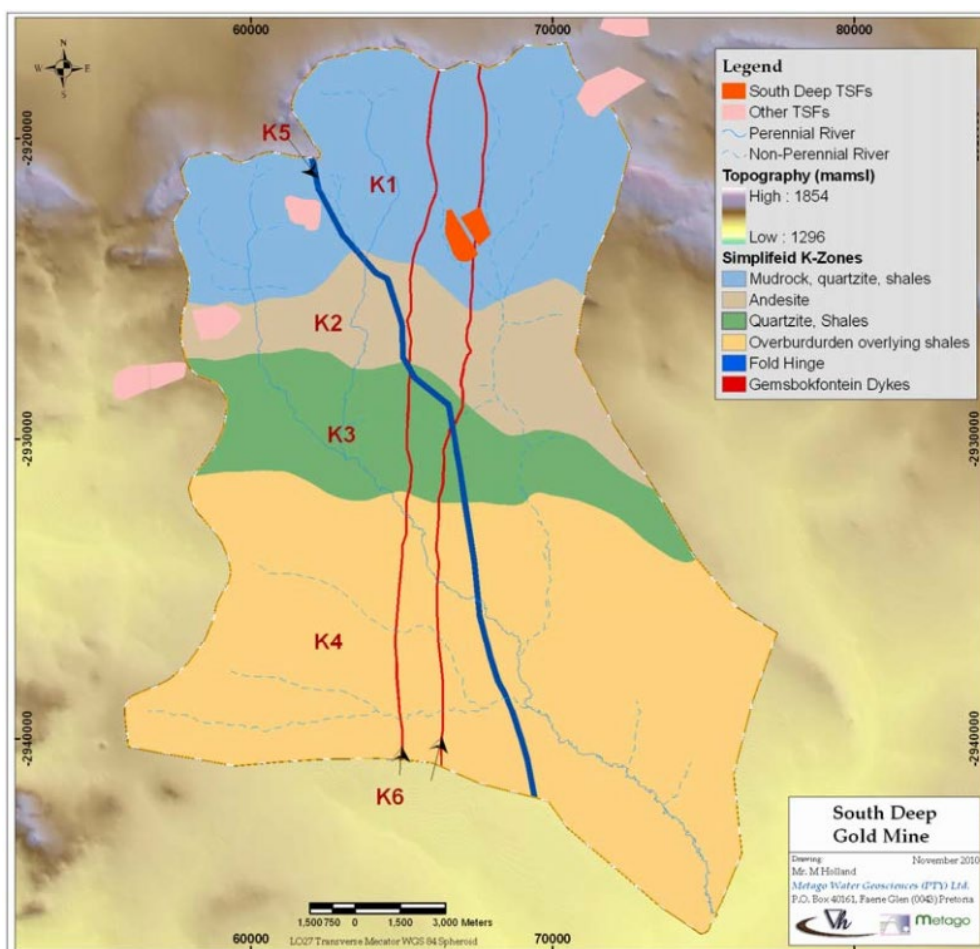


Figure 3.6 The hydraulic conductivity zones used in the development of the South Deep Gold Mine groundwater flow model in 2011 (Metago, 2011).

Table 3.2 Summary of the calibrated hydraulic conductivity zone values (see Figure 3.6) as determined for the groundwater flow models in 2011 and 2014 (Metago, 2011; Rison Groundwater Consulting, 2014).

Hydraulic Conductivity (K) Zone in Figure 3.6	Hydraulic Conductivity (m.day ⁻¹)
Timeball Hill (mudrock, quartzites, shales)	0.05
Hekpoort lava (Andesite)	0.045
Strubenkop, Daspoort & Silverton (shales, quartzites)	0.08
Overburden (overlying Strubenkop & Silverton)	0.1
Gemsbokfontein Dykes	0.0055
Fold hinge zone	1.0

Based on these 78 measurements, the average depth to groundwater was calculated as 10.34 m below ground level, with a range of 0.17 to 30.90 m below ground level. Groundwater flow within the area is mainly controlled by the geology of the region but regionally the groundwater mimics the topography. Figure 3.7 and Figure 3.8 confirms this hypothesis, with good correlations between topographic elevation and groundwater elevation for the 2014 and 2011 models, respectively.

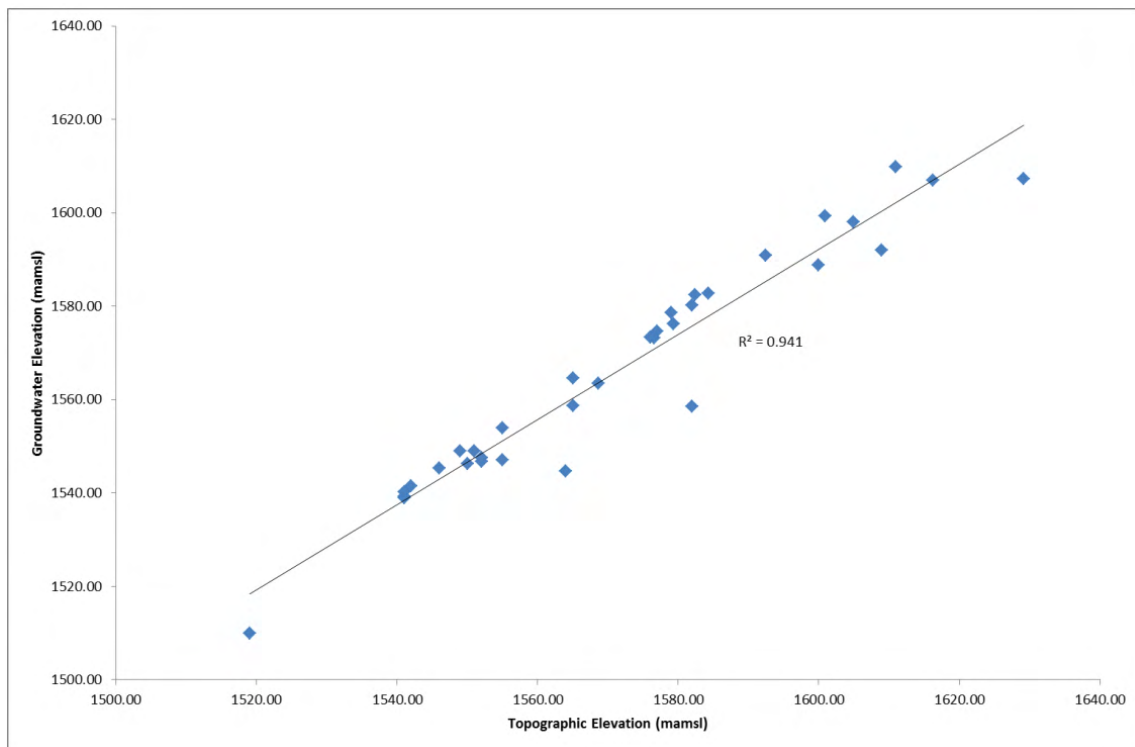


Figure 3.7 Correlation between topographic elevation and groundwater elevation (Rison Groundwater Consulting, 2014).

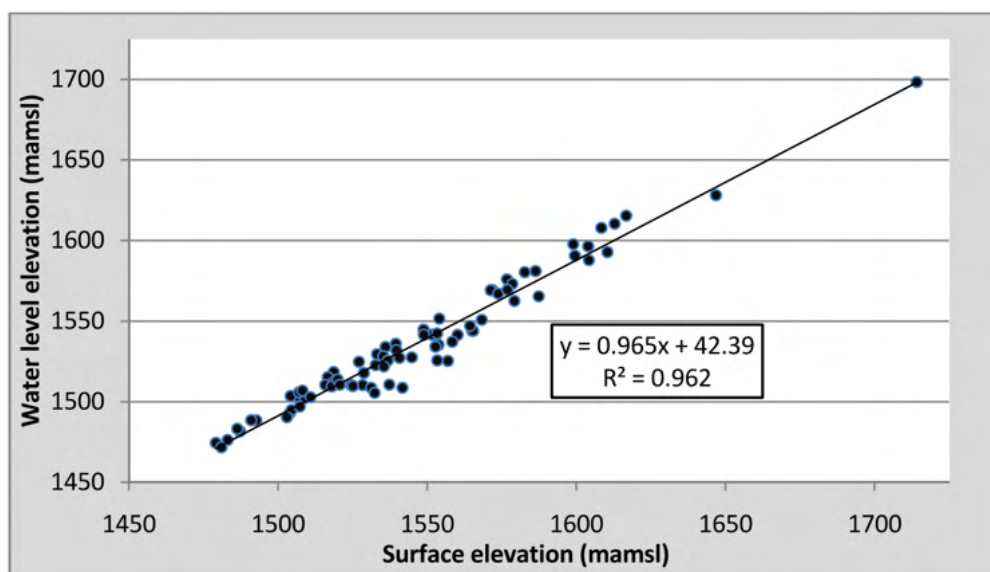


Figure 3.8 Correlation between topographic elevation and groundwater elevation (Metago, 2011).

The variability of groundwater table elevations is thus a function of the topography, and groundwater flows from the higher-lying ground towards lower lying ground and is generally towards the surface streams. The mounding effect of water levels underneath existing TSFs and the influence of the low and high permeable zones (i.e., dykes or fold hinge) are evident in the calibrated groundwater levels presented in Figure 3.9.

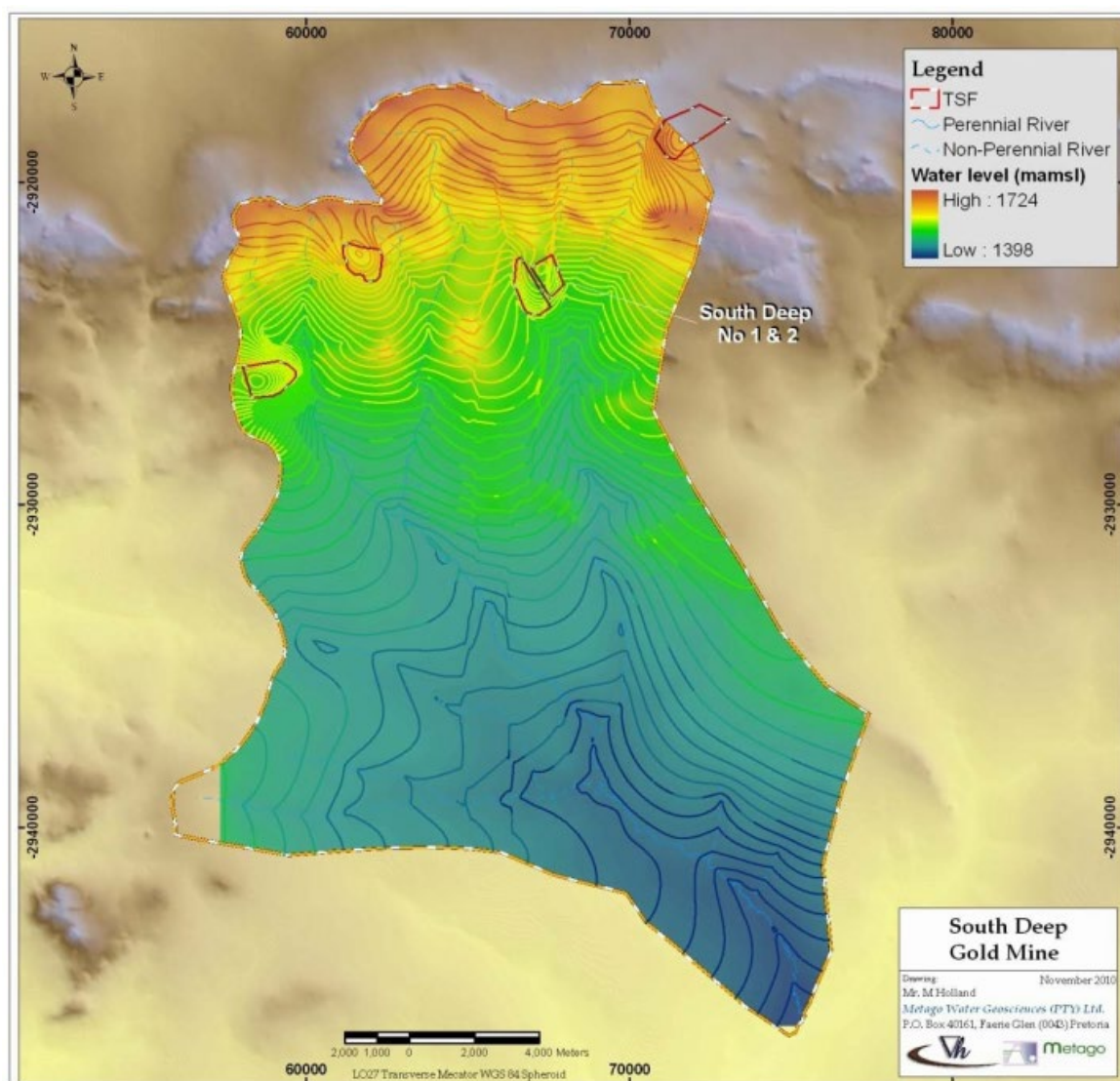


Figure 3.9 Calibrated groundwater levels development of the South Deep Gold Mine groundwater flow model in 2011 (Metago, 2011).

3.4.5 Contaminant Transport

The focus of the contaminant transport simulations in Metago (2011) was the performance of the South Deep TSF Complex, while Rison Groundwater Consulting (2014) evaluated both the South Deep TSF Complex and the Doornpoort TSF. Time-dependent unmitigated and various mitigated conditions and scenarios (e.g., scavenger wells, blast curtain drain, or reclamation of the TSFs) were evaluated.

Figure 3.10 shows the sulphate concentration plume development downstream of the South Deep TSF Complex after the continuous operation without any mitigation measures (“do nothing option”) for a further 30 years after 2011 before closure (i.e., continuous TSF source strength in terms of the concentration and leakage rate). Also, it shows plume development for a further 50 and 100 years, with reduced leakage rates after closure. As such it provides a worst-case scenario for the groundwater impact assessment (Metago, 2011). Plume development in the 2014 study (Rison Groundwater Consulting, 2014) for the current situation is similar.

Figure 3.10 shows that the dominant spreading direction of the contaminant plume in the leachate is in a southward downstream direction. Mounding effects and hydrodynamic dispersion will cause a limited circular spreading of potential pollutants around the TSFs. As a result of the low hydraulic conductivity of the aquifer and mixing with groundwater, the relative concentrations decrease within a short distance (~ 500 m) from the source. The spatial extent of the evolving plume with sulphate concentration below drinking water limits (< 400 mg.L⁻¹) is limited to ~ 400 m from the TSF footprint after 30 years and limited to ~ 670 m from the TSF footprint after 100 years.

Figure 3.11 shows the contaminant plume for the Doornpoort TSF after 50 years of deposition without any mitigation measures. The model simulation suggests that the plume would migrate about 2,800 m south of the Doornpoort TSF. The sulphate concentration on the edge of the plume is predicted to be in the region of 110 mg.L⁻¹. The Gemsbokfontein west dyke is a major controlling factor on groundwater and contaminant flow towards the south.

The seemingly excessive lateral migration of the plume is attributed to the higher transmissivity value assigned to the quartzites and shales (K3 zone) of the model domain. Natural drainage (unnamed) to the south of Doornpoort TSF that was designated a recharge boundary, controls the flow. There is a possibility that the contaminant plume could decant into this drainage and then ultimately report to the Rietspruit (Rison Groundwater Consulting, 2014).

3.5 Meteorological Conditions

3.5.1 General

The purpose of this section is to provide a summary description of the meteorological conditions. A detailed description of the prevailing meteorological conditions and associated air quality impacts is provided by Airshed (2015), supplemented with information provided in Parc Scientific (2020).

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 South Deep Gold Mine thus requires a good understanding of the regional climate and local air dispersion potential of the study area.

The regional climate is classified as Cwb (warm temperature, winter dry, warm summer) under the Köppen-Geiger climate classification. It is a 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.

3.5.2 Precipitation

Rainfall is important to air pollution studies since it represents an effective removal mechanism of atmospheric pollutants and a natural dust suppression mechanism for fugitive dust sources. Figure 3.13 presents the long-term rainfall data from the South African Weather Service's Westonaria Kloof Mine station (A2E022) from 1970 to 2015, while Figure 3.13 presents the average monthly rainfall. The most rain was received during December and January.

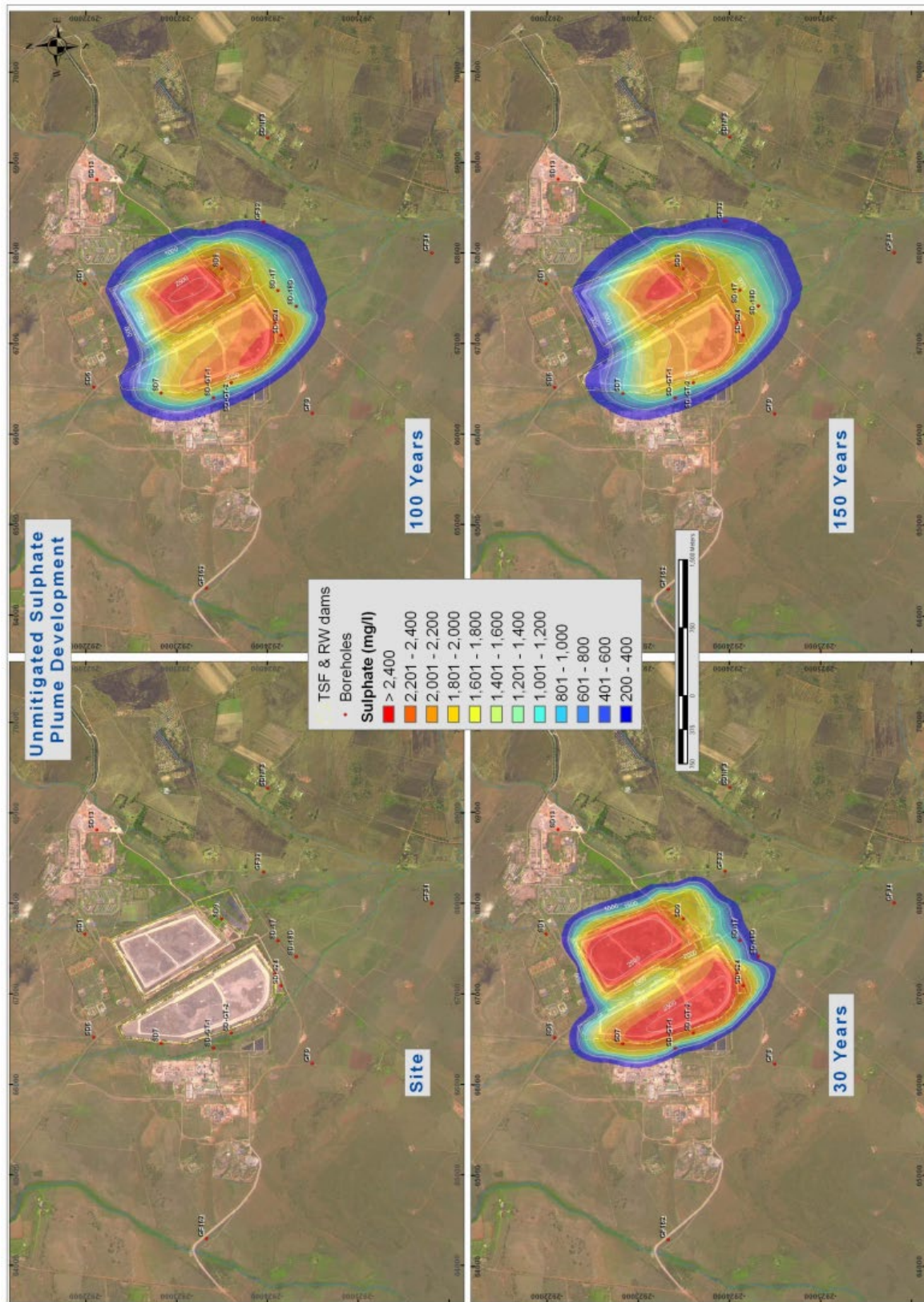


Figure 3.10 The sulphate concentration plume development downstream of the South Deep TSF complex after continue operation without any mitigation measures (“do nothing option”) for a further 30 years after 2011 before closure (Metago, 2011).

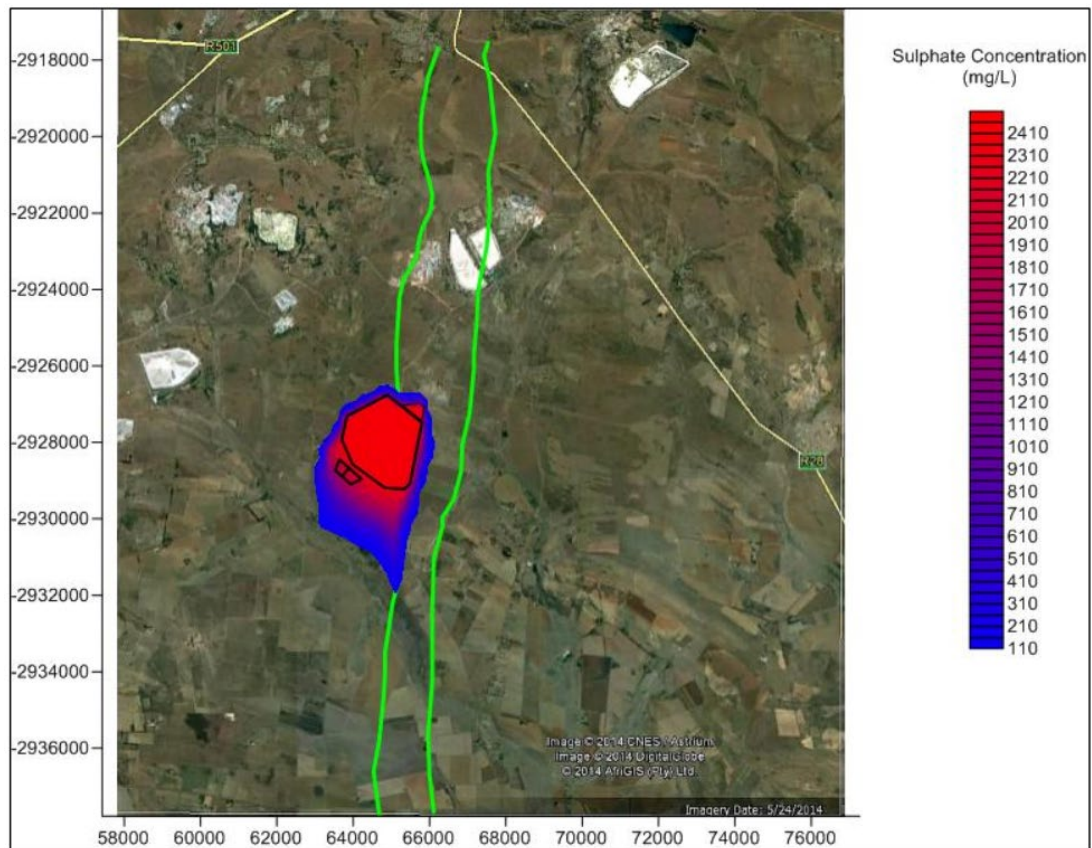


Figure 3.11 Contaminant plume development from the Doornpoort TFS after 50 years of dispositioning without mitigation measures (Rison Groundwater Consulting, 2014).

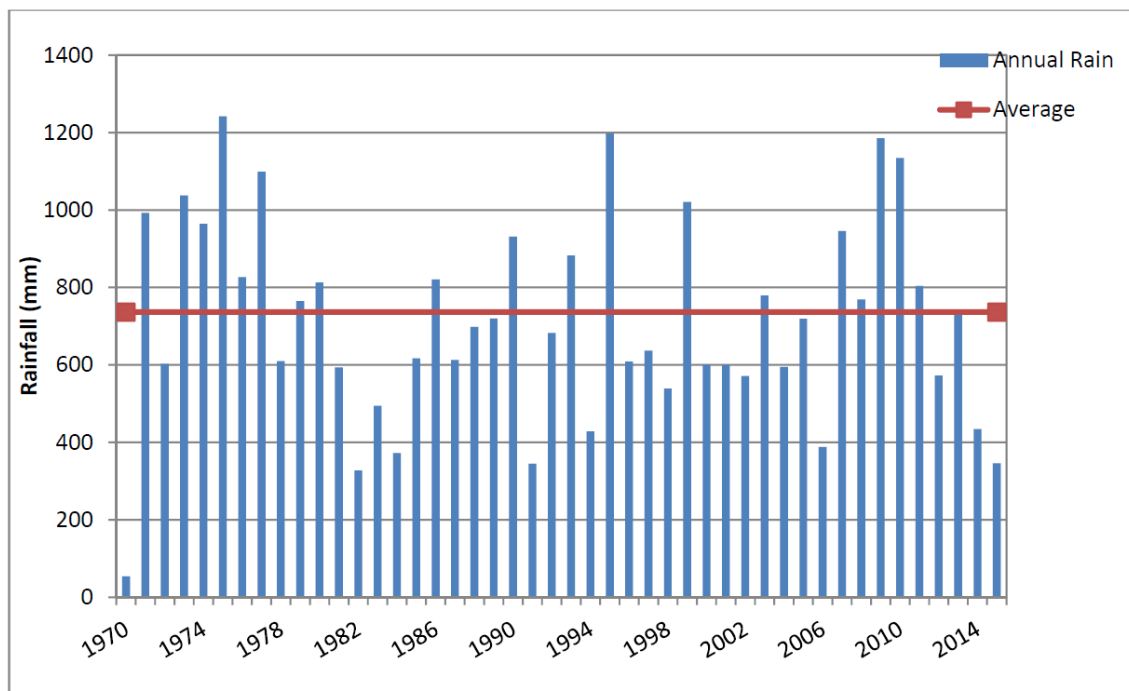


Figure 3.12 Annual and average rainfall data for the period 1970 to 2015 (Golder Associates, 2016).

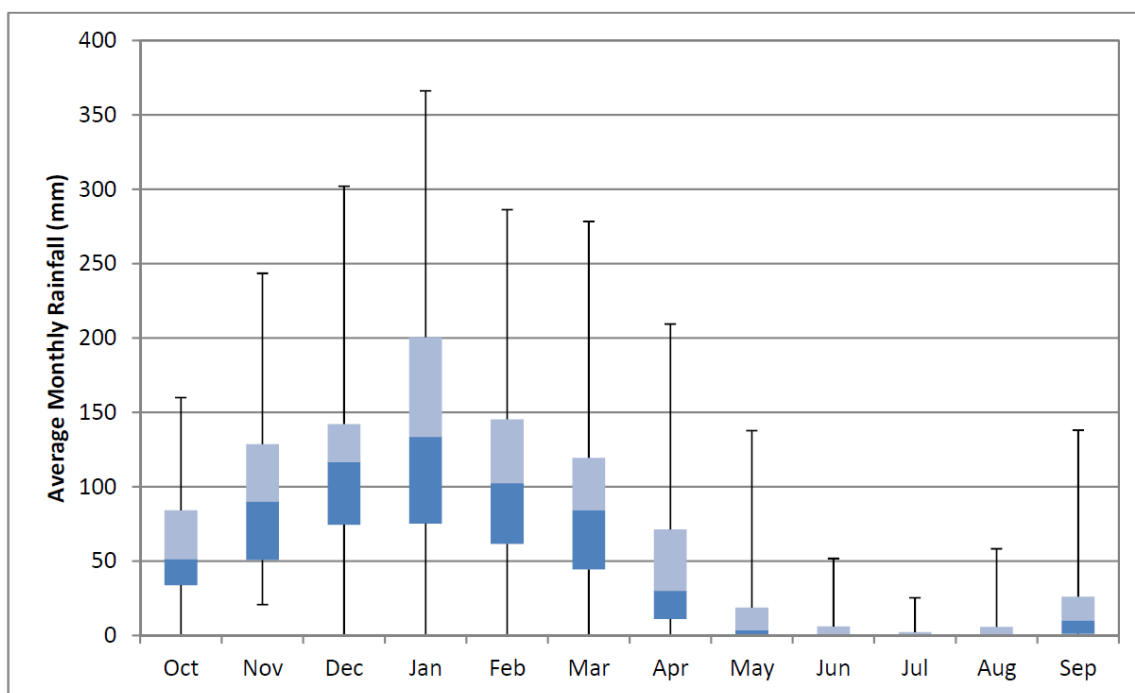


Figure 3.13 Average monthly rainfall data for the period 1970 to 2015 (Golder Associates, 2016).

3.5.3 Temperature and Evaporation

Ambient air temperature is important to determine the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume can rise), and to determine the development of the mixing depth and inversion layers. Daytime temperatures peak during the summer months while decreasing during the winter months.

The diurnal temperature profile for South Deep Mine (MM5 data, 2012 to 2014) is shown in Figure 3.14. Period average, maximum and minimum temperatures were 16°C, 31°C and -3°C, respectively. The months with the highest average temperature was January and February (22°C) while the coldest months were June and July (9°C). Maximum daytime temperatures reached 31°C in January, while the coldest temperature recorded was -3 °C in July.

3.5.4 Local Wind Field

The horizontal dispersion of pollution is largely a function of the wind field. The wind speed determines both the distance of downwind transport and the rate of dilution of pollutants. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness.

Wind roses are used to represent the local wind field. It comprises 16 spokes, which represent the directions from which winds blew during a specific period. The colours used in the wind roses below reflect the different categories of wind speeds; the yellow area, for example, representing wind speeds between 5 and 7.5 m.s⁻¹. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories.

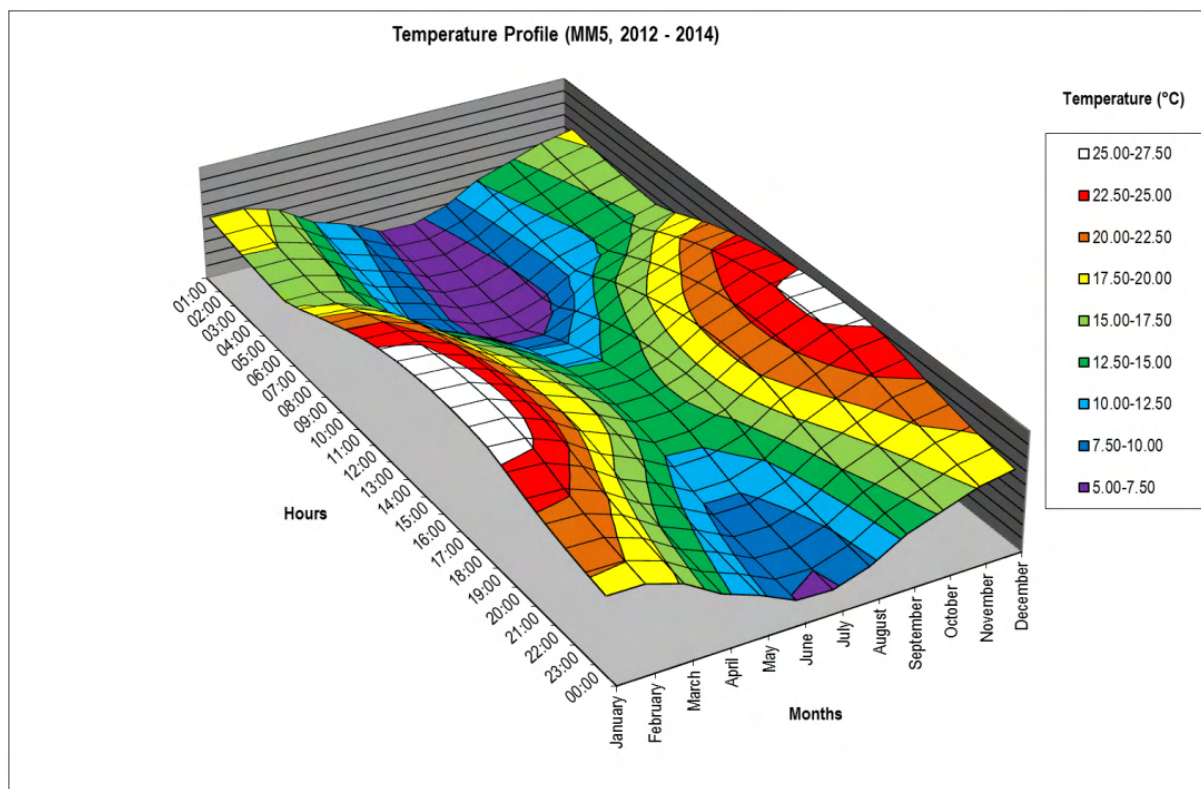


Figure 3.14 MM5 diurnal temperature profile data for the period 2012 to 14 (Airshed, 2015).

The frequency with which calms occurred, i.e., periods during which the wind speed was below 1 m.s^{-1} are also indicated. Figure 3.15 presents the wind rose data for the period 2016 to 2018 used by Parc Scientific (Parc Scientific, 2020) for the air quality impact assessment. The annual wind rose indicates the dominance of the NNW wind direction with a strong frequency of occurrence from the NE. The NNW direction is most prominent in the summer months, while the NE direction occurs most strongly in winter. The distribution for daytime and night-time shows similar patterns with NW wind directions becoming more prominent during the night hours (Parc Scientific, 2020).

Wind speed of 5.7 to 8.8 m.s^{-1} and higher occurs with a frequency of $> 4\%$ in summer and daytime periods spread almost homogeneously between NW and NE directions. In winter, these speeds happen with a frequency of approximately 7% only from the N and NNE. High-speed winds occur with a frequency of less than 4% in winter and are limited to the NE direction. The annual average wind speed is 2.3 m.s^{-1} and the fraction of calm (speed $< 1 \text{ m.s}^{-1}$) periods amount to 26.1% (Parc Scientific, 2020).

3.5.5 Ambient Air Quality: Dust Fall-out

Fall-out dust has been collected at the South Deep Gold Mine for the period 2013 to 2015 as part of the establishment of an air quality management plan (AQMP). The dust-fall monitoring network consists of 6 multidirectional dust collection buckets placed at various locations around the operation. The location of the buckets is indicated in Figure 3.16.

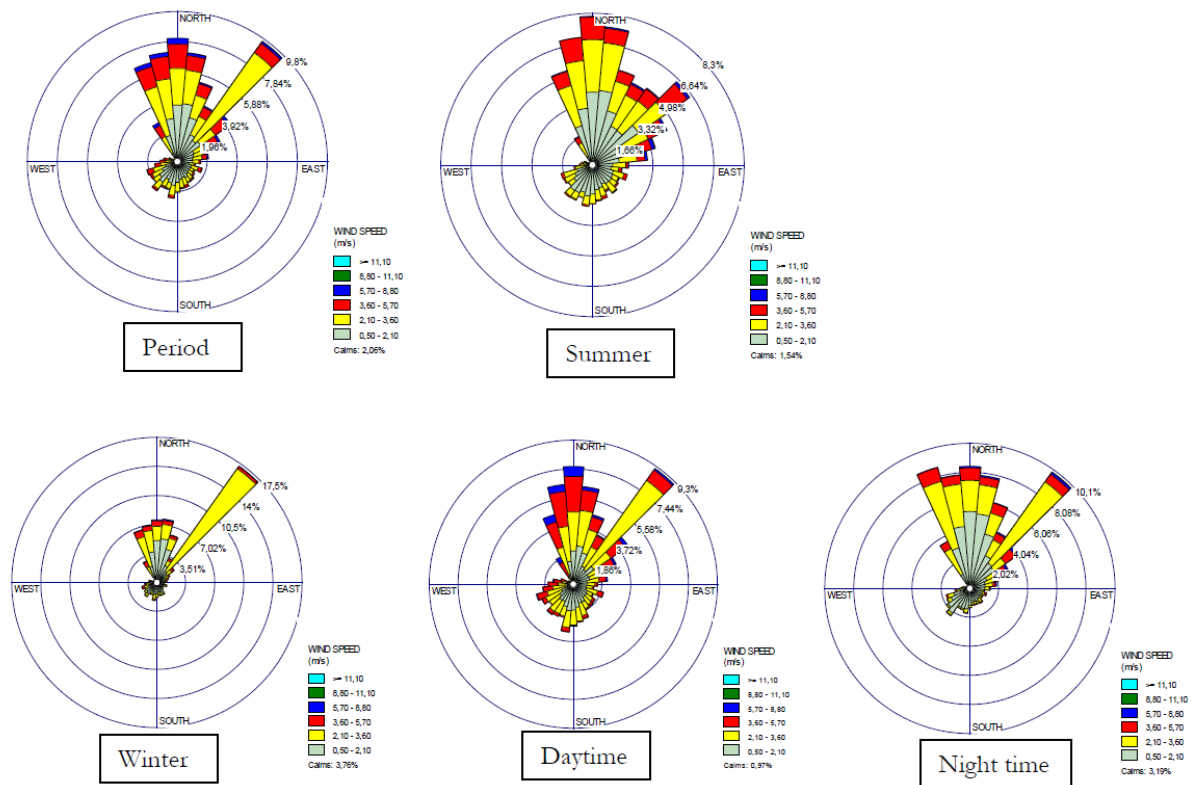


Figure 3.15 Wind rose data for the period 2016 to 2018 used by Parc Scientific (Parc Scientific, 2020).

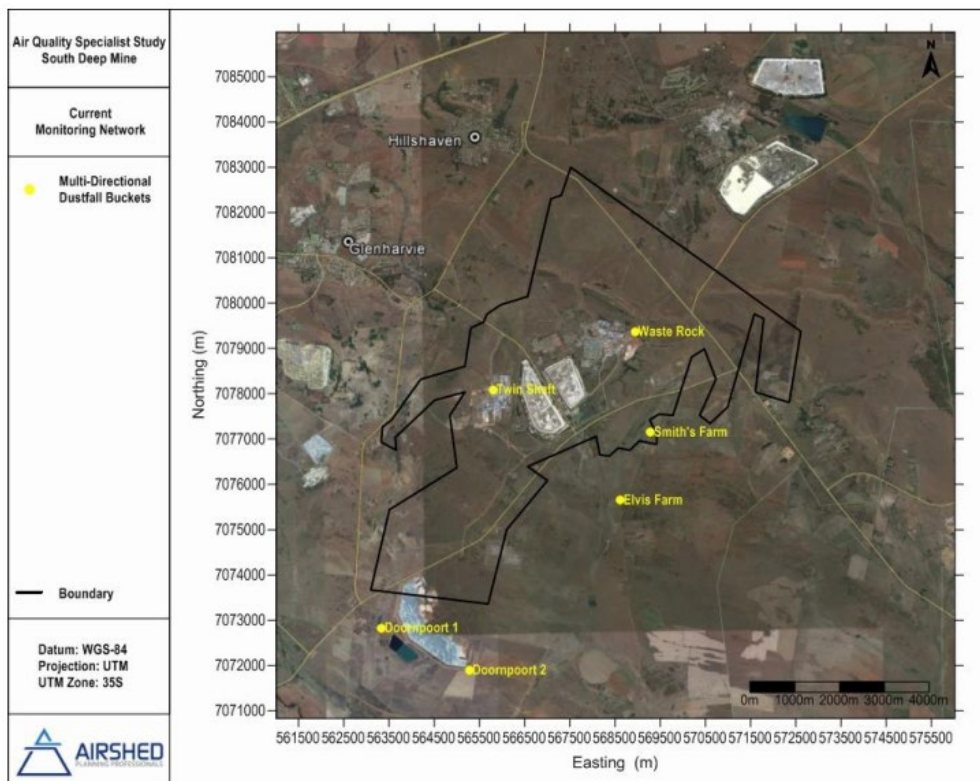


Figure 3.16 South Deep Gold Mine current air quality monitoring network (Airshed, 2015).

The result presented in Figure 3.17, Figure 3.18 and Figure 3.19 showed that the dust fallout rates decreased between 2013 and 2015 at all dust buckets except Doornpoort 1 and Doornpoort 2, likely due to wind-blown dust from the Doornpoort TSF. The greatest dust fall rates were measured at Doornpoort 2 during the drier months (June to August) in 2014 and this is also likely a result of windblown tailings. Dust fallout rates for 2015 (up to June 2015) were well below the National Dust Control Regulations for residential areas with the highest rates at Twin Shaft, Waste Rock and Doornpoort 1 and Doornpoort 2.

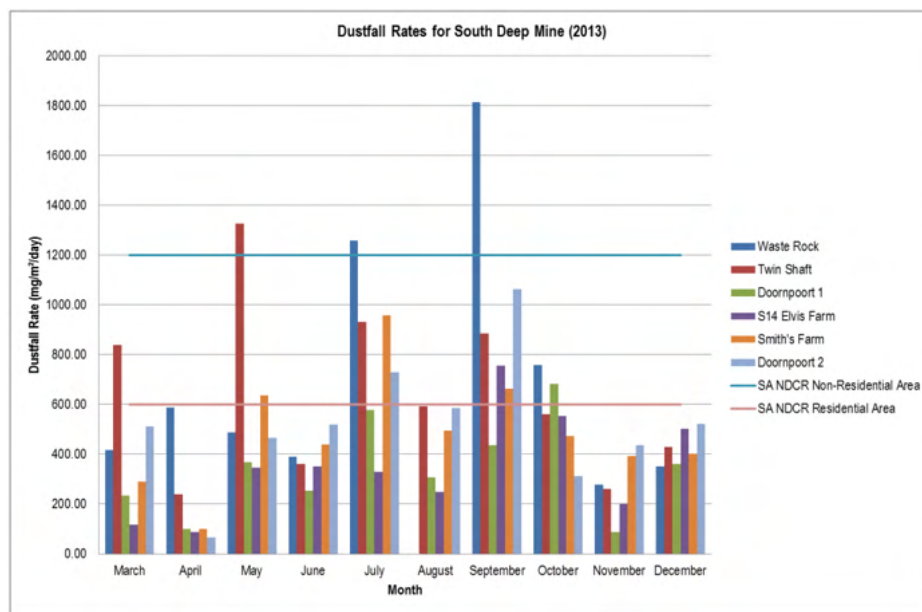


Figure 3.17 Dust fallout rates for South Deep Gold Mine for the year 2015 (Airshed, 2015).

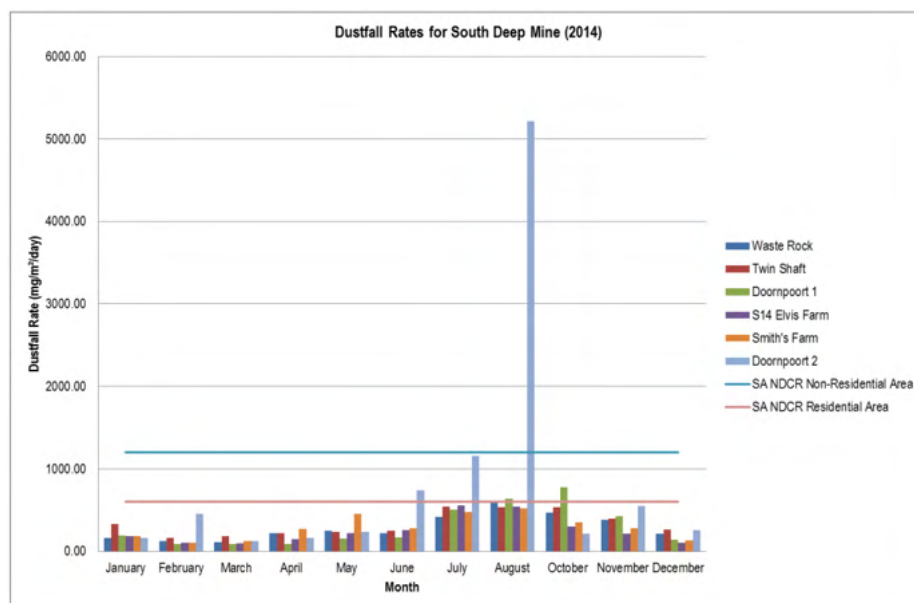


Figure 3.18 Dust fallout rates for South Deep Gold Mine for the year 2015 (Airshed, 2015).

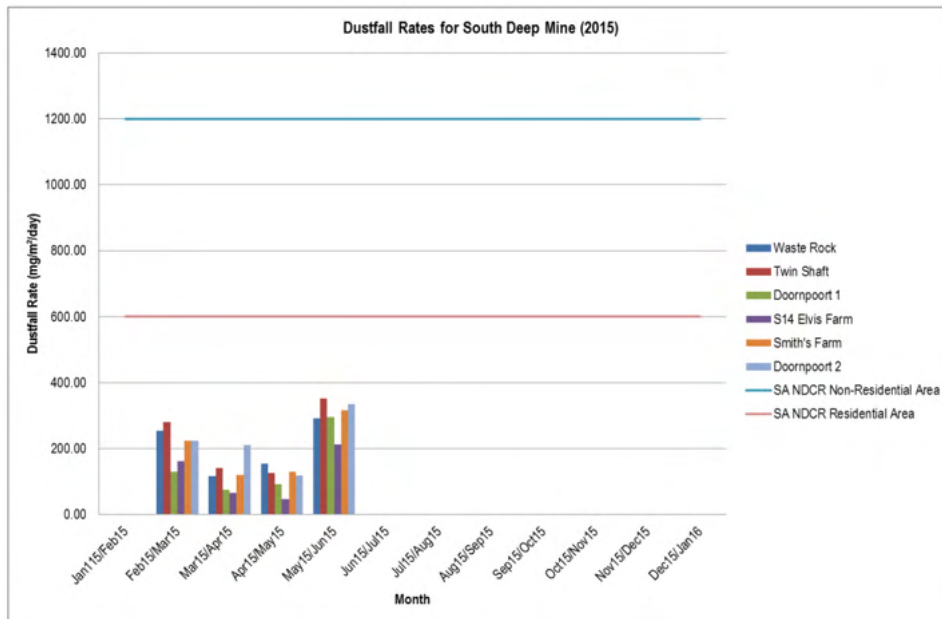


Figure 3.19 Dust fallout rates for South Deep Gold Mine for the year 2015 (Airshed, 2015).

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4 Demographic and Human Behavioural Characteristics

4.1 General

The purpose of this section is to provide an overview of the demographic, land use, and human behavioural conditions of communities living near the South Deep Gold Mine. This information provides context regarding the potentially affected environment and receptors of radiation exposure as part of a Source-Pathway-Receptor (SPR) analysis. Within the assessment framework presented in Figure 1.1, the SPR analysis serves as a basis for the definition and justification of a discrete set of public exposure conditions.

The main source of the information presented here is a Social Research Study conducted for the South Deep Gold Mine by Equispectives (Equispectives, 2016; 2020). Equispectives (2020) performed a desktop research study using secondary quantitative data from Statistics South Africa as well as visual comparisons of aerial maps of the area at different points in time. Census 2011 data was used according to the 2016 municipal ward demarcation and compared to Community Survey 2016 data. Some of the ward boundaries have changed in 2016 after the first report was submitted. StatsSA made Census 2011 data available that is grouped according to the 2016 boundaries. *Note that Community Survey 2016 data does not provide data on a Ward level, only on a municipal level and, therefore, limited comparisons are possible.*

The section is structured as follows. Section 4.2 provides a locality description, followed by an overview of the land use conditions observed in the area, in Section 4.3. Section 4.4 is devoted to an overview of the demographic and socio-economic characteristics of the region, while Section 4.5 describes the residential areas and household structures. Section 4.6 describes the social infrastructure and services, while Section 4.7 provides a general overview of the behavioural characteristics observed in communities living near the South Deep Gold Mine.

4.2 Locality Description

Details on the regional geographical setting of the South Deep Gold Mine were provided in Section 2.2. Figure 4.1 shows that the South Deep Gold Mine is situated in the Gauteng Province and West City Local Municipality (LM) that forms part of the West Rand District Municipality. The Rand West City LM was established in August 2016 by the amalgamation of the Randfontein LM and the Westonaria LM. There are approximately five gold mines near the town of Westonaria and the Greater Westonaria consists of several satellite towns, namely Westonaria, Hillshaven, Glenharvie, Venterspost, Libanon, Waterpan, Bekkersdal and Simunye. Most of these communities were established in response to mining activities in the area.

The South Deep Gold Mine is located in an area that is mainly rural and is mostly surrounded by farms. The mine villages Hillshaven and Glenharvie are located relatively close to the mine, as well as an informal settlement named Thusanang. Figure 4.1 shows the South Deep Gold Mine relative to the surrounding communities. It is located in Ward 30 of the Rand West City LM, with Ward 23 and Ward 26 within a 5 km radius from the operations. Ward 21 of Merafong City is also located within a 5 km radius from the operations.

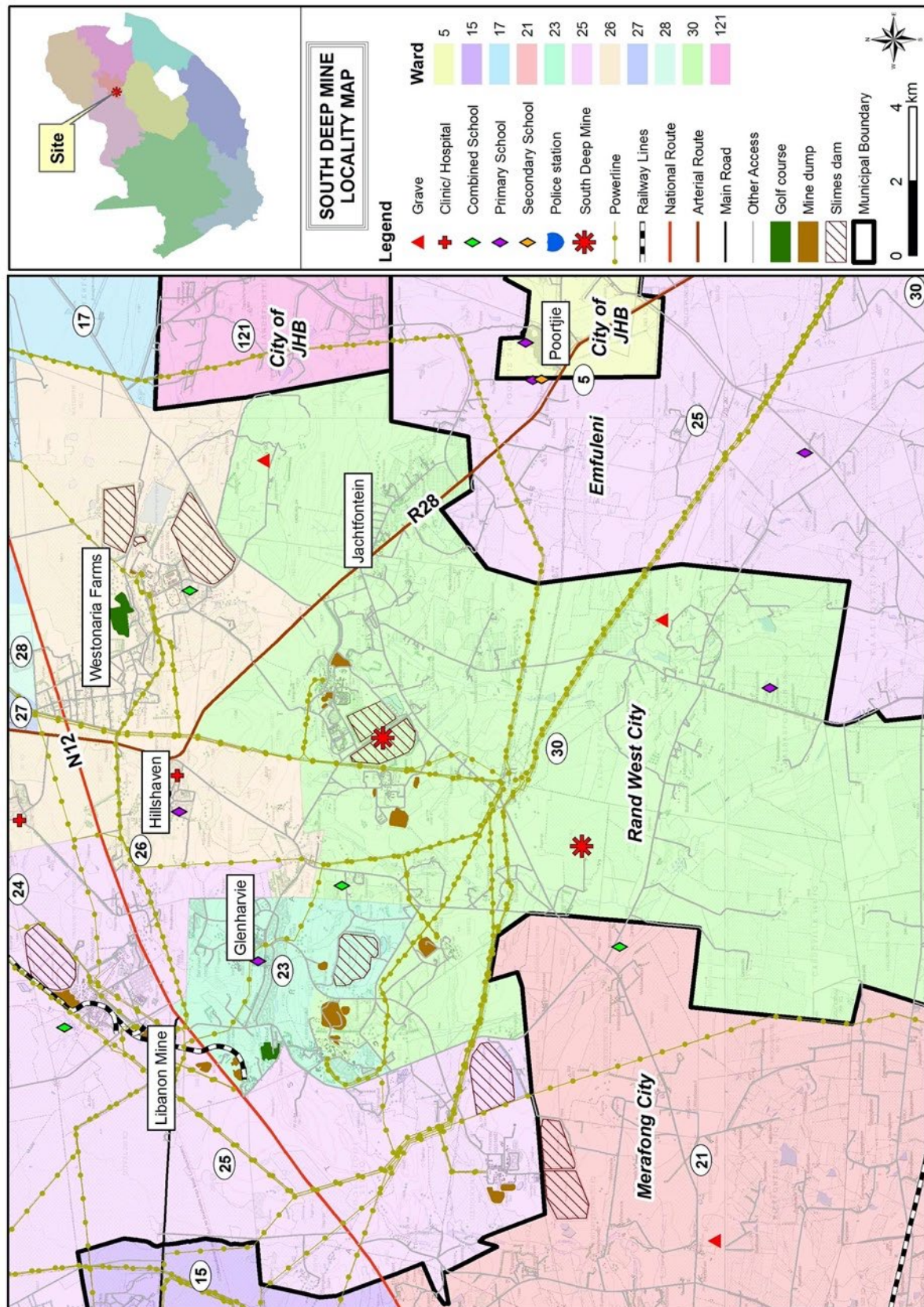


Figure 4.1 Map showing the South Deep Gold Mine located within the magisterial districts of Westonaria and Vanderbijlpark (Gauteng province), some 45 kilometres south-west of Johannesburg (Equispectives, 2020).

4.3 Land Use and Community Types

4.3.1 General

Figure 4.2 shows a 5 km radius around the South Deep Gold Mine surface infrastructure, as well as the potentially sensitive receptors within the 5 km radius. The South Deep Gold Mine is located in an area that is mainly rural and is mostly surrounded by farms. The Hillshaven and Glenharvie villages are located near the mine, as well as the Thusanang informal settlement. Sibanye-Stillwater's Kloof and Cooke Operations are the closest other mining operations. Most of the households in the area reside in areas classified as urban. Ward 30, where the South Deep Gold Mine is located, is the area with the highest incidence of households living on farms. Table 4.1 presents the breakdown for households according to geo types as per Census 2011.

Table 4.1 Breakdown of households according to geo types (source: Census 2011) (Equispectives, 2020).

Geo Type	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Urban area	87,426	5,394	3,893	2,495	68,199	2,468
Tribal or Traditional Area	0	0	0	0	0	0
Farm area	7,074	0	114	562	2,207	259
Total	94,499	5,394	4,008	3,057	70,406	2,728

Figure 4.3 shows the land cover observed near the South Deep Gold Mine, from which it is clear that the dominant land use condition is open grassland, followed by agricultural (cultivated cropland), mining and residential land use conditions. Equispectives (2020) divided communities into those living in formal structures, communities living in informal structures, commercial agricultural communities, and small-scale subsistence farming communities.

4.3.2 Formal Residential Structure Communities

A formal dwelling can be described as *"A structure built according to approved plans, i.e., house on a separate stand, flat or apartment, townhouse, a room in a backyard or rooms or flatlet elsewhere"* (Statistics South Africa, 2012). In some areas there may be a formal as well as an informal dwelling on a stand, creating a community with *mixed dwelling types*. Formal residential areas found in the area include Hillshaven, Glenharvie, and the Mining village and Emoyeni hostel (see Figure 4.2).

4.3.3 Informal Residential Structure Communities

An informal dwelling can be described as *"A makeshift structure not approved by a local authority and not intended as a permanent dwelling. Typically built with found materials (corrugated iron, cardboard, plastic, etc.), and is contrasted with formal dwelling and traditional dwelling"* (Statistics South Africa, 2012). Thusanang is the only informal community in the area (see Figure 4.2).

4.3.4 Commercial Agricultural Communities

Commercial agriculture includes farms where the farmer earns a livelihood from agriculture, such as crop, livestock or game farming. Areas with smallholdings are categorised according to

their character.

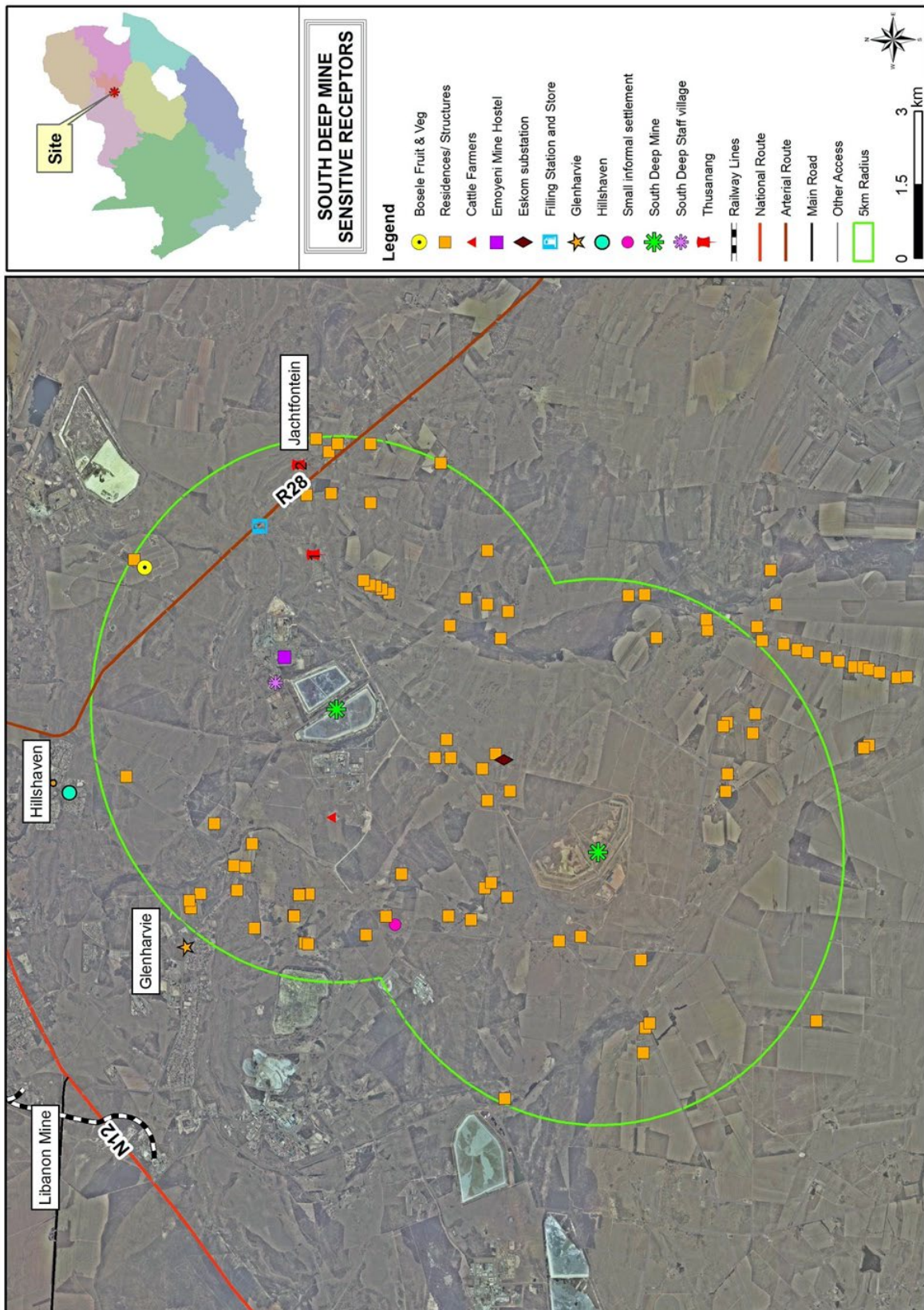


Figure 4.2 Map indicating the study area used for the AngloGold Ashanti Baseline Social

and Land Use Assessment (Equispectives, 2020).

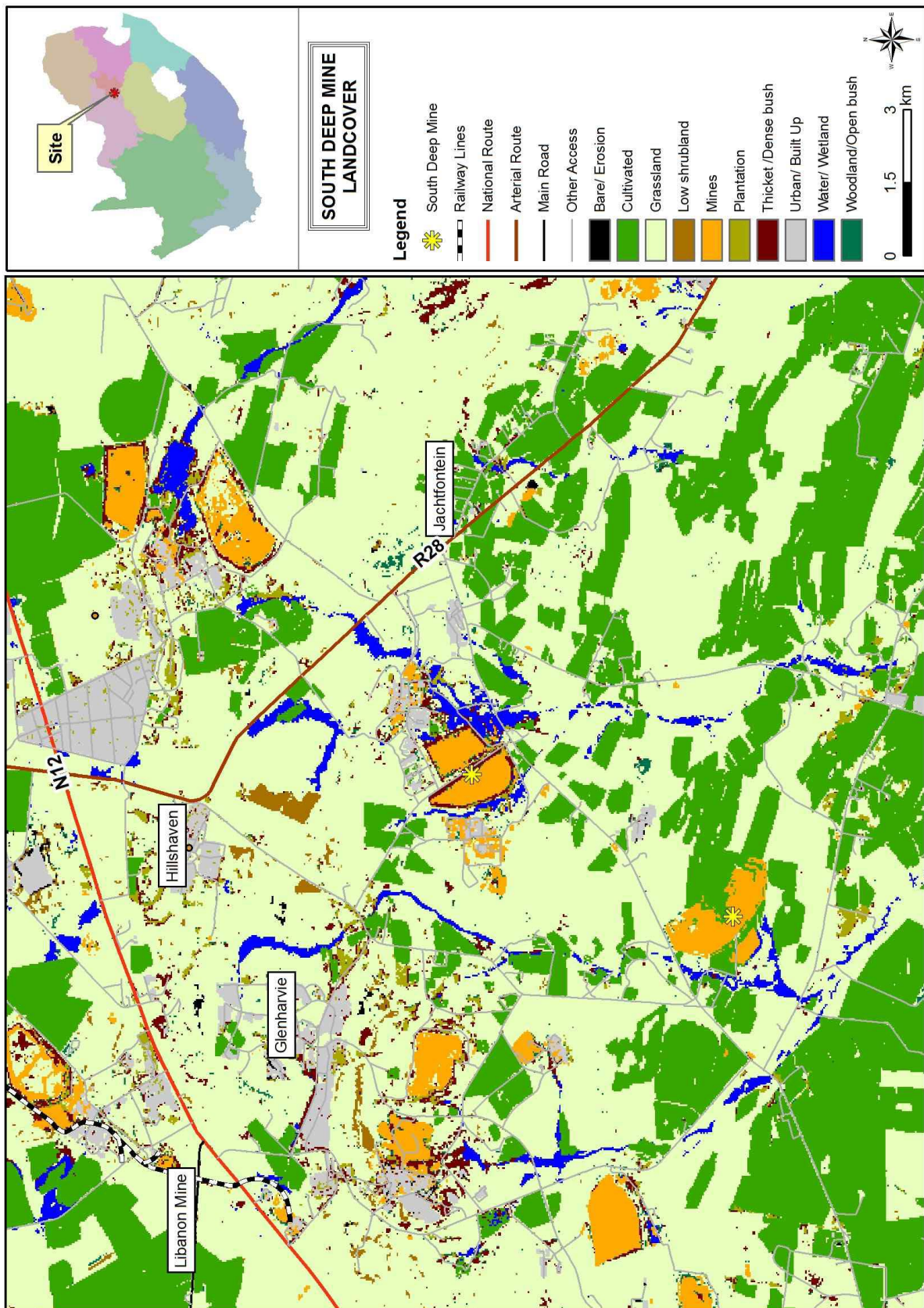


Figure 4.3 Map showing the land cover in the vicinity of the South Deep Gold Mine

(Equispectives, 2016).

If the residents of the smallholdings practise agriculture, they are grouped with commercial agriculture, if they just reside in the area or have a business on the smallholding not related to agriculture, the area is classified as formal residential.

4.3.5 Small-Scale Subsistence Farming

Small-scale subsistence farming can be described as large-scale food gardening on a piece of land that is not in someone's backyard. The land is usually cultivated by different members of the community and they may belong to a formalised group. Food gardens in the backyard of an organisation like a school or crèche would also be grouped in this category. Keeping livestock in the community or on the outskirts of the community would form part of this group.

Agricultural projects conducted as part of a Social and Labour Plan of a mine can contain characteristics of both commercial agriculture and subsistence farming. To classify these projects, the following guideline is used: if the project has reached a stage where it is sustainable and functions with minimal to no input from the mine, it is classified as commercial agriculture. However, if the mine is still heavily involved, it is classified as small-scale subsistence farming as the project has not yet proved its sustainability. Examples include the South Deep Gold Mine cattle farmers, and subsistence farmers in Thusanang (see Figure 4.2).

4.4 Demographic and Socio-economic Characteristics

4.4.1 General

Figure 4.1 shows the Wards directly affected by the South Deep Gold Mine, which is located in Ward 30 of the Rand West City LM. Ward 23 and Ward 26 are within a 5 km radius from the South Deep Gold Mine. Ward 21 of Merafong City is also located within a 5 km radius from the operation.

4.4.2 Demographics

The population in the Rand West City LM showed an increase of 1.85% and an increase in households of 9.61% between 2011 and 2016. As shown in Table 4.2, this is much lower than on the provincial level, while average household sizes have decreased. In Merafong City LM, the population has decreased but the number of households showed a greater increase than on district and provincial level. This suggests an increased demand for housing and infrastructure, as well as open space that can be converted to residential areas.

Table 4.3 shows that in most Wards, the majority of the population belong to the Black population group. Ward 26, where Hillshaven is located, has the highest proportion of people belonging to the White population group (31.2%). Ward 26 also include Waterpan and a part of Westonaria town. Between 2011 and 2016, the proportion of residents belonging to the Black population group has decreased in the Merafong City LM from 86.52% to 83.43%, while the proportion for the White population has increased from 11.79% to 15.07%. In all other areas, the proportions have remained more or less the same.

Table 4.2 Change in population and number of households between 2011 and 2016 (source: Census 2011 and Community Survey 2016) (Equispectives, 2020).

	Census 2011	Community Survey 2016	Difference
Rand West City Local Municipality			
Population	261 053	265 887	1.85%
Households	94 499	103 584	9.61%
Average household size	2.76	2.57	
Merafong City Local Municipality			
Population	197 520	188,843	-4.39%
Households	66 624	79,834	19.83%
Average household size	2.96	2.37	

Table 4.3 Breakdown of the population distribution in the different areas (source: Census 2011) (Equispectives, 2020).

Population	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Black African	205,419	8,235	6,749	4,789	170,897	3,347
Coloured	15,368	48	116	12	2,130	942
Indian or Asian	990	29	90	7	564	26
White	37,809	1,307	3,165	465	23,291	4,238
Other	1,467	10	11	59	639	82
Total	261,053	9,630	10,131	5,332	197,520	8,636

4.4.3 Family Structure

Census 2011 data summarised in Table 4.4 shows that more than half of households on provincial, regional, local and Ward level consist of 1 to 2 people, except in Ward 21 of Merafong City LM where the incidence is just under half. Wards 23 (66.75%) and 30 (69.35%) had the highest incidence of households consisting of only one person. The proportion of single-person households has decreased at all levels between 2011 and 2016. In the Rand West City LM, the proportion of single-person households decreased from 38.04% to 28.29%, while in the Merafong City LM it has decreased from 40.11% to 30.72%. This can be indicative of people trying to cut their living expenses by sharing a dwelling. Average household sizes have decreased between 2011 and 2016.

Census 2011 data summarised in Table 4.5 shows that more than two-thirds of households in the Rand West City LM and the Merafong City LM are headed by males. On a Ward level, this proportion increases to more than three quarters, except in Ward 21 where the proportion is just below three quarters. Community Survey 2016 shows that there has been a slight increase in female-headed households in the Rand West City LM from 30.1% in 2011 to 32.69% in 2016, while the proportion in the Merafong City LM has remained more or less the same. Female-headed households are often financially less well off than similar male-headed households and can be considered as more vulnerable.

Table 4.4 Household sizes (source: Census 2011) (Equispectives, 2020).

Household size	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
1	35,952	3,600	1,862	2,120	28,238	637
2	18,781	713	658	400	13,387	694
3	13,700	449	477	233	9,677	457
4	11,417	348	449	154	8,207	473
5	6,505	166	283	67	4,651	233
6	3,627	62	144	31	2,737	119
7	2,106	32	69	21	1,555	47
8	1,073	11	30	22	904	32
9	590	3	21	4	422	14
10+	748	8	15	7	627	21
Total	94,499	5,394	4,008	3,057	70,406	2,728
Average household size	2.76	1.79	2.53	1.74	2.81	3.17

Table 4.5 Gender of the head of household (source: Census 2011) (Equispectives, 2020).

Gender distribution	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Male	66,069	4,867	3,297	2,604	49,583	2,038
Female	28,404	526	711	453	20,752	689
Total	94,473	5,393	4,008	3,057	70,335	2,728

Census 2011 data summarised in Table 4.5 shows a bias towards males on a district, local and ward level, except in Ward 21 that have a more or less equally split between males and females. In Ward 23 and Ward 30, more than two-thirds of the population are males. The split between males and females has remained more or less the same between 2011 and 2016.

Table 4.6 Gender distribution (source: Census 2011) (Equispectives, 2020).

Gender distribution	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Male	136,038	6,627	5,623	3,594	107,157	4,339
Female	125,016	3,003	4,508	1,738	90,363	4,297
Total	261,053	9,630	10,131	5,332	197,520	8,636

Census 2011 data presented in Figure 4.4 shows that Ward 23 and Ward 30 have the highest proportion of people older than 17 years of age, while Ward 21 has the lowest. A portion of the town of Fochville is located in Ward 21, but it is more than 10 km away from the South Deep Gold Mine. The portion of Ward 21 located within a 5 km radius from the South Deep Gold Mine contains farmland. Between 2011 and 2016, the proportion of people older than 17 years of age in the Rand West City LM and the Merafong City LM have increased slightly, while the proportion of people under 2 years has decreased slightly.

4.4.4 Socio-Economic Conditions

Census 2011 data summarised in Table 4.7 shows that the employment levels for the economically active part of the population (aged 15 to 64 years) vary. Ward 23 and Ward 30 have

the highest levels of employed people, higher than on local, district and provincial level. In 2016 (Equispectives, 2016), residents of Hillshaven have indicated that there are high levels of unemployment in the community, especially amongst the youth.

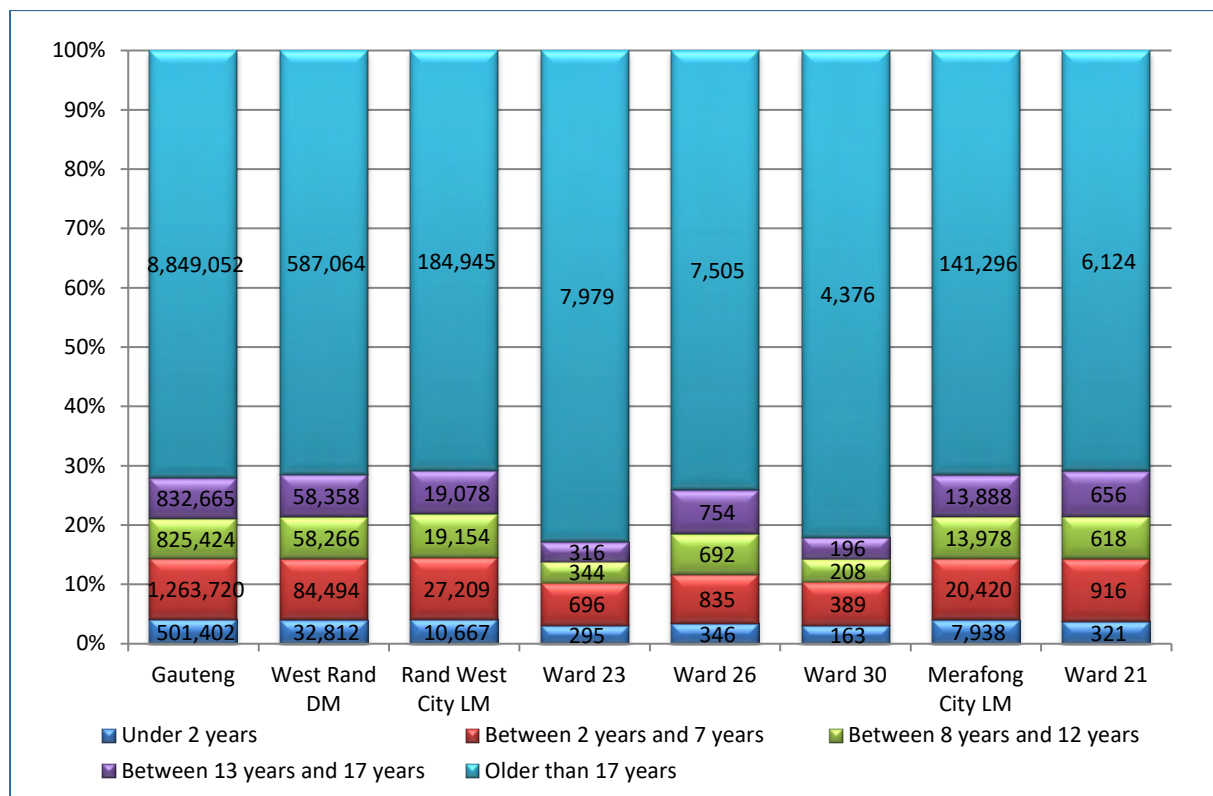


Figure 4.4 Age distribution of the population (shown in percentage; source: Census 2011) (Equispectives, 2020).

Table 4.7 Employment status (persons aged 15 to-64 years in age, source: Census 2011, shown in percentage) (Equispectives, 2020).

Employment Status	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Employed	49.29	71.82	62.01	66.12	46.51	57.12
Unemployed	19.36	12.18	10.38	15.24	17.37	8.71
Discouraged work-seeker	3.41	1.63	2.00	1.49	3.47	2.00
Other not economically active	27.93	14.38	25.61	17.15	32.66	32.17
Total	100.00	100.00	100.00	100.00	100.00	100.00

In Thusanang, most people are unemployed. According to residents, there are a high number of illegal immigrants in the community that did not have the required documentation to access services such as health care. It must be noted that large scale retrenchments took place in the gold mining industry since 2012. On a national level, the number of direct employees in gold mining has dropped from 142,201 in 2012 to 101,085 towards the end of 2018. At the South Deep Gold Mine, just over a thousand workers were retrenched towards the end of 2018 / beginning of 2019. As such, it is anticipated that the proportion of unemployed people in the area have increased since 2016.

Census 2011 data summarised in Table 4.8 shows that Ward 30 and Ward 21 have the highest incidence of households with no income. In Ward 30, almost a fifth of households had no income in 2011 and only 12.7% of households had an annual household income of more than R76,400. In Ward 26, just over 40% of households have an income of more than R76,400, compared to 27.9% in Ward 23 and 46% in Ward 21. In Ward 30 and Ward 21, just over 31% of households earned less than R19,601 in 2011 and as such would be below or just above the lower bound poverty line. In Ward 23, approximately 10.1% of households had a household income of less than R19,601 and in Ward 26 the figure was just below 20%.

Table 4.8 Annual household income (source: Census 2011, shown in percentage) (Equispectives, 2020).

Annual household income	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
No income	16.51	4.94	8.24	18.68	15.97	16.87
R 1 - R 4 800	4.32	0.61	1.93	2.33	3.99	1.25
R 4 801 - R 9 600	6.16	1.83	2.58	3.28	5.88	3.07
R 9 601 - R 19 600	12.70	2.71	6.42	7.28	11.12	10.73
R 19 601 - R 38 200	17.56	10.86	20.24	22.64	14.94	10.31
R 38 201 - R 76 400	20.23	51.11	19.91	33.05	26.43	11.76
R 76 401 - R 153 800	10.10	13.88	13.14	8.12	10.99	14.30
R 153 801 - R 307 600	7.30	9.54	15.13	3.62	6.58	17.69
R 307 601 - R 614 400	3.81	3.27	9.60	0.81	3.01	10.30
R 614 001 - R 1 228 800	0.93	0.78	1.96	0.04	0.75	2.88
R 1 228 801 - R 2 457 600	0.18	0.27	0.23	0.00	0.19	0.38
R 2 457 000 or more	0.18	0.19	0.58	0.15	0.14	0.47
Unspecified	0.01	0.00	0.03	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00

4.5 Residential Areas and Household Structures

4.5.1 General

The different residential areas in the area can be grouped according to the settlement types and the housing structures present in each area. Equispectives (2016) noted that residential areas such as Fochville and Westonaria have been excluded since these areas fall outside the 5 km radius. Table 4.9 summarises the settlement types and representative residential areas that are included in the discussions (see also Figure 4.2).

Table 4.9 Summary of community types and representative residential areas inside the study are identified for the South Deep Gold Mine.

Settlement Type	Representative Area
Formal Residential	Hillshaven and Glenharvie
Informal Residential	Thusanang informal settlement
Mine Workers Residences	Emoyeni Mine Hostel
Agricultural areas	Surrounding farming community

4.5.2 Household and Dwelling Types

Table 4.10 shows that the majority of households live in dwellings that are brick or concrete structures, such as a dwelling in a separate yard, a block of flats, a cluster house or townhouse in a complex, or a semi-detached house. The exception is in Ward 30 where more than a third of households (35.5%) live in an informal dwelling that is not in a backyard. Thusanang, an informal settlement, is located in Ward 30. In 2016, Equispectives (2016) indicated that most of the dwellings in Thusanang consisted of zinc structures. Aerial photography shows that this still applies.

Table 4.10 Main dwelling types (households, source: Census 2011) (Equispectives, 2020).

Annual household income	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
House or brick/concrete block structure on a separate stand or yard or on a farm	47,415	2,657	2,389	1,313	39,776	2,203
Traditional dwelling/hut/structure made of traditional materials	199	5	7	43	137	1
Flat or apartment in a block of flats	2,881	155	133	205	4,634	40
Cluster house in complex	516	5	20	5	846	15
Townhouse (semi-detached house in a complex)	883	1	84	3	204	51
Semi-detached house	399	4	11	41	174	11
House/flat/room in backyard	5,387	125	252	26	2,867	63
Informal dwelling (shack; in backyard)	7,078	5	9	10	3,576	38
Informal dwelling (shack; not in backyard; e.g., in an informal/squatter settlement or on a farm)	16,833	45	14	1,045	10,600	13
Room/flatlet on a property or larger dwelling/servants quarters/granny flat	799	3	23	10	1,292	13
Caravan/tent	71	1	0	2	36	1
Other	936	48	21	243	2,482	6
Unspecified	401	18	19	17	352	31
Not applicable	10,702	2,322	1,025	94	3,430	240
Total	94,499	5,394	4,008	3,057	70,406	2,728

Community Survey 2016 shows that the number of households living in formal dwellings or houses on a separate stand has decreased in the Rand West City LM from 56.9% in 2011 to 54.4% in 2016, while in the Merafong City LM it has increased from 59.7% in 2011 to 64.5% in 2016. In the Rand West City LM, the proportion of households living in an informal dwelling in a backyard has increased from 8.5% in 2011 to 12.2%, while the proportion of households living in an informal dwelling that is not in a backyard has decreased from 20.2% in 2011 to 13.6% in 2016. In Merafong City LM, the proportion of households living in any type of informal dwelling has decreased between 2011 and 2016. In 2016 about a fifth (20.0%) of households in the Rand West City LM and a quarter (24.8%) of households in the Merafong City LM have indicated that they live in RDP or government-subsidized dwellings. More than half of those living in RDP or government-subsidized dwellings (58.5% in the Rand West City LM and 61.3% in the Merafong City LM) have rated the overall quality of the dwellings as good.

4.5.3 Formal Residential Areas

Hillshaven is a gated community with one entrance that is access-controlled. Most of the houses are well-maintained. The majority of houses are brick structures with tile roofs, although there are some with zinc roofs (see Figure 4.5). At some dwellings, the main building has a tiled roof, while the outbuildings have zinc roofs. All the yards are fenced and the dwellings vary in size. There is also a block of flats as well as single living quarters in the community (see Figure 4.6).



Figure 4.5 Dwellings in Hillshaven (Equispectives, 2016).



Figure 4.6 Flats and single quarters in Hillshaven (Equispectives, 2016).

Glenharvie is similar in appearance to Hillshaven but is not a gated community and many street hawkers are visible. Most dwellings have zinc roofs, except on a newly developed area where the houses have tiled roofs (see Figure 4.7 and Figure 4.8). Glenharvie is closer to the Sibanye-Stillwater Operations than the South Deep Gold Mine and thus was mostly excluded from further analysis.



Figure 4.7 Dwellings in Glenharvie (Equispectives, 2016).



Figure 4.8 More dwellings in Glenharvie (Equispectives, 2016).

4.5.4 Informal Residential Areas

Thusanang is an informal settlement where almost all the dwellings are constructed using zinc (see Figure 4.9). Many of the yards are fenced. A portion of Thusanang is a distance away on the other side of the R28 than South Deep.

4.5.5 Mine Workers Residences

The Emoyeni mine residence (hostel) consists of single and double-storey buildings with zinc roofs (see Figure 4.10), while the mining village consists of small brick houses with tiled roofs and individual yards (see Figure 4.11). The houses are well maintained. Males and females live in the residence, in separate sections.



Figure 4.9 Dwellings in Thusanang, showing that most of the dwelling is constructed using Zinc (Equispectives, 2016).



Figure 4.10 Mine residence in the Emoyeni mine hostel (Equispectives, 2016).



Figure 4.11 Dwellings in the mining village (Equispectives, 2016).

4.5.6 Agricultural Areas

The farming community can be categorised into two broad groups, namely commercial farmers, of which some has been in the area for many years, and emerging farmers. The dwellings are brick structures with zinc or tiled roofs (see Figure 4.12). Some of the dwellings of the farmworkers are constructed of stones and have zinc roofs (see Figure 4.13).



Figure 4.12 Farm dwellings (Equispectives, 2016).



Figure 4.13 Farmworker dwellings (Equispectives, 2016).

The dwellings tend to be in clusters and often there would be another dwelling near that is rented out to people working in the area. Not all farms have farmworkers living on the farm. Some farmworkers commute to work.

4.6 Social Infrastructure and Services

4.6.1 Introduction

The infrastructure in the area around the South Deep Gold Mine is fairly limited. Presented here is an overview of the social infrastructure, as well as the status of community services provided in the area. These include access to water, refuse removal, energy sources, and sanitation.

4.6.2 Social Infrastructure

The infrastructure that households have access to indicates the vulnerability of the residents of a specific area. Lack of infrastructure, or using a specific type of infrastructure, can make residents more vulnerable to interacting with pathways of exposure. The 2019/20 Rand West City IDP indicates that on a municipal level there are currently 168 Early Childhood Centres, 33 primary schools, 12 secondary schools, two FET colleges and one school for the mentally handicapped. In terms of recreational facilities, there are seven sports stadiums, three swimming pools, six community halls, 45 parks, two resorts, 17 libraries and five multi-purpose recreational community centres. There are 19 clinics in the municipal area but no public hospital.

In 2016, Equispectives (2016) indicated that social infrastructure in the area is fairly limited. There are schools in Hillshaven and Glenharvie. Hillshaven host a primary school and two crèches (see Figure 4.14 and Figure 4.15). The primary school has about 800 learners, with learners coming not only from Hillshaven but also from neighbouring areas such as Protea (in Soweto), Poortjie, Waterpan and Simunye. The children in Thusanang are transported by bus to a school at Poortjie. Not all the young children in the area could go to crèche as there were a limited number of crèches in the area. Hillshaven has a mobile clinic and a clinic sponsored by the South Deep Gold Mine that opened in Thusanang around 2016. This clinic seems to be still operational.



Figure 4.14 Playground at school in Hillshaven (Equispectives, 2016).

There is no public transport in Hillshaven such as taxis and while there are taxis in Thusanang, residents described them as expensive. There are some sports fields in the area as well as some open space. The area has a high incidence of bottle stores and taverns, but only one supermarket and a few spaza shops. The closest town, with a greater variety of infrastructure, is Westonaria.



Figure 4.15 Playground at crèche in Hillshaven (Equispectives, 2016).

A mobile clinic is supposed to come to Hillshaven once a week but often does not show up. Equispectives (2016) observed that there are many bottle stores in the area, with only one supermarket in Hillshaven (see Figure 4.16). The school has a library with internet facilities that are open to the community at certain times. The community has a secondary (combined) school in Glenharvie as well as some crèches (see Figure 4.17). There are play areas with swings and other equipment for children throughout the area.



Figure 4.16 Supermarket in Hillshaven (Equispectives, 2016).

The community lacks recreational facilities for young people. There are sports grounds at the Hillshaven school and in the community, but the facilities are neglected and not all suitable for use (see Figure 4.18). The community sports grounds in Hillshaven had a soccer field, tennis courts, netball fields and a swimming pool. The swimming pool has been closed after a drowning incident. There is a small gym at the community sports grounds (see Figure 4.19). A sports complex that appears to be neglected has been observed in Glenharvie. There are hawkers in the Glenharvie streets selling items like snacks, fruit and live chickens (see Figure 4.20).



Figure 4.17 Pre-school in Glenharvie (Equispectives, 2016).



Figure 4.18 Sports grounds in Hillshaven (Equispectives, 2016).

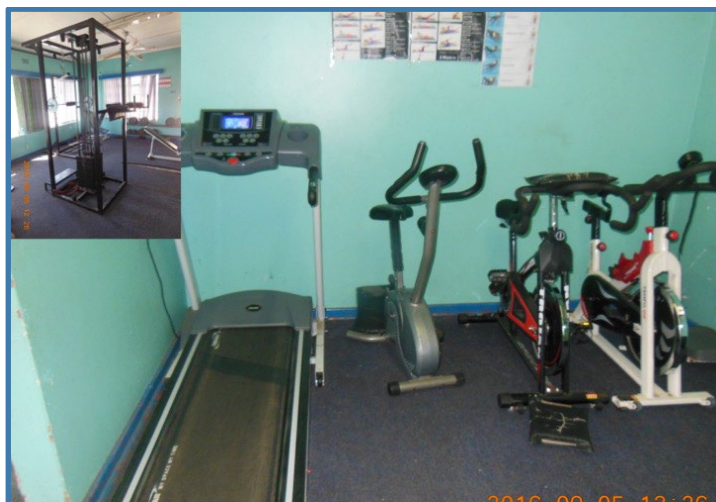


Figure 4.19 Gym in Hillshaven (Equispectives, 2016).



Figure 4.20 Hawkers in Glenharvie (Equispectives, 2016).

There is no public transport in the area, except for taxis. Taxis are not allowed inside the Hillshaven community, and people need to go outside the boomed area if they want to use a taxi. There are dedicated taxis that transport children from areas outside Hillshaven to school. These taxis wait outside the school for the children as it is not worthwhile for them to return to the area that they are from.

The social infrastructure in Thusanang is extremely limited. There are no schools and children are transported by bus to a school at Poortjie. There is one crèche in the community as well as a home-based care centre. There is a clinic sponsored by South Deep Gold Mine. The community has two soccer fields and a netball field, as well as a small play area with swings for children (see Figure 4.21). There are taxis in the area. Indications are that there are more than twelve taverns in the community, and also a few spaza shops (see Figure 4.22).



Figure 4.21 Play area and soccer field in Thusanang (Equispectives, 2016).

There is a country pub called Dalemoor / Oppiplaas that is located in the farming area. Adjacent to the R28 at the turn-off to South Deep Gold Mine, there is a small filling station with a tavern and takeaway store (see Figure 4.23). Car repairs are done at the site and there is also a car wash.



Figure 4.22 Shops in Thusanang (Equispectives, 2016).

In the mining village and Emoyeni residence, there is an area with stalls (tuckshops) where residents can buy fruit, vegetables and some small user items (see Figure 4.24). A small shop, bottle store, TV room and canteen has been observed, as well as an area for socialising, called Nkandla (see Figure 4.25).



Figure 4.23 Shop next to R28 (Equispectives, 2016).

4.6.3 Community Activities

Activities that take place in a community differs from community to community. Based on similar studies over time in other areas, people that live in areas where there are high levels of unemployment tend to spend more time outside. They socialise outside, children tend to play outside for most of the day as many households in these areas cannot afford to send their children for day-care. Informal housing tends to be very cold in winter and hot in summer, and is usually quite small inside, as such these residents prefer to rather be outside. In many lower-income areas, there are usually make-shift sports fields where residents can play soccer or other sport.



Figure 4.24 Hawkers at the mine residence (Equispectives, 2016).



Figure 4.25 Social infrastructure at the mine residence (Equispectives, 2016).

Incidences of food gardens in areas with high levels of poverty and unemployment are higher than in other areas as many residents do not have the means to buy all their food and a higher proportion of people have time available to tend to a food garden. In the previous report, residents have indicated that some of the people in Hillshaven who were unemployed did recycling, washing cars or did piece jobs. Some people cut grass or trees outside the community. The trees were used to make decorative wooden screens. In Thusanang, some cleaned the yards of residents at work for payment and some community members played gambling games to put food on the table. On the farms the farmers and their employees spend most of the day outside, busy with farming activities.

4.6.4 Access to Water

Census 2011 data summarized in Table 4.11 shows that more than 88% of households in the area have access to water from a regional or local water scheme operated by the municipality or other water services providers, except in Ward 30 where only 73% of households have access to water from a local or regional water scheme. Just over 10% of households in Ward 30 get their water

from a water tanker, while 2.6% get their water from a water vendor. In 2016, Equispectives (2016) indicated that in Thusanang (Ward 30), water was pumped from Hillshaven to water tanks in the area and each street had a tap where residents must fetch water, using containers (see Figure 4.26). As the dwellings in Thusanang are still mostly zinc structures, it is unlikely that their source of water has changed to piped water closer to their dwellings since 2016.

Table 4.11 Sources of water for households (source: Census 2011) (Equispectives, 2020).

Source of Water	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Regional/local water scheme (operated by municipality or other water services provider)	84,295	5,318	3,832	2,231	64,953	2,423
Borehole	6,374	8	0	204	1,530	204
Spring	89	0	4	5	53	1
Rainwater tank	172	1	3	19	307	5
Dam/pool/stagnant water	111	0	6	33	51	6
River/stream	40	0	0	10	23	1
Water vendor	363	13	11	78	170	11
Water tanker	1,568	9	5	325	1,570	27
Other	1,487	45	146	151	1,749	50
Total	94,499	5,394	4,008	3,057	70,406	2,728



Figure 4.26 Resident doing laundry in Thusanang (Equispectives, 2016).

Table 4.12 shows that in Ward 23, Ward 26, and Ward 21 more than 70% of households had access to piped water inside their dwellings in 2011, while in Ward 30 just over 20% of households have access to tap water inside their homes. About a third (34.0%) of households in Ward 30 have access to piped water inside their yards. Community Survey 2016 shows that the incidence of households with access to piped water inside the dwelling in the Rand West City LM has increased from 53.0% in 2011 to 55.5% in 2016, while in the Merafong City LM it has increased from 51.0% to 62.1%.

Table 4.12 Households that have access to piped water (source: Census 2011) (Equispectives, 2020).

Source of Water	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Piped (tap) water inside the dwelling	50,053	4,128	2,875	654	35,905	1,908
Piped (tap) water inside the yard	23,977	1,163	1,078	1,040	21,110	576
Piped (tap) water on community stand: distance less than 200m from dwelling	11,981	57	15	455	7,775	158
Piped (tap) water to community stand: distance less than 200m and 500m from dwelling	5,031	4	12	540	2,558	9
Piped (tap) water to community stand: distance less than 500m and 1000m from dwelling	1,483	11	3	264	1,423	5
Piped (tap) water on community stand: distance greater than 1000m (1 km) from dwelling	159	0	0	19	390	4
No access to piped (tap) water	1,414	13	6	68	893	36
Unspecified	401	18	19	17	352	31
Total	94,499	5,394	4,008	3,057	70,406	2,728

In Community Survey 2016, approximately 9.1% of households in the Rand West City LM and 6.7% in the Merafong City LM have indicated that they do not have access to safe drinking water while about 8.8% of people in the Rand West City LM and 12.6% of people in the Merafong City LM rate the overall quality of water services as poor.

Approximately 22.2% of the households in the Merafong City LM and 5.3% of households in the Rand West City LM have indicated that they have experienced municipal water interruptions in the past three months while 15.0% of households in the Merafong City LM and 2.5% of households in the Rand West City LM have indicated that they had water interruptions that lasted for longer than two days.

In the Merafong City LM, 40.8% of the households that experienced water interruptions have indicated that they used water from a water tanker, 22.6% an 'other' water source (it is not specified what the alternative sources are) and about 28% used no other alternative water source during interruptions. In the Rand West City LM, 27% of the households that experienced water interruptions have indicated that they used water from a water tanker, 27.7% an 'other' water source and about 32.5% used no other alternative water source during interruptions.

The majority of people in the Rand West City LM (76%) and the Merafong City LM (80.9%) that do not have access to piped water inside their dwellings or yard have access to a source of water within less than 200 m.

The farms get their water from boreholes. Some farms have water tanks that catch rainwater. Some of the farms close to the R28 have complaints about the quality of the borehole water. The South Deep cattle farmers get potable water piped from the South Deep Gold Mine.

4.6.5 Refuse Removal

Census 2011 data summarized in Table 4.13 shows that the majority of households have their refuse removed at least once a week by the local authority or a private company, except in Ward 30 where only about 41.1% of households have their refuse removed at least once a week. The remainder of households in Ward 30 mostly make use of a communal (6.0%) or private (38.8%) refuse dump.

Table 4.13 Refuse disposal (households, source: Census 2011) (Equispectives, 2020).

Refuse Disposal	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Removed by the local authority/private company at least once a week	69,961	5,233	3,603	1,249	51,926	2,349
Removed by the local authority/private company less often	2,346	46	155	299	3,239	21
Communal refuse dump	4,134	37	149	160	4,195	14
Own refuse dump	13,269	38	63	1,180	6,740	260
No rubbish disposal	3,704	15	10	94	3,334	49
Other	686	8	9	58	620	4
Unspecified	401	18	19	17	352	31
Not applicable	-	-	-	-	-	-
Total	94,499	5,394	4,008	3,057	70,406	2,728

Equispectives (2016) indicated in 2016 that the farming community have their refuse removal methods, with some farmers removing their refuse to a landfill, while others burying or burning it. In Thusanang residents had indicated that many residents burn their refuse as the municipality was not removing the refuse as they were supposed to (see Figure 4.27). In Hillshaven, refuse is removed by the municipality once a week, while there is also a landfill in Hillshaven. Refuse is also removed by the municipality in Glenharvie but on the outskirts of Glenharvie, there are places where refuse is dumped next to the road (see Figure 4.28). In the mine village and residence, refuse is removed, while bins for recycling have been provided to the mine residence as well.

Community Survey 2016 indicated that the proportion of households in the Rand West City LM and the Merafong City LM with refuse removal once a week has increased from approximately 74 % in 2011 to just over 79% in 2016. The proportion of households in the Rand West City LM that use communal refuse dumps has increased from 4.4% in 2011 to 5.7% in 2016, while those using their own refuse dumps have decreased from 14.1% in 2011 to 9.0% in 2016. In Merafong City LM, the proportion of households that use communal refuse dumps have decreased from 6.0% in 2011 to 3.6% in 2016, while those using their own refuse dumps have decreased from 9.6% in 2011 to 6.6% in 2016. In 2016, 60.4% of residents in the Rand West City LM rated the quality of refuse removal as good, while in the Merafong City LM 53.9% rated it as good.



Figure 4.27 Refuse in old cement dam in Thusanang (Equispectives, 2016).



Figure 4.28 Refuse dumped next to the road outside Glenharvie (Equispectives, 2016).

4.6.6 Energy Source

Census 2011 data summarized in Table 4.14 shows that more than 84% of households in Ward 23, Ward 26 and Ward 21 have access to electricity for cooking purposes but in Ward 30 the incidence is only 55.5%. Ward 30 has the highest incidence of households using paraffin (36.7%). Paraffin as an alternative to electricity is usually chosen due to economic circumstances. Community Survey 2016 shows that the incidence of households in the Merafong City LM that use electricity for cooking purposes has increased from 73.6% in 2011 to 83% in 2016. In the Rand West City LM, this incidence has remained more or less the same.

Census 2011 data summarized in Table 4.15 shows that for heating purposes, more than 71% of households in Ward 23, Ward 26 and Ward 21 use electricity but in Ward 30 this incidence is much lower at 55.7%. Almost 30% of households in Ward 30 use paraffin for heating purposes. Ward 21 (8.8%) and Ward 30 (10.5%) have the highest incidence of households using wood for heating purposes. Community Survey 2016 distinguishes between space heating and water heating and as such the questions are not directly comparable.

Table 4.14 Main source of energy for cooking (households, source: Census 2011) (Equispectives, 2020).

Source of Energy for Cooking	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Electricity	68,722	5,274	3,881	1,688	51,578	2,284
Gas	2,900	14	52	78	1,296	127
Paraffin	20,600	67	19	1,117	15,736	199
Wood	1,239	6	28	100	869	73
Coal	158	0	2	3	123	0
Animal dung	30	0	1	4	44	0
Solar	128	8	2	1	108	2
Other	90	4	0	6	131	9
None	231	3	3	44	169	2
Total	94,099	5,376	3,989	3,040	70,054	2,697

Table 4.15 Main source of energy for heating (households, source: Census 2011) (Equispectives, 2020).

Source of Energy for Heating	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Electricity	60,877	5,261	3,473	1,693	45,407	1,923
Gas	2,757	20	127	45	1,171	157
Paraffin	10,146	69	22	901	9,819	51
Wood	8,146	9	52	320	4,164	238
Coal	1,412	0	4	5	862	7
Animal dung	60	2	5	1	71	3
Solar	147	9	4	3	121	4
Other	4	0	0	0	3	1
None	10,550	5	301	71	8,434	313
Total	94,099	5,376	3,989	3,040	70,054	2,697

Census 2011 data summarized in Table 4.16 shows that more than 93% of households in Ward 23, Ward 26 and Ward 21 use electricity for lighting purposes. In Ward 30, only 57.4% of households have access to electricity for lighting purposes, while 27% use paraffin and 13.3% use candles. Community Survey 2016 shows that the incidence of households that use electricity for lighting has increased from 81.6% in 2011 to 86.8% in 2016 in the Merafong City LM, while the proportion in the Rand West City LM has remained more or less the same. The usage of candles has decreased from 16.8% in 2011 to 11.2% in the Rand West City LM and the Merafong City LM, the proportion has decreased from 13.5% to 7.1%. In the Rand West City LM, the incidence of households using paraffin has increased from 7.4% to 11.0%.

Equispectives (2016) indicated in 2016 that all households in Hillshaven and Glenharvie have access to electricity. Due to financial constraints, not all households use electricity. Alternative sources of energy used for lighting are paraffin and candles. Alternative energy sources used for cooking are gas and paraffin. Wood is also used for heating. However, there is no electricity in Thusanang. For lighting purposes, paraffin, candles and solar panels are used, while small solar panels are often used to charge devices (see Figure 4.29. Those who have televisions, power them

with generators. For cooking purposes, residents use paraffin, wood, gas, corn cobs or solar devices, Wood is used for heating as well and is gathered from the adjacent areas (see Figure 4.30). The mine village and residence all have access to electricity. The farms have access to electricity. Wood is also used for cooking and heating purposes (see Figure 4.31).

Table 4.16 Main source of energy for lighting (households, source: Census 2011) (Equispectives, 2020).

Source of Energy for Lighting	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Electricity	70,630	5,284	3,953	1,746	57,182	2,519
Gas	256	3	9	10	95	8
Paraffin	6,943	32	5	822	2,957	13
Candles	15,814	43	14	405	9,438	146
Solar	175	9	4	6	144	6
None	281	5	4	51	237	4
Total	94,099	5,376	3,989	3,040	70,054	2,697



Figure 4.29 Solar panels in Thusanang (Equispectives, 2016).



Figure 4.30 Firewood in Thusanang (Equispectives, 2016).



Figure 4.31 South Deep cattle farmers cooking (Equispectives, 2016).

4.6.7 Sanitation

Census 2011 data summarized in Table 4.17 shows that most households in the area have access to flush toilets that are connected to a sewerage system, except in Ward 30 (33.9%) where several households use pit latrines with ventilation (23.7%), pit latrines without ventilation (12%) or have no access to sanitation (16.4%).

Table 4.17 Sanitation systems (households, source: Census 2011) (Equispectives, 2020).

Source of Energy for Lighting	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
None	2,439	4	9	501	811	31
Flush toilet (connected to sewerage system)	66,500	5,253	3,882	1,035	55,096	2,282
Flush toilet (with septic tank)	4,167	34	47	260	1,458	133
Chemical toilet	562	17	1	4	442	3
Pit toilet with ventilation (VIP)	9,772	2	24	724	1,591	10
Pit toilet without ventilation	8,913	53	9	366	9,376	20
Bucket toilet	994	4	5	75	396	11
Other	751	8	11	75	885	207
Unspecified	401	18	19	17	352	31
Total	94,499	5,394	4,008	3,057	70,406	2,728

Equispectives (2016) indicated in 2016 that in Thusanang in Ward 30, many households did not have access to toilet facilities and people used the bushes outside the residential areas. Some parts of Thusanang had pit toilets without ventilation or flush toilets connected to a septic tank. Households in Hillshaven and Glenharvie have flush toilets connected to a sewerage system, although it is not always functional. The farming community have flush toilets connected to a septic tank or French drains. The mine village and residence have flush toilet systems installed. Community Survey 2016 shows an increase in both the Rand West City LM and the Merafong City LM in households with access to flush toilets connected to a sewerage system. In the Rand West

City LM, households with access to flush toilets connected to a sewerage system have increased from 70.4% in 2011 to 73.4% in 2016 and the Merafong City LM, it has increased from 78.3% in 2011 to 85.6% in 2016.

In 2016, more than half of the households in the Rand West City LM (57.0%) and the Merafong City LM (63.3%) have indicated that the main toilet facility is in the dwelling or house, while 38.9% of households in the Rand West City LM and 34.2% of households in the Merafong City LM have indicated that the toilet facility is in the yard. About a third of the households in the Rand West City LM (33.8%) and the Merafong City LM (39.0%) have indicated that they share their toilet facility with other households. The majority of households in the Rand West City LM (66.9%) and Merafong City LM (75.4%) have indicated that they maintain the toilet facilities themselves while the municipality maintains the toilet facilities of 21.4% of households in the Rand West City LM and 15.3% in the Merafong City LM. Less than two-thirds of households in the Rand West City LM (61.8%) and the Merafong City LM (60.8%) rated the overall quality of toilet/sanitation services as good.

Community Survey 2016 shows that the number of households with no access to a sanitation system in both the local municipalities has decreased since 2011, as has the number of households that have pit toilets with or without ventilation, except in the Merafong City LM where the number of households with pit toilets with ventilation has increased slightly. The number of households that uses a bucket toilet that is collected by the municipality has more than tripled. The majority of households in the Rand West City LM (95.8%) and the Merafong City LM (97.5%) have access to toilet facilities within their dwelling or yard.

4.7 Human Behavioural Characteristics

4.7.1 Daily Activities and Time Spent Outside

In Hillshaven, the children at the crèche play outside for up to an hour, while the children in the primary school have an hour sports period in the afternoons when they spend time outside. Some adults play netball or soccer and practise in the afternoons. There are no recreational facilities for teenagers, with the result that they wander around in the streets, hang out at the old sports fields, old houses and dumpsites. Some people occasionally go fishing in the dams in the area. Many people spend time in shebeens or sit at the filling station or car wash and drink.

In Thusanang, many adults spend time outside drinking, socialising, gambling or dancing. The males have soccer games on Sundays, and there are a few males in the area that occasionally go out to hunt. Some females work as part of the Government's Community Works Programme. Females also cook, clean, sing and do washing outside. There is no entertainment for young adults and teenagers. Drinking and unplanned pregnancies is a challenge in the community. Some teenagers drop out of high school. There are gangs in the community, but they do not seem to pose a challenge for the community. Small children play outside, often in the streets. Small children often have no food. The crèche can only accommodate children with parents that can pay for it, as it requires money for its running expenses.

Farmers and their employees spend at least 8 to 10 hours outside, busy with farming activities. The farmers with families have indicated that their families also spend a lot of time outside.

It can be anticipated that people at the mine village and residence spend time outside when they are socialising. In the mining village, there are many vegetable gardens and people were observed working in the garden. People were also observed walking in the streets.

4.7.2 Eating Habits

Food consumption is to a great extent based on personal preferences and beliefs and not only varies between households in an area but sometimes also within a household. Affordability plays a role in the types and quantities of food consumed. Residents in the study area have not been interviewed to explore their food consumption and the discussion in this section is based on trends that emerged from similar studies in other areas.

In higher-income households, residents tend to source almost all their food from formal stores such as supermarket chains, greengrocers or butcheries that need to meet certain legal standards to operate. In areas where there are high levels of poverty, such as Thusanang, households tend to buy from informal stores or someone in the area that farm with a specific product such as vegetables, poultry, eggs or milk, or they have their own food garden. In some communities access to, or availability of, water poses a barrier to maintaining a food garden. In some instances, access to land can also be a challenge. Equispectives (2016) indicated in 2016 that the school in Hillshaven had a feeding scheme for needy children, while in Thusanang residents often did not know where their next meal would come from. Some people harvested medicinal plants such as roots, African potatoes and aloes in the field.

Households in high-income areas tend to consume a greater variety of food products and tend to include processed food to a greater extent (based on personal preferences). Households that live in poverty tend to have meals that underwent little processing. Bread and/or pap (porridge made of maize meal) is a staple and is usually consumed with vegetables such as tomatoes, onions, spinach or cabbage. Potatoes and beans are also consumed often in some households. Meat is included depending on income, and then it is usually chicken with red meat consumed on special occasions. Some households can only afford chicken once a week or less. Households that live in poverty often do not have access to a fridge and need to choose food that does not require refrigeration and any meat need to be consumed as soon as possible.

Food preparation depends on the dish that is prepared as well as the available facilities. Households that paraffin, wood or coal tend to cook outside at a designated area.

The volume of food consumed depend on personal preference as well as the available means to buy food. Community Survey 2016 indicates that 16.8% of people in the Rand West City LM and 25.3% of people in the Merafong City LM ran out of money to buy food during the past 12 months, while 52.5% of people in the Rand West City LM and 61.6% of people in the Merafong City LM who ran out of money to buy food, ran out of money to buy food for five or more days during the past 30 days. Approximately 11.8% of the population in the Rand West City LM and 18.7% of the population in the Merafong City LM have indicated that they have skipped a meal in the past 12 months, and 56.9% of these people in the Rand West City LM and 63.5% in the Merafong City LM skipped a meal for five or more days during the past 30 days.

4.7.3 Agricultural Activities

4.7.3.1 General

Equispectives (2020) reported that the Census 2011 on agricultural activities is unreliable and, therefore, not used. Similar studies that were conducted in other areas show that urban areas households in areas with high levels of poverty are more likely to engage in agricultural activities, especially if they are located close to open land, which is often found in mining areas or around tailings facilities. Some households in urban areas engage in agricultural activities. Some only for the enjoyment thereof or to produce their own organic food, while for others it is a livelihood strategy.

The agricultural activity with the highest incidence in these areas is food gardening, which consists mostly of growing vegetables such as spinach, cabbage, onions, tomatoes, beetroot, carrots, potatoes, beans, maize and pumpkin. In many township areas, there are a lot of fruit trees, mainly peach and apricot, that were planted some years ago as part of a government project and it may be the case in some of these areas as well. Food gardens are mainly grown in backyards, However, those living on the edge of an open space will often use space in this area to grow vegetables or crops on a greater scale. Cattle or goats are usually also kept on the edge of an open space. Most schools in areas with high levels of poverty have food gardens to provide for learners to some extent.

Equispectives (2016) indicated in 2016 that the incidence of food gardens was low in Hillshaven and that there were a small number of residents that were unemployed that grew vegetables for a living. In Thusanang, most people had their own food gardens but the availability of water and the quality of the soil were challenges. At the time there were approximately 3 to 4 large food gardens in the area. Root vegetables grown in food gardens included turnips, beetroot, carrots, onions, potatoes and sweet potatoes, while leafy vegetables included lettuce, cabbage and spinach. Other vegetables included peas, beans, maize, pumpkin, tomatoes, peppers and chillies. A wide variety of fruit trees were found such as peach, fig, loquat, apricot, lemons, prickly pear, grape, mulberry, plum and apple. Crops grown commercially in the area included maize, beans, sunflower and soya. Sorghum, oats, sugar graze (a sorghum hybrid) and babala (a type of grass) were grown as feed for the cattle, while one of the emerging farmers planned to start growing garlic commercially. Vegetables grown commercially in the area included spinach, cabbage and watermelon.

In Thusanang, residents kept cattle on the outskirts of the area, while other livestock included horses, chickens, ducks, geese and turkeys. In Hillshaven and Glenharvie municipal by-laws did not allow for the keeping of livestock, but some chickens were observed. The commercial farmers farmed mainly with cattle. Some had sheep but were phasing them out, while one farmer was farming with cattle. The quality of water in the area was a challenge for cattle farmers. One of the emerging farmers had a dairy on the farm and there were plans for a piggery.

In Census Survey 2016, 6.5% of households in the Rand West City LM and 8.1% of households in the Merafong City LM have indicated that they are involved in agriculture. Although Census Survey 2016 has asked where the households operate their agricultural activities (farmland,

communal land, backyard, etc) and what the main purpose of the activity was, this data was not released in the public domain. A smaller proportion of households in the Rand West City LM (2.4%) and the Merafong City LM (2.2%) have indicated that they own poultry or livestock.

In terms of the type of farm practice for crop farming, 17.8% of households in the Rand West City LM that farm with crops have indicated that in Census Survey 2016 that they use irrigation, 37.2% use dry land, and 44.9% use both irrigation and dry land. In Merafong City LM, 22.2% of households that farm with crops have indicated that in Census Survey 2016 that they use irrigation, 34.7% use dry land and 43.1% use both irrigation and dry land.

4.7.3.2 Food Production

The incidence of food gardens in Hillshaven is low. There are a small number of unemployed residents that grow vegetables to make a living (see Figure 4.32). These include:

- Root vegetables (e.g., turnips, beetroot, carrots, onions, potatoes);
- Leafy vegetables (e.g., lettuce, cabbage, spinach);
- Other vegetables (e.g., peas, maize, pumpkin, tomatoes); and
- Fruit trees (e.g., peach, apricot, lemons, figs, prickly pears, grapes, mulberry, loquat, plum, apple).



Figure 4.32 Food gardens in Hillshaven (Equispectives, 2016).

The incidence of fruit trees is quite high and are found in many gardens. Indications are that residence harvest/use aloes in the area for medicinal purposes. Very few food gardens were observed in Glenharvie. Fruit trees observed include peach, lemon, prickly pear, mango, avocado and loquat.

Most of the Thusanang residents have their food gardens (see Figure 4.33, Figure 4.34, Figure 4.35, Figure 4.36, and Figure 4.37). The availability of water and the quality of the soil has been mentioned as challenges. There are approximately 3 to 4 large food gardens in the area. Residents have indicated that they grow the following:

- Root vegetables (e.g., turnips, beetroot, carrots, onions, potatoes, sweet potatoes);
- Leafy vegetables (e.g., lettuce, cabbage, spinach);
- Other vegetables (e.g., peas, beans, maize, pumpkin, tomatoes, peppers, chillies); and
- Fruit trees (e.g., peach, loquat, figs).



Figure 4.33 Food gardens in Thusanang (Equispectives, 2016).



Figure 4.34 More food gardens in Thusanang (Equispectives, 2016).

Crops grown as part of commercial farming in the area include maize, beans, sunflower and soya. The crops go to a nearby silo for distribution. One of the farmers farms commercially with vegetables and some of the emerging farmers also grow vegetables commercially. Vegetables grown commercially include spinach, cabbage and watermelon.



Figure 4.35 Even more food gardens in Thusanang (Equispectives, 2016).



Figure 4.36 Irrigation of food gardens in Thusanang (Equispectives, 2016).

The commercial vegetables are sold at the market and to President Supermarket. Sorghum, oats, sugar graze (a sorghum hybrid) and babala (a type of grass) are grown as feed for the cattle. One of the emerging farmers plans to start growing garlic commercially. Some of the farms have their own vegetable gardens (see Figure 4.37), and the following have been mentioned:

- Root vegetables (e.g., turnips, beetroot, carrots, onions, shallots, kale Chou Moullier, potatoes, sweet potatoes);
- Leafy vegetables (e.g., lettuce, cabbage, spinach);
- Other vegetables (e.g., peas, beans, pumpkin, tomatoes, chillies); and
- Fruit trees (e.g., peach).

The South Deep Gold Mine adopted farmers at the old 'Murray & Roberts' site does not plant any crops and they do not have any food gardens. One of the emerging farmers has a peach orchard that they plan to grow commercially (see Figure 4.38). Bambanani Fruits are located adjacent to

the R28, close to the Sibanye-Stillwater Ezulwini mine. They produce peaches, apples, nectarines and plums commercially. They test their products regularly for safety. No food gardening has been observed in the mine residence. However, almost all the yards in the mining village have vegetables growing. The following have been observed:

- Leafy vegetables (e.g., spinach, cabbage, lettuce);
- Root vegetables (e.g., garlic in large volumes); and
- Fruit trees (e.g., peach).



Figure 4.37 Crops in Thusanang (Equispectives, 2016).



Figure 4.38 Food garden at emerging farmers (Equispectives, 2016).

4.7.3.3 Livestock

The Westonaria LM by-laws do not allow for the keeping of livestock in the residential areas. A few chickens have been observed in Hillshaven and Glenharvie (see Figure 4.40). Thusanang residents keep cattle on the outskirts of the area. Other livestock includes goats, sheep, pigs, chickens and horses (see Figure 4.41 and Figure 4.42). No livestock has been observed in the Mine village and residence.



Figure 4.39 Orchard at emerging farmers (Equispectives, 2016).



Figure 4.40 Chickens in Hillshaven (Equispectives, 2016).



Figure 4.41 Pigs in Thusanang (Equispectives, 2016).



Figure 4.42 Livestock in Thusanang (Equispectives, 2016).

The farmers at the old 'Murray & Roberts' site farm with cattle. They also have horses, chickens, ducks, geese and turkeys for personal use (see Figure 4.43). They sell cattle when the market is good, and sometimes send cattle home to the area where they came from.



Figure 4.43 Poultry at South Deep farmers (Equispectives, 2016).

The commercial farmers farm mainly with cattle (see Figure 4.44). Some still have sheep, but it has become less viable over time and some farmers are phasing out sheep. One of the farmers also has a game on his farm. In the area closest to the R28, some farmers complain that their cattle fail to thrive, despite being fed well due to the quality of the water (see Figure 4.45).

Some farmers keep the cattle for their meat, and they mostly go to the abattoir in Vanderbijlpark, or where they can get the best price at the time. One of the emerging farmers has a dairy on the farm. The milk is sterilised and removed from the farm in a refrigerated container. There are plans for a piggery in the pipeline as well. For personal use, farmers have indicated that they keep sheep, chickens, geese and turkeys, although the geese are unlikely to be eaten (see Figure 4.46).



Figure 4.44 Cattle on a commercial farm (Equispectives, 2016).



Figure 4.45 Cattle on a farm near R28 (Equispectives, 2016).



Figure 4.46 Chickens on a farm (Equispectives, 2016).

4.8 Summary

The communities closest to the South Deep Gold Mine include Hillshaven, Glenharvie, Thusanang, the South Deep Gold Mine staff village and residence, as well as several commercial and subsistence farms. Other nearby towns such as Fochville and Westonaria are outside the potential zone of influence of the South Deep Gold Mine.

The South Deep Gold Mine is surrounded by farms and is in an area where several other gold mining companies are operating. The first study exploring human behaviour related to the different pathways of exposure in the communities surrounding the mining activities of the South Deep Gold Mine as conducted towards the end of 2016 (Equispectives, 2016). From the available information, it appears that little has changed in the area, except for large-scale retrenchments that took place at the South Deep Gold Mine towards the end of 2018. A downward trend in employment in the gold mining industry over the past decade and retrenchments at gold mining companies during this time resulted in greater unemployment in the area which in turn led to increased levels of poverty in the area. As such the community groups in the area can be considered as more vulnerable than when the 2016 study was conducted.

Table 4.18 summarises the socio-economic, demographic and human behavioural data for the area surrounding the South Deep Gold Mine, as compiled and presented in Equispectives (2020) [ENREF 1](#).

Table 4.18 Summary of the socio-economic, demographic and human behavioural data for the area near the South Deep Gold Mine (Equispectives, 2020).

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
<i>Location</i>	Hillshaven Glenharvie	Thusanang	Areas around mine	Thusanang
<i>Population distribution</i>	Hillshaven and Glenharvie – not known, but it appears that the majority of residents belong to the Black population group.	All from the Black population group.	The majority of the commercial farmers belong to the White population group, while all the emerging farmers belong to the Black population group.	All from the Black population group.
<i>Family structure</i>	Not known for all the areas, but most likely family groups in Hillshaven and Glenharvie.	Mix between families and adults that live alone, or with a family member, friend or partner.	Mixed. The farmers mostly live on the farm with their families. Most of the farmworkers that live on the farm live alone. On some farms, there may be farmworkers living with their families.	As per the area where they live.
<i>Community activities</i>	Most likely similar to the previous report: Hillshaven – people do not spend a lot of time outside. Children play outside or practise sport for about an hour. Teenagers tend to wander in the street. Many	People spend time outside gardening, drinking, socialising, gambling, occasionally hunting. Small children play in the streets.	People spend the whole day outside, busy with farming activities.	Most of the day outside.

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
	people socialise at a tavern or close to the filling station. Not many people observed outside. Glenharvie – not known. Most likely similar to Hillshaven.			
<i>Access to water</i>	Access to piped water inside a dwelling.	Access to tap outside the yard in the street. Water that is pumped from Hillshaven is kept in tanks.	Boreholes and rainwater tanks.	As per the area where they live.
<i>Energy sources</i>	Electricity. Alternative energy sources for lighting (mostly due to financial constraints) are paraffin and candles. Alternative sources for cooking are paraffin and gas, while wood is an alternative source of energy for heating.	Energy for lighting – paraffin, candles and solar panels. Generators to run equipment such as TV. Energy for cooking – paraffin, wood, gas, corn cobs, solar devices. Energy for heating – wood.	Electricity. Wood sometimes used for cooking and heating.	As per the area where they live.
<i>Refuse removal</i>	Refuse removed by the municipality or private company.	Refuse removed by the municipality or burnt by residents.	Varies. Some remove to landfill; others burn or bury.	As per the area where they live.
<i>Sanitation</i>	Flush toilets connected to the sewerage system.	Pit toilets without ventilation, flush toilets connected to septic tanks or no toilet facilities.	Flush toilets connected to septic tanks or French drains.	As per the area where they live.
<i>Dwellings</i>	Hillshaven – brick structures with mostly tiled roofs Glenharvie – brick structures with mostly zinc roofs (except in newly built area)	Zinc structures.	Brick structures with tiled or zinc roofs.	As per the area where they live.
<i>Source of food</i>	Mostly shops, in areas with high poverty people tend to grow their own food. Most likely similar to the previous report. Previously some residents got milk from a dairy farm in the area	Spaza shop Own vegetable garden/food garden in the community Roots and small game from the field	Shops in town Meat mostly from farm Vegetables from a shop in town, own vegetable garden, a farmer in the area Farmworkers source roots and plants as well as small game from the field	As per the area where they live
<i>Food production</i>	Most likely similar to the previous report: Low incidence of food gardens in Hillshaven and Glenharvie, but there is a high incidence of fruit trees. Root vegetables: turnips, beetroot, carrots, onions, potatoes. Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, maize, pumpkin, tomatoes Fruit trees: peach, apricot, lemon, fig, prickly pear,	Most likely similar to the previous report: High incidence of food gardens. Root vegetables: turnips, beetroot, carrots, onions, potatoes, sweet potatoes Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, beans, maize, pumpkin, tomatoes, peppers, chillies Fruit trees: peach, loquat, fig	Most likely similar to the previous report: Commercially farmers grow maize, beans, soya and sunflower. One farmer grows spinach, cabbage and watermelon commercially. Another farm has an orchard that they intend to use commercially (not known whether this has materialised). Feed for livestock grown include sorghum, oats, sugar graze and babala.	As per the area where they live.

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
	grape, mulberry, loquat, plum, apple, mango, avocado		Vegetables for own use: Root vegetables: turnips, beetroot, carrots, onions, shallots, kale chou moullier, potatoes, sweet potatoes Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, beans, pumpkin, tomatoes, chillies Fruit trees: peach	
<i>Categories of food</i>	Most likely similar to the previous report: Most foods are store-bought. A dairy farm from the area delivered milk to Hillshaven. Some people in Hillshaven nought vegetables from people in the community with food gardens. In Glenharvie hawkers sold vegetables and live chickens.	Most likely similar to the previous report: Many residents made their own steamed or baked bread. Vegetables were sourced from their gardens when available and there was a vegetable truck that visited the community. Vegetables like onions, spinach, tomatoes and potatoes were consumed daily. The chicken was consumed about once a week and was sourced from a farm in the area. Other vegetables consumed once a week or more, but not daily, included beans, pumpkin and sweet potato. When a vegetable was in season, more would be consumed at the time, but not necessarily during the rest of the year, such as maize. Some harvested medicinal plants such as roots, aloe and African potatoes. Some hunted and would consume animals such as rabbits and small antelopes.	Most likely similar to the previous report: Eating habits vary. Some farmers consumed red meat, milk, eggs, spinach, cabbage, tomatoes, onions, beans, carrots, pumpkin, sweet potatoes and potatoes more than once a week to daily. Other farmers could not afford to eat meat daily, and their food consisted of cabbage, spinach, onions, mealie pap and eggs with chicken more than once a week. Some baked their own bread once or twice a week.	As per the area where they live.
<i>Food preparation</i>	Variety of methods used.	Variety of methods used.	Variety of methods used.	As per the area where they live.
<i>Volume of food</i>	Depends on personal preference In lower-income areas, it also depends on the availability	Depends on the availability of food	Depends on personal preference	As per the area where they live
<i>Livestock</i>	Chickens in Hillshaven and Glenharvie.	Cattle, goats, sheep, pigs, chickens and horses	Commercial farmers farm mainly with cattle. Some have sheep. Cattle are for meat and dairy.	As per the area where they live
<i>Social infrastructure</i>	Most likely similar to the previous report: Hillshaven - Primary school	Most likely similar to the previous report: Crèche, home-based care	Most likely similar to the previous report: In residential areas. Pub,	As per the area where they live.

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
	and two crèches, mobile clinic, supermarket, a library at school, a small gym, sports facilities at school Glenharvie –Crèches, combined school, play area and sports complex.	centre, clinic, sports fields, play area, spaza shops and taverns.	filling station and takeaway store in the area.	
<i>Socio-economic status</i>	Most likely similar to the previous report: Hillshaven – residents owned or rented dwellings, therefore in most households there was at least one person that was employed. Residents reported high levels of unemployment, especially among youth. Alcohol and drug abuse were a challenge. Glenharvie – not known but was anticipated to be similar to Hillshaven.	Most people are unemployed and are living under the poverty line.	Varies – some are comfortable, while others battle to make a living.	As per the area where they live.



5 Radiological Baseline Conditions

5.1 General

The area and associated facilities that constitute the South Deep Gold Mine have a long history with different operating mining houses and companies over the past 70 to 80 years. As environmental management and radiation protection improved over this period, so did the radiological monitoring and surveillance programmes, as well as the data acquisition in support of public radiation protection. This led to a large body of information available in support of the 2020 South Deep Gold Mine RPSA.

The purpose of this section is to provide an overview of the radiological conditions associated with the mining and mineral processing infrastructure of the South Deep Gold Mine, as well as the environmental media (e.g., soil, water, sediment, and air) near the South Deep Gold Mine. Note that the quality and completeness of the data varies. For some media full-spectrum, radioanalysis results are available, while for others only the total chemical uranium concentrations are reported. However, in all instances, the most complete and recent datasets are presented.

The section is structured as follows. The radiological conditions associated with the surface infrastructure and operational features associated with the South Deep Gold Mine are presented in Section 5.2, while the available environmental monitoring data is presented in Section 5.3.

5.2 Radioactivity Associated with the South Deep Gold Mine

5.2.1 General

As described earlier, the primary source from which the radionuclides present at a typical gold mining and mineral processing operation originate is the naturally occurring radioactive material (NORM) brought to the surface from underground through the mining activities. The NORM associated with the ore is transferred to the products and residues generated as well as to the environment through releases of gases, solids and liquids from the operational activities and surface infrastructure.

The radiological conditions associated with the surface infrastructure and operational features are of particular importance to the quantification of the radioactivity released into the environment from the South Deep Gold Mine. Radiological release rates specific to these facilities are of importance to quantify the release of radioactivity into the environment. These release rates provide input into the environmental pathway modelling, notably the atmospheric, surface water and groundwater pathways.

The operational features at the South Deep Gold Mine that are known to contain or emit naturally occurring radionuclides into the environment under normal operating conditions were sorted into categories according to infrastructure type (see Section 2.2). Table 5.1 summarises those features.

Table 5.1 Surface infrastructure and operational features of the South Deep Gold Mine known to contain or emit naturally occurring radionuclides to the environment.

Source Category	Individual Sources Included
Tailings Storage Facilities (TSFs)	South Deep TSF 1
	South Deep TSF 2
	Doornpoort TSF
Waste Rock Dumps (WRDs)	South Shaft Complex WRD
	Twin Shaft Complex WRD
	Industrial Waste Site
Ventilation Shafts	South Shaft Complex Ventilation Shaft
	Twin Shaft Complex Ventilation Shaft
Minerals Processing Facilities	South Deep Gold Processing Plant
Surface Water Dams	South Deep TSF 1 RWD
	South Deep TSF 2 RWD
	Doornpoort RWD
	Pollution Control Dams

Differences between the listed features in terms of their operational conditions, the amount of radioactive material they contain, as well as their physical parameters, imply that they do not release radioactivity in the same way. For example, waste rock material may be shown to contain little naturally occurring radionuclides and consequently are not considered radioactive in terms of regulatory standards. Similarly, some metallurgical processing plants that may process material with a comparatively high radionuclide content do not emit significant quantities of this material to the environment and consequently are considered insignificant from a public radiation exposure perspective.

5.2.2 Tailings Storage Facilities

5.2.2.1 General

Of the three TSFs at the South Deep Gold Mine, only the Doornpoort TSF is operational at present. The South Deep TSF 1 and South Deep TSF 2, have been dormant for several years and has been rehabilitated with the establishment of vegetation on the side slopes. Recovery and re-processing of tailings from South Deep TSF 1 are currently being undertaken, with the residue resulting from the reprocessing deposited at the Doornpoort TSF or used in the backfill plant.

5.2.2.2 Dormant TSFs

Full-spectrum radioanalysis results of tailings samples available for the 2020 South Deep Gold Mine RPSA, is from the tailings produced at the South Deep metallurgical plant. These tailings were previously deposited to the South Deep TSF 1 and South Deep TSF 2. Table 5.2 summarises the full spectrum radioanalysis results of tailings samples collected over the period 2002 to 2008. The date on which each sample was collected and the corresponding Necsa radioanalysis laboratory report numbers are also listed.

Table 5.2 Summary of full-spectrum radioanalysis results for samples of washed residual (tailings) collected from the South Deep metallurgical plant between 2002 and 2008.

Sample Date	Necsa Report Number	U-238	U-234	Ra-226	Pb-210	U-235	Th-232	Ra-228	Th-228	U	Th
		Bq.kg ⁻¹								µg.g ⁻¹	
2002/01/31	RA-04045	704	-	767	714	32.4	29.2	< 110	58.9	57	7.19
2003/02/17	RA-04735	697	-	753	651	32.1	29.6	-	19.3	56.4	7.29
2003/05/19	RA-04962	735	-	679	738	33.8	29.8	40.4	28.3	59.5	7.34
2003/08/18	RA-05131	676		667	721	31.1	28.9	34.6	36.4	54.7	7.13
2004/11/08	RA-05927	623	-	604	-	28.7	25.9	25.8	41.9	50.5	6.39
2005/05/10	RA-06336	462	-	585	-	21.3	26.8	47.3	23.9	37.4	6.61
2006/02/13	RA-06882	888	-	762	1,030	40.9	36.6	-	29.9	71.9	9.01
2006/08/04	RA-07311	593	-	595	786	27.3	23.8	53.7	23.6	48	5.85
2006/09/27	RA-07481	474	-	466	604	21.8	26.2	32.3	26.1	38.4	6.45
2007/05/24	RA-08019	657	-	597	793	30.3	35	-	23.5	53.2	8.62
2008/05/16	RA-08907	638	644	590	753	29.4	25.4	25	25.9	-	-
2008/05/20	RA-09018	470	474	379	356	21.7	22.4	< 40	18.5	-	-

More recently, composite samples made up of several individual samples collected from the South Deep metallurgical plant were submitted to the Necsa radioanalysis laboratory for full spectrum analysis. Table 5.3 summarises the analysis results of samples collected in three consecutive years (2014 to 2016). The Necsa radioanalysis laboratory reports are attached as Appendix A.

Note that no new full-spectrum analysis results (2017 to 2020) of the South Deep metallurgical plant is available for use in the 2020 South Deep Gold Mine RPSA.

Table 5.3 Summary of full-spectrum radioanalytical results for tailings samples collected from the South Deep metallurgical plant (2014 to 2016).

Necsa Report Number	RA15466-01	RS2015-3509-01	RS2016-0504-01	RS2016-2550-01
Date	06/06/2014	23/12/2015	15/04/2016	20/07/2016
Radionuclide	Bq.kg ⁻¹			
U-238	678	675	684	621
U-234	683	681	690	626
Ra-226	668	< MDA (40)	645	642
Pb-210	922	933	1120	1,170
U-235	31.2	31.1	31.5	28.6
Th-232	37.6	35.2	31.9	28.9
Ra-228	26.2	< MDA (79)	< MDA (110)	< MDA (100)
Th-228	678	< MDA (100)	33	< MDA (150)
Gross α	7,080	5,880	7,110	5,280
Gross β	2,660	5,880	2,700	2,590

5.2.2.3 Doornpoort TSF

Full-spectrum radioanalysis results of two tailings samples collected from the Doornpoort TSF are available for use in the 2020 South Deep Gold Mine RPSA, a summary of which is presented in Table 5.4. A direct comparison with the results in Table 5.2 and Table 5.3 suggest that these concentrations are significantly lower than historical values, which can be attributed to the fact that the Upper Elsburg Formation is now mined as opposed to the Ventersdorp Contact Reefs.

Note that no new full-spectrum analysis results (2017 to 2020) of the Doornpoort TSF is available for use in the 2020 South Deep Gold Mine RPSA.

Table 5.4 Summary of full-spectrum radioanalytical results for two tailings samples collected in 2016 from the Doornpoort TSF.

Necsa Report Number	RS2016-0501-01	
Date	28/02/2016	
Radionuclide	Bq.kg ⁻¹	
U-238	35.2	33.2
U-234	35.5	33.5
Ra-226	21	46.7
Pb-210	<MDA	<MDA
U-235	1.62	1.53
Th-232	27.2	30.2
Ra-228	<MDA	<MDA
Th-228	32	23

5.2.3 Waste Rock Dump

Both the South Shaft Complex WRD and the Twin Shaft Complex WRD are dormant at present, with the area where the former is located rehabilitated to a large extent (see Section 2.4.4.1). In 2012, the South Deep Gold Mine had a surface gamma survey conducted of the rehabilitated area, from which the waste rock has been removed (see Figure 5.1 for location) (PSI Risk Consultants, 2012). The objective of the survey was to delineate areas of the site where residual concentrations of radionuclides may exceed regulatory guidelines and identify where subsequent rehabilitation should be focussed.

The surface gamma survey found elevated levels of radioactivity in the southern part of the rehabilitated area (see Figure 5.2). Samples collected of the top layer of soil over the rehabilitated area were analysed for the total uranium concentration. Results of the sampling and analysis confirm the results of the survey, indicating higher concentrations of uranium in the southern portion of the site.

PSI Risk Consultants (2012) calculated uranium specific radioactivity values to estimate the radioactivity content of the soil samples. These values are extrapolated to total activity, assuming secular equilibrium among parent and daughter radionuclides to derive values that can be compared to regulatory levels. The results show that all but one of the 40 soil samples could exceed the regulatory threshold level of 0.5 Bq.g⁻¹.

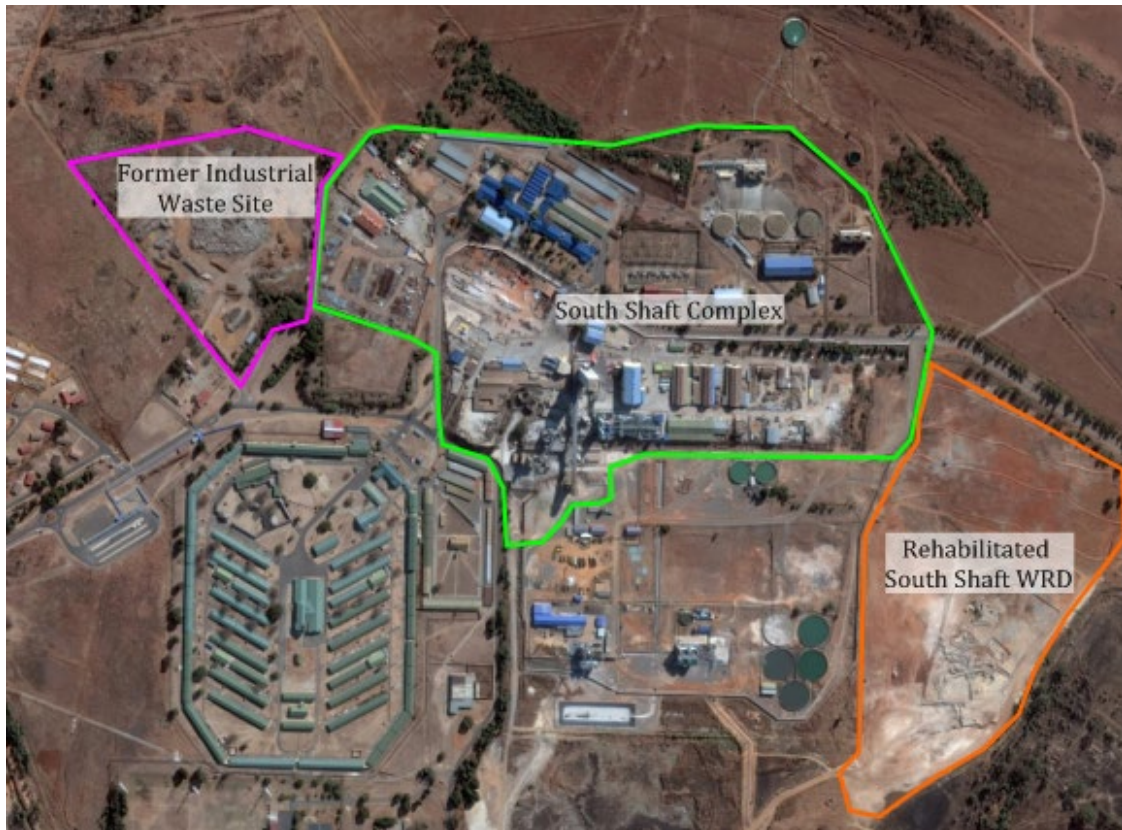


Figure 5.1 Areas used for the storage of waste rock near the South Shaft Complex.

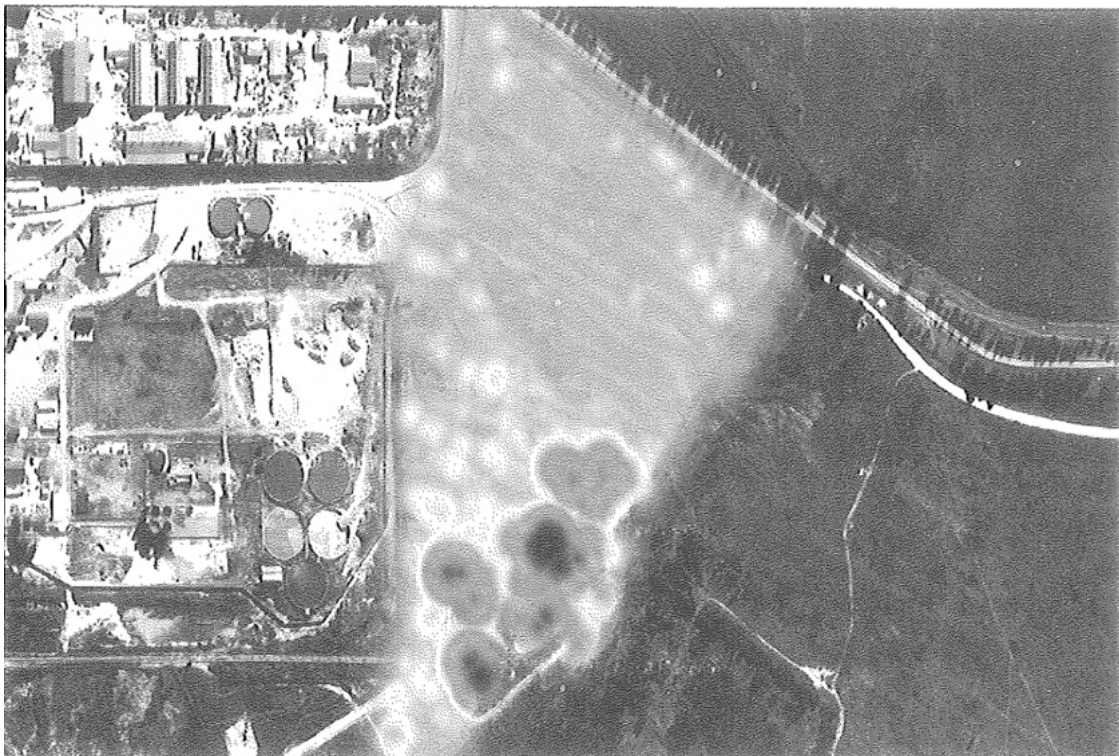


Figure 5.2 Graphical representation of surface gamma survey results (PSI Risk Consultants, 2012).

Another area where waste rock is currently being stored is on a former industrial waste disposal site, located to the west of the South Shaft complex (see Figure 5.1). Here the South Deep Gold Mine had a surface gamma survey conducted in 2010 (ChemRad, 2010).

The purpose of the surface gamma survey was to determine the presence, if any, of radioactive contamination on the surface and immediate sub-surface of the waste disposal site. The measurements collected on the surface indicated several areas of exhibiting activities above the 0.5 Bq.g^{-1} threshold level. The survey report indicated that the material present on-site comprise building rubble, domestic waste, glass and polymeric containers, mining slime, etc., which has been dumped on the site over many years (ChemRad, 2010).

A graphical representation of the results (see Figure 5.3) indicates three major areas of contamination above 0.5 Bq.g^{-1} , whilst a classed post map chart (See Figure 5.4) identifies, in addition to the three major areas, several other minor areas of contamination above 0.5 Bq.g^{-1} .

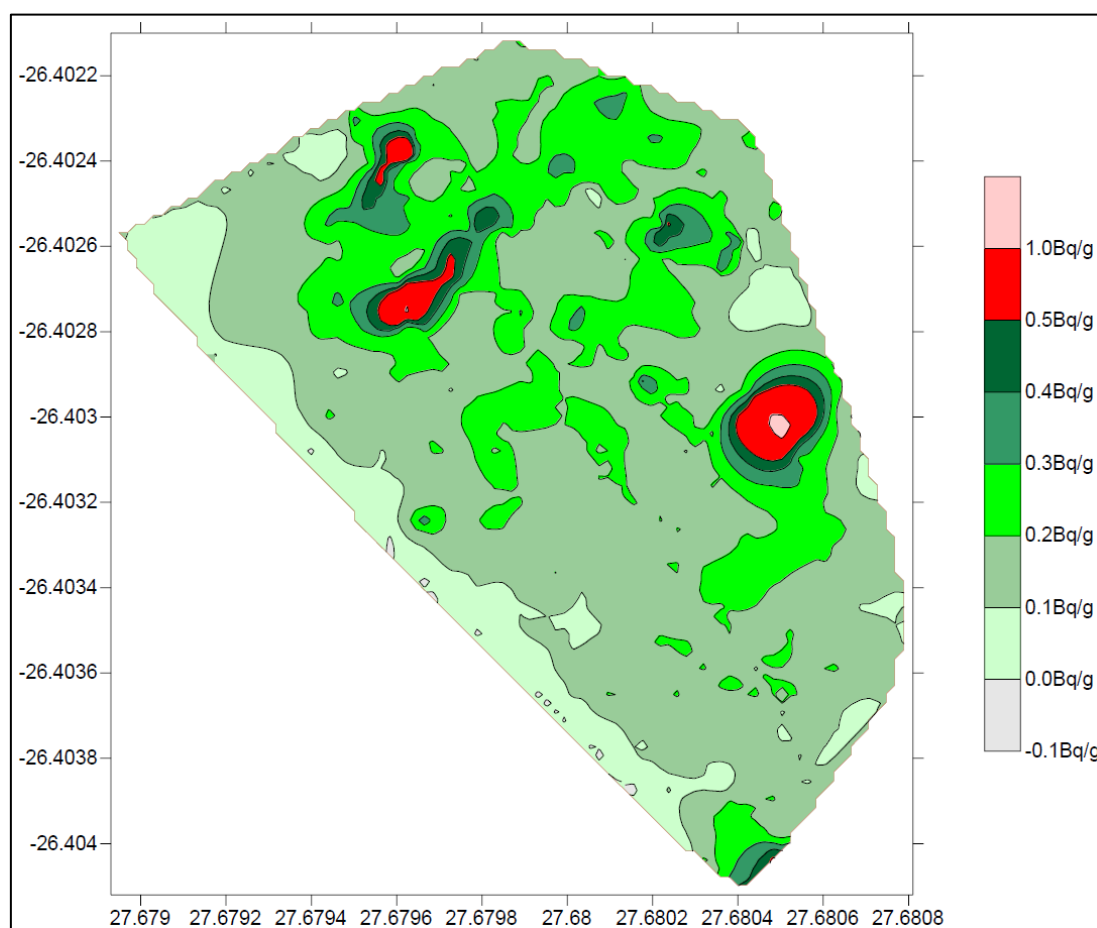


Figure 5.3 Gamma survey contours (ChemRad, 2010).

The Twin Shaft Complex WRD was also the subject of a more recent radiological survey, initiated in support of a safety assessment for workers involved in the recovery of the waste rock. The purpose of this assessment was to determine the specific activity of the waste rock and also to determine whether the waste rock could be exempted or excluded from regulatory control (Arconsa, 2016). The South Deep Gold Mine waste rock is recovered for use in road building and aggregate in a concrete mix.

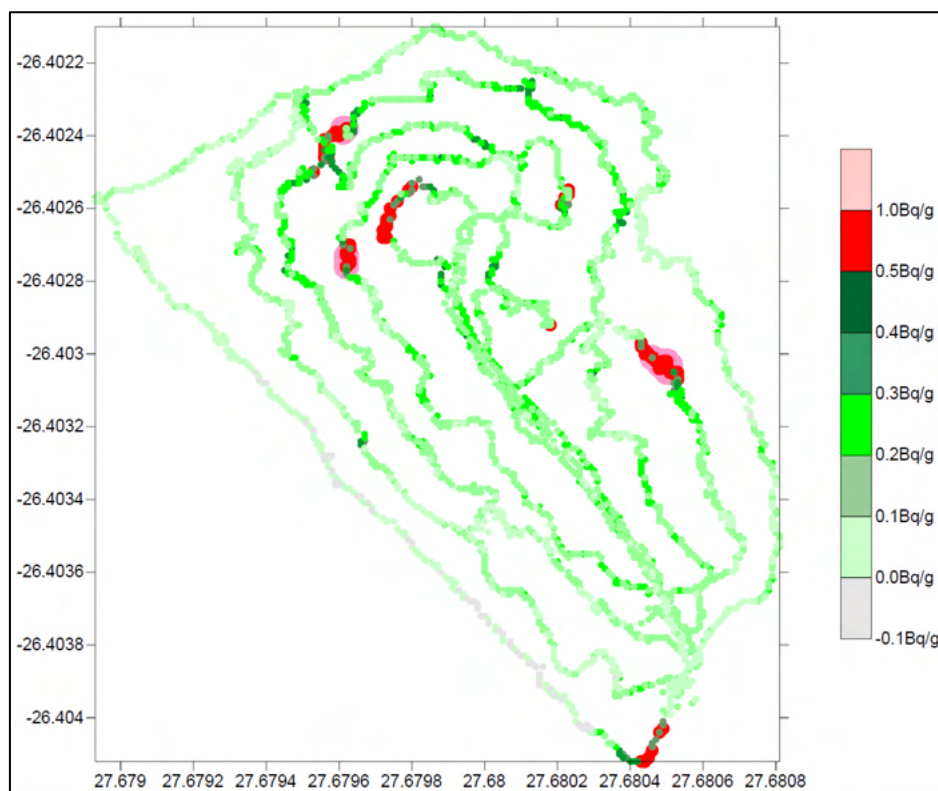


Figure 5.4 Gamma survey measured points (ChemRad, 2010).

Individual samples of waste rock were obtained from the Twin Shaft Complex WRD and five composite samples were compiled and submitted to the Necsa Radioanalysis laboratory for full spectrum analysis. Table 5.5 summarises the results for the five composite samples, while the Necsa laboratory report is attached as Appendix A. A surface gamma survey conducted around the footprint of the WRD indicated varying activity concentrations of uranium and thorium in the soil. Table 5.6 summarises the minimum, maximum and average of the measured activity concentrations and dose rate (Arconsa, 2016).

Note that no new full-spectrum analysis results (2017 to 2020) of waste rock material is available for use in the 2020 South Deep Gold Mine RPSA.

Table 5.5 Summary of nuclide specific analysis results of five composite waste rock samples from the Twin Shaft WRD (Necsa Report No RS2015-0179-01, sample date 26 February 2015).

Radionuclide	SD1	SD2	SD3	SD4	SD5
	Bq.kg ⁻¹				
U-238	643	4,520	67.4	11.6	12.7
U-234	649	4,560	68	11.7	12.8
Ra-226	457	1,020	60	<37	<39
U-235	29.6	208	3.1	0.535	0.586
Th-232	45.8	119	59.6	8.28	8.97
Ra-228	51	<140	<86	<68	<67
Th-228	34	110	51	<83	<100

Table 5.6 Summary of values measured in a surface gamma survey of the area surrounding the Twin Shaft WRD (Arconsa, 2016).

Parameter	U activity	Th activity	Dose Rate
	Bq.kg ⁻¹		nSv.h ⁻¹
Minimum	0	0	6.2
Maximum	804.05	70.24	521.7
Average	58.42	30.77	66.84

5.2.4 Radon Exhalation Rates

The presence of Ra-226 in the tailings and waste rock materials may result in the exhalation of Rn-222 (radon) from these materials. In 1998, samples of waste rock and tailings were collected from the South Deep Gold Mine by Parc Scientific (Parc Scientific, 1998), who measured the flux of radon from these materials. The samples collected are of waste rock from the South Shaft WRD and the South Deep TSF 1 (indicated as Tailings Dam East in the report) and the South Deep TSF 2 (indicated as Tailings Dam West).

Table 5.7 summarises the average, standard deviation, minimum and maximum radon flux values (Bq.m⁻².s⁻¹) as measured for the three facilities, together with the resulting average source term values (Bq.s⁻¹).

Table 5.7 Summary of the average, standard deviation, minimum and maximum radon flux values as measured for three sources at the mine (Parc Scientific, 1998).

	Waste Rock Dump	Tailings Dam (West)			Tailings Dam (East)		
		Edge	Beach	Pond	Edge	Beach	Pond
	Average Radon Flux [Bq.m ⁻² .s ⁻¹]						
Average	0.096	0.268	0.116	0.306	0.225	0.302	0.112
Standard Deviation	0.022	0.069	0.053	-	0.104	0.061	-
Minimum	0.069	0.162	0.168	-	0.044	0.218	-
Maximum	0.123	0.461	0.063	-	0.361	0.364	-
Source Term [Bq.s ⁻¹]	4.399E+03	1.962E+05			1.530E+05		

The seasonal variation of the radon exhalation from the tailings storage facilities and waste rock dumps occurs mostly due to moisture content variations as a result of rainfall. Table 5.8 presents a summary indicating the influence of seasonal variations is on radon exhalation, which compared the measurements of an intermediate and wet source with those of a dry source.

Table 5.8 Wet and intermediate source terms in terms of total source strength, and fractional reduction concerning dry season values (Parc Scientific, 1998).

Source	Dry [Bq.s ⁻¹]	Intermediate [Bq.s ⁻¹]	Reduction	Wet [Bq.s ⁻¹]	Reduction
Tailings Dam (West)	1.96E+05	1.46E+05	-26 %	8.57E+04	-56 %
Tailings Dam (East)	6.72E+05	7.93E+05	18 %	4.50E+05	-33 %

Another method that can be used to estimate radon exhalation rates from TSFs and WRDs is to use correlation coefficients derived from measured data collected from similar materials. Parc Scientific (2006) summarised radon exhalation rates measured from residue storage facilities in the South African gold mining industry and reported coefficients, derived from regression lines fitted through these data points that can be used to estimate radon exhalation rates from TSFs and WRDs. For this purpose, Parc Scientific (2006) 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 or waste rock 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 derived diffusion coefficients therefore also represent average and maximum values. The equations and coefficients used for deriving radon exhalation rates for the South Deep Gold Mine TSFs are as follows (Parc Scientific, 2006):

Average: Radon exhalation rate (Bq.m⁻².s⁻¹) = (0.000554 ± 0.000014) x Ra-226 (Bq.kg⁻¹)

Maximum: Radon exhalation rate (Bq.m⁻².s⁻¹) = (0.000609 ± 0.000017) x Ra-226 (Bq.kg⁻¹)

Similarly, the equation and coefficients that can be used for estimating radon exhalation rates from the waste rock are:

$$\text{Radon exhalation rate (Bq.m}^{-2}\text{.s}^{-1}\text{)} = (0.000376 \pm 0.000043) \times \text{Ra-226 (Bq.kg}^{-1}\text{)}$$

The average and maximum radon exhalation rates estimated from the measured radium concentration in the tailings material of the three TSFs and waste rock from the South Shaft WRD are listed in Table 5.9. The calculated values are slightly higher than the measured data presented in Table 5.7 but correlate well with the average measured values.

Table 5.9 Estimated average and maximum radon exhalation rates for the South Deep Gold Mine tailings and waste rock.

Material	Average	Maximum
	Bq.m ⁻² .s ⁻¹	
Tailings	0.355	0.391
Waste rock	0.107	0.135

5.2.5 Materials Handling

Ore brought to the surface from the underground workings is crushed screened and milled at the South Deep metallurgical plant. To determine the radionuclide content of the materials handled, samples of the ore are periodically collected and submitted to the Necsa Radioanalysis laboratory for full spectrum analysis.

Two sets of analysis results from these periodic ore samples are available for use in the 2020 South Deep Gold Mine RPSA. Table 5.10 summarises the results of ore samples collected from 2002 to 2008.

Table 5.10 Summary of full-spectrum radioanalysis results for samples of leach feed (milled ore) collected from the South Deep metallurgical plant between 2002 and 2008.

Sample Date	Necsa Report Number	U-238	U-234	Ra-226	Pb-210	U-235	Th-232	Ra-228	Th-228	U	Th
		Bq.kg ⁻¹								µg.g ⁻¹	
2002/01/31	RA-04045	840	-	778	873	38.7	35.2	< 110	44.5	68	8.66
2003/02/17	RA-04735	670	-	727	576	30.8	26.3	-	23.6	54.2	6.48
2003/05/19	RA-04962	681	-	700	740	31.4	28.5	-	39.4	55.1	7.02
2003/08/18	RA-05131	624	-	670	621	28.8	26.1	54.2	29.6	50.5	6.44
2004/11/08	RA-05927	588	-	645	-	27.1	25.7	22.3	39.3	47.6	6.33
2005/05/10	RA-06336	421	-	468	-	19.4	28.3	-	39.1	34.1	6.97
2006/02/13	RA-06882	833	-	718	856	38.4	31.1	23.5	37.5	67.5	7.67
2006/08/04	RA-07311	491	-	444	654	22.6	22.8	-	26.8	39.7	5.61
2006/09/27	RA-07481	441	-	415	530	20.3	25.8	34.6	21.5	35.7	6.35
2007/05/24	RA-08019	697	-	741	953	32.1	30.8	27.3	24.3	56.4	7.58
2008/05/16	RA-08907	688	693	653	739	31.7	28	30.3	21	-	-
2008/05/20	RA-09018	626	631	567	684	28.8	24.8	< MDA	29.4	-	-

More recently, composite samples made up of several individual samples of milled ore collected from the South Deep metallurgical plant were submitted to the Necsa radioanalysis laboratory for analysis. Table 5.11 summarises the results of the analysis for samples collected in three consecutive years (2014 to 2016). The Necsa laboratory reports are attached as Appendix A.

Note that no new full-spectrum analysis results (2017 to 2020) of crushed ore material is available for use in the 2020 South Deep Gold Mine RPSA.

Table 5.11 Summary of full-spectrum radioanalytical results for samples of milled ore from the South Deep metallurgical plant (2014 to 2016).

Necsa Report Number	RA15466-01	RS2015-3509-01	RS2016-0504-01	RS2016-2550-01
Date	06/06/2014	23/12/2015	15/04/2016	20/07/2016
Radionuclide	Bq.kg ⁻¹			
U-238	578	690	651	688
U-234	583	696	656	693
Ra-226	588	655	633	685
Pb-210	1,900	973	952	1,250
U-235	26.6	31.8	30	31.7
Th-232	30.5	36.2	29	31.8
Ra-228	31	60.2	< MDA (99)	< MDA (90)
Th-228	14	23	61	< MDA (120)
Gross α	5,240	6,110	7,640	6,500
Gross β	2,090	3,050	2,720	2,620

5.2.6 Upcast Ventilation Shafts

Upcast ventilation shafts (or vent shafts) release air circulated through the underground workings to the atmosphere. Particulates and radon gas are released with this air from the underground working environment, which have the potential to expose members of the public living downwind of the release points to radioactivity. Radon concentrations measured in return air from underground workings is used to estimate the radon released from upcast ventilation shafts. Table 4.12 lists the average and maximum values collected over 32 days (1 August 2016 to 2 September 2016). Assuming a flow rate of $1,200 \text{ m}^3.\text{s}^{-1}$ and $1,250 \text{ m}^3.\text{s}^{-1}$ for the South Shaft and Twin Shaft ventilation shafts, respectively, the radon exhalation rates equate to $1,606,042 \text{ Bq.s}^{-1}$ and $238,878 \text{ Bq.s}^{-1}$, respectively.

Note that no new radon concentrations released from the ventilation shafts are available for use in the 2020 South Deep Gold Mine RPSA.

Table 5.12 Average and maximum radon concentrations measured in the South Deep Gold Mine upcast ventilation shafts (1 August 2016 to 2 September 2016).

Parameter	Units	Twin Shaft	South Shaft
Average	Bq.m^{-3}	191.1	1,338.4
Maximum		221.9	1,427.6

5.2.7 Water Management Infrastructure

Return water collected from the TSFs is regularly sampled to determine radionuclide concentrations. Monitoring data dating back to 2003 was made available for the 2020 South Deep Gold Mine RPSA. The results represent monitoring data collected from the return water dams at South Deep TSF 1 (SIDA3) and South Deep TSF 2 (SIDA8), the mining process water dam (SIDA19) at the Twin Shaft Complex, as well as the Doornpoort TSF RWD (SIDA22 and SIDA23). Figure 5.5 shows that location of the monitoring points, while Table 5.18 presents the coordinates for the monitoring points.

Table 5.13 to Table 5.17 summarises the historical monitoring data, which includes both regular monitoring data and sporadic samples. The Necsa radioanalytical laboratory reports are attached as Appendix A to this report.

5.3 Radiological Conditions in the Environment

5.3.1 Surface Water

The South Deep Gold Mine sample several surface water bodies for radionuclide contamination as part of the surface water monitoring programme. Figure 5.5 shows the locations of the surface water monitoring points, while Table 5.18 presents the coordinates for the monitoring points. Table 5.20 to Table 5.27 summarises radioanalytical data from seven surface water monitoring points, for which radiological data is available. The Necsa radioanalytical laboratory reports are attached as Appendix A to this report.

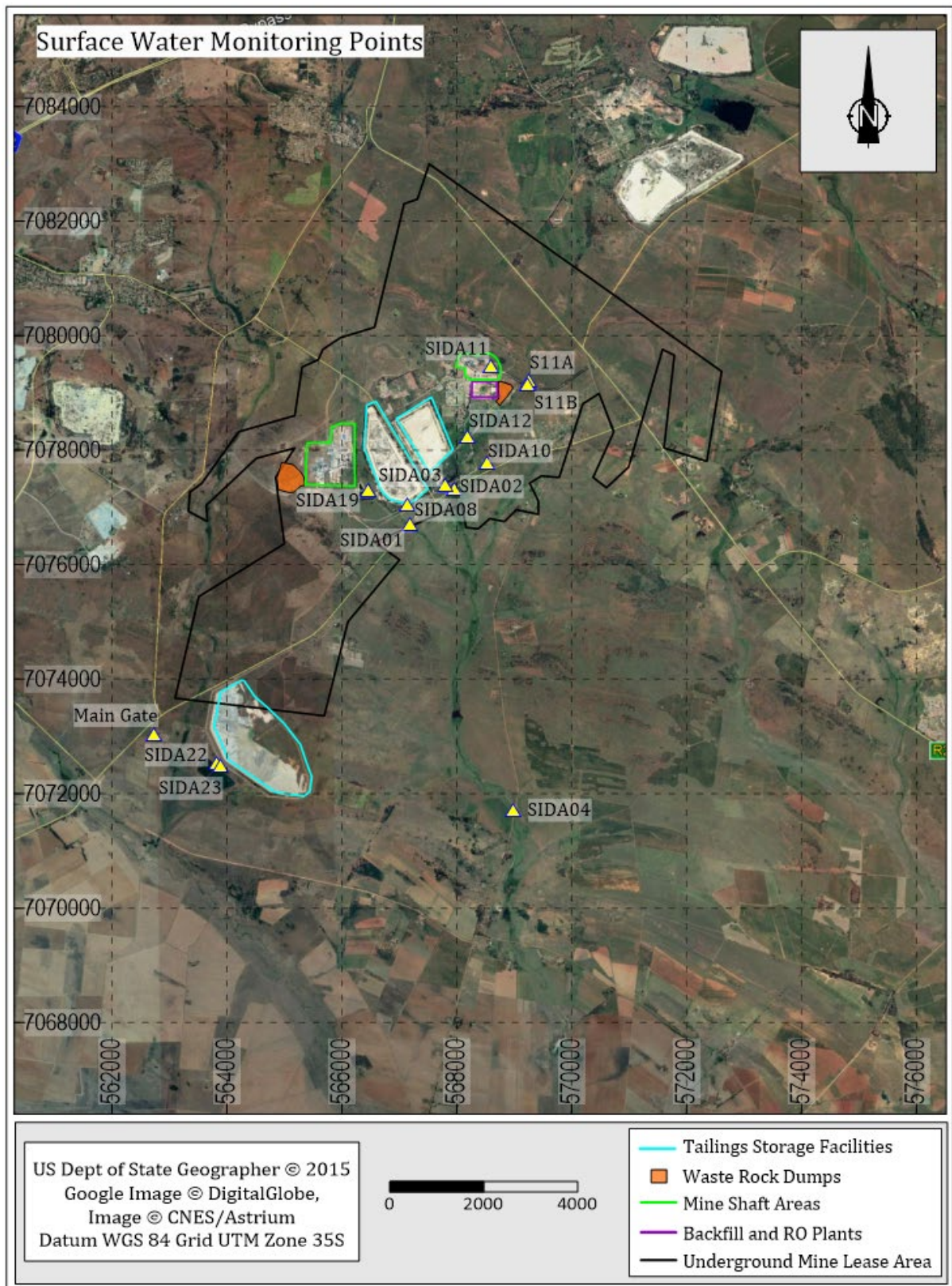


Figure 5.5 Map showing radiological surface water monitoring points at the South Deep Gold Mine.

Table 5.13 Summary of nuclide specific data for surface water samples from monitoring point SIDA03.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-06467	31 May 2005	1,750	1,660	2.49	260	5.46	5.46	75.2	14	23.9	4.22	2.6	6.8
RA-06863	29 November 2005	3,470	3,080	2.06	191	9.6	9.6	150	9.73	4.46	4.43	4.74	20.7
RA-06964	25 January 2006	3,610	3,260	69.9	198	6.58	6.58	169	11.1	13.5	4.57	2.28	3.44
RA-07446	26 July 2006	1,050	982	2.71	141	-	9.32	48.2	9.17	9.73	4.96	7.96	0.602
RA-07312	06 June 2006	647	619	17.5	119		1.56	29.8	7.25	8.27	6.99	3.85	1.97
RA-07662	17 October 2006	1,420	1,260	0.285	144		3.49	65.3	19.9	-2.33	4.23	5.34	1.17
RA-07997	22 March 2007	585	528	3.92	186			26.9	10.1	25	3.94	1.34	7.06
RA-08199	14 June 2007	429	434	46.8	132			20.7	10.1	12.1	7	7.72	12
RA-08850	04 February 2008	6,080	5,400	621	165		16.8	283	29.5	15.1	43	24.4	14.3
RA-11123	27 January 2011	3,860	3,520	84	333	41.1	8.28	172	38.9	9.92	5.23	8.12	2.64
RA-11431	18 March 2011	1,350	1,240	135	174	-	7.8	59.9	18.3	13.6	35.6	10.3	6.77
RA-11623	09 June 2011	522	464	57.9	143	4.2	4.2	24	12.6	-0.19	3.1	9.39	1.2
RA-12381	25 November 2011	2,710	2,480	27.6	136	12.9	12.9	139	22.4	17.2	4.71	8.89	4.75
RA-12784	21 June 2012	5,470	4,940	-	-	-	28.3	263	-	-	-	-	-
RA-13375-02	31 July 2012	1,510	1,330	140	103	-	10.5	69.6	17.7	5.98	9.91	15.8	2.67
RA-13644-01	01 October 2012	11,700	10,200	881	117	-	6.22	539	31.3	30	45	20.9	6.87
RA-14049-02	05 March 2013	3,850	3,290	281	107	46.4	0.72	177	63.6	12.1	10.4	15.4	24.8
RA-14557-02	05 July 2013	1,090	989	17	192	8.9	0.779	50.3	10.3	4.55	2.06	3.07	< MDA
RA-15228-01	22 November 2013	1,840	1,690	57.5	257	31.1	-4.7	84.9	40.6	11.8	4.7	12.8	4.74
RA-15475-01	21 February 2014	3,960	3,480	42.5	217	16.4	16.4	182	35.4	-14	2.01	9.22	2.3
RA-15934-02	30 May 2014	346	335	60	178	6.4	6.4	15.9	9.2	-8	9.8	21.6	<MDA
RS2015-3507-02	23 October 2015	859	743	42.8	207	5.38	5.38	39.6	5.1	2.51	9.35	6.51	5.47
RS2016-4963-01	07 November 2016	729	790	60.6	85	8.15	8.15	33.6	1.2	< MDA	14.1	8.03	1.1
RS2016-5538-01	12 December 2016	1,440	1,420	28.8	150	3.56	3.56	66.2	15.3	< MDA	17.4	4.7	< MDA
RS2019-1421-01	02 April 2019	2,140	1,820	36.6	150	14.8	< MDA	98.7	4.85	2.38	4.15	5.17	1.1

Table 5.14 Summary of nuclide specific data for surface water samples from monitoring point SIDA08.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-06467	31-May 2005	214	212	1.46	178	6.6	58.6	10.4	5.66	24.6	2.24	1.8	30.3
RA-06863	29-November 2005	1,020	943	10.2	161	2.8	2.8	47.1	14.4	3.87	6.35	4.8	-
RA-06964	25-January 2006	109	96.7	4.23	199	6.15	6.15	5.01	6.84	9.43	2.52	7.49	0.325
RA-07446	26-July 2006	100	112	0.0085	105	-	2.9	4.62	4.94	-1.55	1.1	1.44	0.999
RA-07312	06-June 2006	65.8	82.7	5.07	109	-	125	3.03	11.6	15.9	4.61	12.3	2.44
RA-07662	17-October 2006	107	106	0.63	93.9	-	1.79	4.94	14.3	6.91	0.312	4.97	4.97
RA-07997	22-March 2007	102	107	4.68	-	-	-	4.67	12.7	-	3.71	17.5	-
RA-08199	14-June 2007	287	288	24.2	167	-	-	13.2	12.8	14.2	-0.747	3.66	3.78
RA-08850	04-February 2008	2,060	1,830	237	164	-	1.96	94.5	39	-6.9	727	44.3	7.87
RA-11123	27 January 2011	8,670	7,390	41.5	188	58.3	3.84	399	36.5	42.4	5	6.41	3.1
RA-11431	18 March 2011	387	368	30.6	164	-	5.59	19.2	18.4	10.2	1.6	15.2	2.27
RA-11623	09 June 2011	3,950	3,500	44.7	179	15.2	15.2	182	26.8	8.11	1.96	5.84	2.13
RA-12381	25 November 2011	172	156	14.1	161	2.12	2.12	7.91	28.1	9.11	<MDA	7.88	11.4
RA-12784	21 June 2012	399	361	-	-	-	27.9	18.4	-	-	-	-	-
RA-13375-02	31 July 2012	87	94.8	83.5	165	-	14.4	4	9.3	-16	3.59	17.9	< MDA
RA-13644-01	01 October 2012	273	275	84	160	-	4.2	12.6	16.5	8.61	5.73	3.56	0.92
RA-14049-02	05 March 2013	1,010	970	89.1	141	23.4	4.5	46.4	29.2	21	12.3	35.9	22.7
RA-14557-02	05 July 2013	165	179	41	139	7.5	1.35	9.6	29.2	-0.26	1.5	6.04	0.79
RA-15228-01	22 November 2013	5,760	4,950	368	9.12	5.87	5.87	265	60.5	-1.3	39.9	23	3.82
RA-15475-01	21 February 2014	3,400	3,110	179	151	35	0.94	157	45.8	23.5	17	11.7	4.94
RA-15934-02	30 May 2014	258	225	44	185	9.3	0.95	11.9	6.2	-9.2	3.2	34.5	0.87
RS2015-3507-02	23 October 2015	349	359	23.4	40.5	16.2	16.2	16.1	6.2	-3	2.62	13.6	< MDA
RS2016-4963-01	07 November 2016	205	228	39.1	112	12.4	12.4	9.44	9.07		14.4	19.9	0.97
RS2016-5538-01	12 December 2016	1,900	1,770	57.8	201	19	2.9	95.6	36.1	< MDA	36.3	20.5	< MDA
RS2018-1045-01	08 March 2018	880	893	91	288	-	-	40.5	20.3	< MDA	18.2	5.5	2.1
RS2019-1421-01	02 April 2019	344	316	29.3	108	27.3	< MDA	15.8	12.2	< MDA	23.1	12.6	3.08

Table 5.15 Summary of nuclide specific data for surface water samples from monitoring point SIDA19.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-04989	09 April 2003	11,600	9,940	9.61	563	2.07	2.07	533	133	109	7.82	30.5	1.29
RA-05115	30 June 2003	1,940	1,740	6.7	4.28	5.51	5.51	89.4	24.7	41.8	5.58	2.03	-0.583
RA-12176	29 September 2011	27,300	23,600	21.2	144	7.15	7.15	1,260	6.69	0.99	2.33	3.68	1.9
RA-12784	21 June 2012	5,990	5,510	-	-	-	2.08	276	-	-	-	-	-
RA-13375-02	31 July 2012	7,980	7,270	92.1	79	-	4.25	368	25.3	-6.5	5.19	11.8	1.1
RA-13644-01	01 October 2012	4,360	4,130	92.1	300	-	1.4	201	10.4	-25	5.29	4.67	0.77
RS2016-5538-01	12 December 2016	1,360	1,170	18	112	10.1	10.1	66.7	21.2	3.97	4.3	7.71	1.9
RS2018-1045-01	08 March 2018	30.9	264	37.9	59.3	-	-	1.42	12.2	< MDA	39.8	4.5	2

Table 5.16 Summary of nuclide specific data for surface water samples from monitoring point SIDA22.

Necsa Report Number	Sample Delivery 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
RS2018-1045-01	08 March 2018	35.6	64.8	12.8	5.64	-	6.8	1.64	3.6	0.37	3.36	2.3	< MDA
RS2019-1417-01	02 April 2019	612	614	34.2	21.4	24.4	< MDA	28.2	10.2	< MDA	3	3.6	5.2

Table 5.17 Summary of nuclide specific data for surface water samples from monitoring point SIDA23.

Necsa Report Number	Sample Delivery 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
RS2018-1045-01	08 March 2018	34.4	63.8	9.23	8.84	-	14	1.58	5.6	7.43	< MDA	9.09	29.1
RS2019-1421-01	02 April 2019	285	262	64.9	23.2	33.5	< MDA	13.1	5.2	< MDA	10.4	8.08	10.1

Table 5.18 Location coordinates for selected South Deep Gold Mine surface and process water monitoring points.

Monitoring Point	Coordinates	
SIDA01	-26.42825	27.67367
SIDA02	-26.42272	27.68138
SIDA03	-26.42210	27.67983
SIDA04	-26.47333	27.69205
SIDA08	-26.42515	27.67340
SIDA10	-26.41857	27.68715
SIDA11	-26.40333	27.68777
SIDA12	-26.41450	27.68377
S11A	-26.40547	27.69440
S11B	-26.40615	27.69412
Main Gate	-26.46169	27.62928
SIDA19	-26.42300	27.66650
SIDA 22	-26.46606	27.64031
SIDA 23	-26.46664	27.64097

5.3.2 Groundwater

Samples from selected boreholes in the South Deep Gold Mine groundwater monitoring network are periodically sent for full-spectrum radioanalysis. Table 5.19 lists the coordinates of the monitoring points, while Figure 5.6 shows the locations of the groundwater monitoring points for which results are available.

Table 5.28 to Table 5.35 summarises the radioanalytical data from the four groundwater monitoring points, dating back to 2003. The Necsa analytical reports are attached as Appendix A to this report.

Table 5.19 Location coordinates for selected South Deep Gold Mine groundwater monitoring points.

Monitoring point	Coordinates	
SIDA05	-26.48523	27.68868
SIDA06	-26.47387	27.69373
SIDA07	-26.42210	27.67983
SIDA09	-26.42253	27.67864
SIDA13	-26.46242	27.63108
SIDA14	-26.46569	27.63518
SIDA15	-26.46569	27.63516
SIDA16	-26.45943	27.63555
SIDA17	-26.45940	27.63554
SIDA18	-26.46228	27.62997
SIDA20	-26.42503	27.67189
SIDA21	-26.40430	27.69039
SD39	-26.46776	27.63680
SD42	-26.46444	27.64032

Table 5.20 Summary of nuclide specific data for surface water samples from monitoring point SIDA01.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-07446	26-Jul-06	52.3	44.2	0.0931	9.72	-	-0.882	2.41	7.65	1.45	24.6	16.3	-0.439
RA-07312	06-Jun-06	80.8	97.1	9.3	9.86	-	0.695	3.72	32	4.82	5.6	9.1	-0.285
RA-07662	17-Oct-06	308	414	1.09	6.03	-	1.04	14.2	-0.914	2.67	7.97	12.4	3.44
RA-07997	22-Mar-07	22.6	38.7	4.14		-	-	1.04	2.06	-	1.82	5.43	-
RA-08199	14-Jun-07	68.1	87.3	35.8	7.47	-	-	3.14	30.7	-0.305	5.32	15.6	2.4
RA-08850	04-Feb-08	149	163	9.9	13.1	-	9.36	6.86	6.9	2.1	2.69	6.63	-0.61
RA-11123	27 January 2011	555	534	38	11.4	3.17	3.17	25.8	1.9	-0.84	0.55	2.7	<MDA
RA-11431	18 March 2011	132	170	39.5	8.41		2.41	6.68	6.94	-2.2	2.89	7.14	0.79
RA-11623	09 June 2011	394	344	47.7	10.8	6.17	6.17	18.1	7.41	0.55	3.2	<MDA	<MDA
RA-12381	25 November 2011	136	151	16	5.26	0.55	0.55	6.28	10.4	2.1	0.42	4.97	13.8
RA-12784	21 June 2012	155	185	-	-	-	2.36	7.15	-	-	-	-	-
RA-13375-02	31 July 2012	78.7	101	52	3.69	-	3.13	4	7.6	0.064	8.12	13.3	0.73
RA-13644-01	01 October 2012	71	131	128	4.12	-	8.09	3.27	2.1	2.6	25.5	7.1	1.9
RA-14049-02	05 March 2013	37.9	95.4	48.2	9.01	8.87	16.4	1.75	1.3	4.2	1.7	3.4	21.8
RA-14557-02	05 July 2013	135	191	262	5.8	7.5	1.03	6.21	15	0.54	43.2	17	< MDA
RA-15228-01	22 November 2013	102	172	47.8	5.69	5.69	5.69	4.7	24.6	-0.52	15.8	13.7	1.3
RA-15476-01	21 February 2014	195	244	94.9	1	-	2.87	8.98	11.6	-1.3	24.3	6.2	0.7
RA-15934-02	30 May 2014	50.7	71.6	41	3.34	21.9	3.11	2.34	33.2	6.76	4.1	7.91	< MDA
RS2015-3507-02	23 October 2015	73	111	30.6	12.9	14.3	14.3	3.36	7.2	0.46	7.1	1.4	< MDA
RS2016-4963-01	07 November 2016	99.9	150	117	3.87	6.08	6.08	4.6	25	< MDA	35	14	< MDA
RS2016-5538-01	12 December 2016	2980	2170	35.5	112	15.2	15.2	137	19.9	9.75	20.2	17.2	< MDA
RS2018-1046-01	08 March 2018	77.3	133	22.7	0.83	-	9.61	3.56	4.9	1.64	3.21	6.37	< MDA
RS2019-1419-01	02 April 2019	149	171	44	2.95	27.3	< MDA	6.84	9.81	< MDA	7.56	5.9	< MDA
RS2018-1046-01	08 March 2018	166	235	19.7	8.04	-	7.65	7.66	13	< MDA	2.4	1.8	< MDA

Table 5.21 Summary of nuclide specific data for surface water samples from monitoring point SIDA02.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-05115	30 June 2003	3,440	3,110	4.83	44.9	45.5	6.08	148	5.97	4.52	8.55	11.5	1.07
RA-04963	31 March 2003	1,350	1,190	9.02	58.8	1.52	1.52	62.2	3.25	-2.35	15.2	7.93	6.54
RA-06335	31 March 2005	2,110	2,200	1.92	53	4.59	4.59	97.2	1.84	-5.9	0.813	1.07	1.33
RA-06467	31 May 2005	1,230	1,180	2.02	73.7	6.05	6.05	56.6	1.93	11.1	0.779	0.64	6.86
RA-06717	28 September 2005	1,590	1,470	3.51	8.84	-	-	73	3.13	1.43	1.9	1.24	0.638
RA-06863	29 November 2005	1,190	1,130	4.1	27.6	6.29	9.29	56	1.96	0.904	2.48	2.01	0
RA-06964	25 January 2006	1,200	1,120	5.67	19.8	1.28	1.28	55.3	-0.184	-0.57	1.12	2.24	0
RA-07446	26 July 2006	797	822	0	17.7	-	4.87	36.7	3.44	1.26	1.09	5.04	0.491
RA-07312	06 June 2006	918	884	1.92	9.97	-	1.44	44.5	3.64	6.67	2.43	4.27	3.83
RA-07662	17 October 2006	1,340	1,290	0.289	23.1	-	0.159	57.6	11.8	1.77	3.43	3.42	5.72
RA-07997	22 March 2007	1,080	975	1.06		-	-	49.5	9.1		5.63	8.41	
RA-08199	14 June 2007	1,550	1,420	31.8	17.6	-	-	69.3	27.8	-0.744	15.7	23.1	0.795
RA-08850	04 February 2008	1,760	1,600	12.4	42.4	-	2.96	81.1	3.74	-8.1	3.84	3.82	< MDA
RA-11123	27 January 2011	545	518	2.6	66.2	2.17	2.17	25.1	8.23	-4	2	1.3	0.63
RA-11431	18 March 2011	793	781	7.16	9.82		1.6	33.6	2.9	0.22	2.8	8.93	0.69
RA-11623	09 June 2011	447	383	34.3	15.3	9	9	20.6	-0.5	0.6	3.34	7.95	<MDA
RA-12381	25 November 2011	1,280	1,170	18.6	8.38	38.5	-17	58.8	12.3	-0.32	1	3.46	1.4
RA-12784	21 June 2012	799	709	-	-	-	0.13	39.6	-	-	-	-	-
RA-13375-02	31 July 2012	1,450	1,420	61.3	6.47	-	3.25	71.6	8.1	-2	2.55	10.7	< MDA
RA-13644-01	01 October 2012	1,780	1,670	38.2	16.5	-	0.93	82.1	8.54	0.2	3	7.16	< MDA
RA-14049-02	05 March 2013	940	877	104	9.6	4.46	6.46	43.3	9.13	2.1	9.8	8.82	14.9
RA-14557-02	05 July 2013	1,610	1,400	71	12.2	16	6.92	74.3	17.1	0.36	12.9	7.73	< MDA
RA-15228-01	22 November 2013	992	919	69.5	7.44	4.4	4.4	45.7	10.1	-1	22.2	8.7	1.1
RA-15476-01	21 February 2014	1,120	1,010	87.4	4.8	-	2.38	51.6	5.3	0.54	21	8.42	2.23
RA-15934-02	30 May 2014	1,370	1,250	45	4.6	20.1	4	63.1	1.1	-1.2	9.27	24.2	< MDA
RS2015-3507-02	23 October 2015	323	310	38.4	6.04	4.66	4.66	14.9	9.9	0.91	2.6	13.3	< MDA

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RS2016-4963-01	07 November 2016	225	217	495	8.22	29.6	29.6	10.4	1.4	0.061	57.4	8.2	< MDA
RS2016-5538-01	12 December 2016	638	591	20	3.63	6.83	6.83	21	14.2	1.39	14.3	4.7	< MDA
RS2018-1046-01	08 March 2018	623	630	35.5	11.2	-	4.6	28.7	13.1	2.86	0.57	1.2	3.3
RS2019-1419-01	02 April 2019	912	824	64.2	6.11	27.3	< MDA	42	5.6	< MDA	5.86	11.7	2.1
RS2018-1046-01	08 March 2018	1,320	1,220	14	20.8	-	22.1	60.6	16.1	< MDA	1.6	6.17	4.9

Table 5.22 Summary of nuclide specific data for surface water samples from monitoring point SIDA04.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-05115	30-June 2003	3,190	2,940	4.5	4.44	7.08	7.08	147	10.1	-0.269	7.2	5.79	-1.12
RA-04963	31-March 2003	930	825	13.4	23.7	-59.5	29.6	42.8	9.3	3.83	9.28	3.27	5.24
RA-05370	24-November 2003	3,350	2,970	14.8	5.62	4.97	4.97	158	2.39	-0.208	6.47	1.72	-1.69
RA-06335	31-March 2005	1,310	1,290	3.29	10.1	2.07	2.07	60.3	8.46	0.00997	1.63	6.44	-0.613
RA-06467	31 May 2005	1,320	1,370	2.21	12.9	4.2	4.2	60.9	7.02	1.01	5.24	4.79	1.6
RA-06717	28 September 2005	2,870	2,830	2.92	35.1	-	-	132	2.13	-4.2	5.05	0.712	2.08
RA-06863	29 November 2005	844	827	27.7	6.07	4.45	4.45	38.9	3.64	-0.514	24.9	1.33	0.581
RA-06964	25 January 2006	1,420	1,300	33.6	3.67	5.85	5.85	65.3	22.3	3.17	11.5	11.5	0
RA-07446	26 July 2006	1,120	1,070	0.552	3.44	-	4.04	47.3	9.99	3.35	4.84	9.74	0.48
RA-07312	06 June 2006	590	587	5.02	12.8	-	3.48	26.3	7.36	3.65	4.02	3.58	1.86
RA-07662	17 October 2006	1,250	1130	0	6.32	-	0.129	57.7	9.9	1.54	2.07	3.43	7.81
RA-08199	14 June 2007	496	460	26.6	13.9	-	-	22.5	8.05	-3.51	2.13	3.49	4.32
RA-08850	04 February 2008	656	572	9.4	5.08	-	8.75	30.2	1.7	-0.42	0.99	2.63	1.6
RA-11123	27 January 2011	290	293	48.9	3.34	1.7	1.7	13.4	1.8	0.53	9.34	7.61	0.87
RA-11431	18 March 2011	1,070	1,000	69.4	7.57	-	1.7	49.3	2.5	-2	4.9	2.7	0.71
RA-11623	09 June 2011	1,400	1,360	22.9	3.52	7.51	7.51	64.6	0.86	-0.22	3.41	2.3	<MDA
RA-12381	25 November 2011	2,060	1,900	26.2	3.18	3.2	-1.4	94.7	14.2	1.1	0.4	5.56	0.61
RA-12784	21 June 2012	869	800	-	-	-	11.6	40	-	-	-	-	-

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-13375-02	31 July 2012	1,530	1,450	45	3.46	-	11.7	70.5	11.2	-0.35	3.9	2.3	< MDA
RA-13644-01	01 October 2012	911	864	31.8	12.3	-	2.1	42	5	-2.4	7.86	11.1	1.1
RA-14049-02	05 March 2013	750	700	53.3	3.26	21	2.32	34.5	19	0.47	2.7	16.4	16.4
RA-14557-02	05 July 2013	1,690	1,500	16	5.46	1.6	0.13	77.6	3.6	0.5	4.13	11.3	< MDA
RA-15934-02	30 May 2014	2,000	1,800	22	10.3	-8.2	34.3	92	3.7	0.93	4.6	15.1	< MDA
RS2015-3507-02	23 October 2015	993	982	49.6	3.15	17.1	1.4	45.7	2.2	10.5	15.4	13	2.53
RS2016-4963-01	07 November 2016	1,080	1,140	28.9	3.02	10.3	10.3	49.7	5.57	0.91	3.98	2.6	< MDA
RS2016-5538-01	12 December 2016	55.3	254	62.3	7.49	8	8	2.54	1.5	0.5	18.1	4.4	< MDA
RS2018-1046-01	08 March 2018	1,460	1,480	19.5	10.4	-	13.8	67.3	7.5	1.6	0.017	3.8	8.14
RS2019-1419-01	02 April 2019	26.7	210	21.3	15.6	7.59	7.59	1.23	1.5	0.43	3.56	1.1	1.7
RS2018-1046-01	08 March 2018	650	681	12	11.6	-	8.37	29.9	19.4	4.76	< MDA	2	11.9

Table 5.23 Summary of nuclide specific data for surface water samples from monitoring point SIDA10.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-11123	27 January 2011	27.6	25.4	20	7.19	7.55	1.7	1.27	-1.3	19.7	2.5	6.85	1
RA-11431	18 March 2011	540	497	14.3	1.19	-	0.25	23.8	3.8	0.2	0.85	4.23	<MDA
RA-11623	09 June 2011	58	55.3	23	5.33	9.67	9.67	2.67	-2.6	-1.5	2.46	8.16	<MDA
RA-12381	25 November 2011	16.2	22.8	79.2	1.5	11.5	-4.8	0.747	21.2	-0.65	2.2	7.02	0.53
RA-12784	21 June 2012	33.6	26.8	-	-	-	0.69	1.55	-	-	-	-	-
RA-13375-02	31 July 2012	42.4	47.6	-	0.61	-	5.77	1.95	-	0.41	-	-	< MDA
RA-13644-01	01 October 2012	13.8	43.6	81.1	2.94	-	2.2	0.637	1.3	-0.46	7.24	9.81	< MDA
RA-14049-02	05 March 2013	21.7	18	38.9	2.65	2.4	2.4	1	8.06	0.59	4.28	7.22	16.7
RA-14557-02	05 July 2013	54.2	89.7	73.2	5.49	17	1.2	2.5	29.2	-2.3	2.6	11.6	< MDA
RA-15228-01	22 November 2013	105	167	197	167	16.9	16.9	4.84	35.2	-7.3	25.9	16.3	7.92
RA-15475-01	21 February 2014	51.6	82.2	32.4	2.88	6.42	6.42	2.37	13	-0.34	3.57	14.1	< MDA
RA-15934-02	30 May 2014	34	36.5	31	3.67	27	0.58	1.56	11	-0.97	11.9	12	0.81

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RS2015-3507-02	23 October 2015	21.5	27.1	83	4.68	6.24	6.24	0.99	1.5	-0.39	10.8	8.17	1.4
RS2016-4963-01	07 November 2016	13.6	36.9	76.3	1.53	5.98	5.98	0.624	6.3	0.39	10.6	3.2	< MDA
RS2016-5538-01	12 December 2016	58	73.6	30.7	4.14	4.59	4.59	2.67	4.6	< MDA	10.6	6.47	< MDA
RS2018-1045-01	08 March 2018	24.8	49	34.1	1.36	-	-	1.14	12	< MDA	33.7	6.33	0.95
RS2019-1421-01	02 April 2019	33.6	27.7	61	2.92	10.3	10.3	1.55	12	< MDA	15.6	13.9	< MDA

Table 5.24 Summary of nuclide specific data for surface water samples from monitoring point SIDA11.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-11123	27 January 2011	5,580	5,190	49.8	181	1.9	1.9	257	-0.18	2.45	5.76	8.29	<MDA
RA-11431	18 March 2011	4,780	4,470	56.8	213	-	7.16	217	3.3	-2.4	1.96	5.81	2.51
RA-11623	09 June 2011	5,720	5,170	13	146	5.42	5.42	263	5.41	-0.5	2.04	5.59	<MDA
RA-12381	25 November 2011	8,600	7,660	20.8	135	2.27	2.27	396	23.3	6.4	1.92	8.5	21.5
RA-12784	21 June 2012	6,520	6,060	-	-	-	2.73	300	-	-	-	-	-
RA-13375-02	31 July 2012	8,730	7,500	-	226	-	10.5	402	-	-3.3	-	-	0.99
RA-13644-01	01 October 2012	6,230	5,590	82.4	307	-	3.41	287	16.2	-7	4.5	5.75	< MDA
RA-14049-02	05 March 2013	3,080	2,850	84.3	267	18	4.6	142	12.4	13.1	0.9	8.86	16.8
RA-14557-02	05 July 2013	11,400	9,970	58.4	352	16	-0.86	525	14	-16	5.3	7.1	3.1
RA-15228-01	22 November 2013	175	251	26	47.9	6.02	6.02	80.8	5	-0.62	3.1	4.9	0.56
RA-15475-01	21 February 2014	3,810	3,700	12	321	5.11	5.11	161	39	-38	15	12	1.8
RA-15934-02	30 May 2014	2,090	1,900	23	206	18	2.82	96.3	12	0.44	5.3	9	2.93
RS2015-3507-02	23 October 2015	3,320	3,060	69.2	131	15	1.5	153	24.6	14.9	34.3	13.6	5.9
RS2016-4963-01	07 November 2016	5,390	4,190	61	190	24.8	24.8	248	9.08		13.4	5.1	< MDA
RS2016-5538-01	12 December 2016	8,540	7,460	23.3	228	27.3	< MDA	393	11	< MDA	11.9	6.9	2.1
RS2018-1045-01	08 March 2018	1,120	1,130	77.2	44.6			51.4	1.5	< MDA	49.2	2.9	14.3
RS2019-1421-01	02 April 2019	1,070	930	27.3	19.6	12.9	12.9	49.3	5.58	0.98	3.34	0.904	0.8

Table 5.25 Summary of nuclide specific data for surface water samples from monitoring point SIDA12.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-11123	27 January 2011	1,320	1,210	29.8	66.7	1.7	1.7	60.6	2.5	-1.9	5.19	5.7	<MDA
RA-11431	18 March 2011	1,550	1,330	18.2	183		4.22	65.2	5.9	-14	2.1	4.5	1.9
RA-11623	09 June 2011	343	333	40.8	17.7	4.76	4.76	15.8	4.26	-1.4	4	7.55	<MDA
RA-12784	21 June 2012	8,190	7,410	-	-	-	27.6	377	-	-	-	-	-
RA-13375-02	31 July 2012	5,100	4,490	84.4	84.9	-	10.3	235	13.2	-7.6	2.6	8.33	1.4
RA-13644-01	01 October 2012	3,200	2,870	143	109	-	1.4	156	3.6	-1.7	6.71	5.9	0.052
RA-14049-02	05 March 2013	1,700	1,490	25.1	36.6	3.03	3.03	78.5	6.3	4.6	2.12	3.14	18.8
RA-14557-02	05 July 2013	890	850	50	44.3	10	0.0821	41	22.8	-3	7.33	8.9	0.69
RA-15228-01	22 November 2013	227	221	126	8.66	1.8	1.8	10.5	28.3	-2.6	23.2	27	0.79
RA-15935-02	13 May 2014	625	505	14	15.3	35.4	-3.1	30	5.8	0.66	3.2	15.9	< MDA
RA-15475-01	21 February 2014	1,100	986	29.8	15	4.53	4.53	50.6	20.1	0.47	7.76	3.1	< MDA
RS2015-3507-02	23 October 2015	182	185	98.8	12.2	7.48	7.48	8.06	28.4	1.4	26.4	18	2.5
RS2016-4963-01	07 November 2016	7.62	18.7	38.7	2.78	10.5	10.5	0.351	25.5	1.52	9.83	3.9	< MDA
RS2018-1044-01	08 March 2018	1040	971	18	36.6	-	-	47.9	15.4	2.65	1.1	4.4	5.29
RS2019-1421-01	02 April 2019	215	206	115	32.1	5.88	5.88	9.91	48.4	< MDA	33.8	50.4	2.12

Table 5.26 Summary of nuclide specific data for surface water samples from monitoring point S11A.

Necsa Report Number	Sample Delivery 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
RA-13644-01	01 October 2012	643	610	255	52.6		1.64	29.6	8.2	-1.8	17.5	3.2	0.039
RA-14049-02	05 March 2013	1170	1070	111	79.4	3	3	53.9	8.9	4.8	11.3	9.2	33.7

Table 5.27 Summary of nuclide specific data for surface water sample from monitoring points S11B and Main Gate.

Necsa Report Number	RS2016-5536-01	RS2016-0500-01
Sample Delivery Date	12 December 2016	09 February 2016
Sampling Point	S11B	Main Gate
Radionuclide	mBq.L ⁻¹	
U-238	1290	26.2
U-234	1370	60.8
Th-230	105	11.7
Ra-226	45.3	1.09
Pb-210	14.7	-
Po-210	14.7	4.18
U-235	61	1.21
Th-227	11.8	10.9
Ra-223	< MDA	1.3
Th-232	14.8	1.75
Th-228	12.3	2.4
Ra-224	< MDA	< MDA

5.3.3 Underground Mine Water

In addition to groundwater abstracted from boreholes, the South Deep Gold Mine monitors radionuclide concentrations in water collected at the different levels of the underground work areas of the mine. As indicated in Section 2.5.2, there are settling ponds and mine water reservoirs located on most levels that collect fissure water and runoff from dust suppression activities underground or that is supplied as drinking water for the underground workers.

Table 5.36 summarises historical nuclide specific results of underground water from levels 49, 56 and 58 taken in 2003. The respective Necsa analytical laboratory reports are attached as Appendix A. More recent samples of water collected from levels 50, 90, 93, 94, 95, 100, 105 and 110 between 2013 and 2017 were sent for full spectrum radiological analysis. Table 5.37 to Table 5.44 summarises the radioanalysis results. The respective Necsa radioanalytical laboratory reports are attached as Appendix A.

5.3.4 Radiological Conditions in Sediment

The South Deep Gold Mine monitors radionuclide concentrations in the sediments of the two surface water streams potentially affected by the operations. Samples from the Leeu Spruit is collected at a point upstream of the Operations (S11B) and adjacent to the former South Shaft WRD (S11A), while sediment from the diverted portion of the Leeu Spruit is collected at monitoring point S6. Sediment in the Kariega Spruit is collected at monitoring point S10, south of the South Deep TSF 1, as well as at the confluence with the Leeu Spruit (S14).

The approximate locations of the four sediment sampling points are presented in Figure 5.7. Table 5.45 summarises the available nuclide specific analytical results. Also included are results

dating back to 2006 for samples of sediment from two points adjacent to the dormant TSFs. The approximate locations of the two sediment sampling points (SD1 and SD10) are presented in Figure 5.7. The respective Necsa radioanalytical laboratory reports are attached as Appendix A.

Note that no new sediment samples and radioanalytical results are available for use in the 2020 South Deep Gold Mine RPSA.

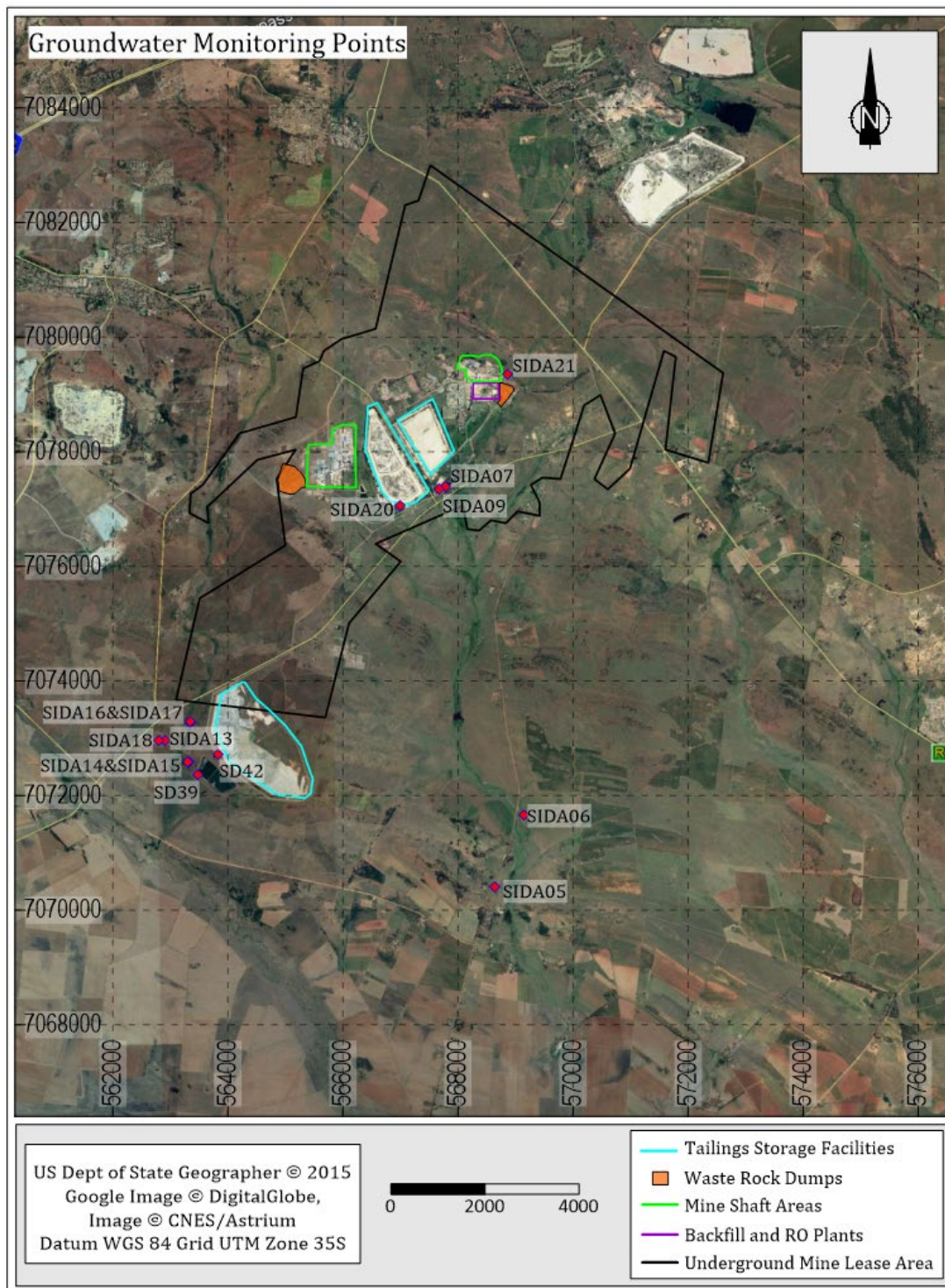


Figure 5.6 Map showing radiological groundwater monitoring points at the South Deep Gold Mine.

Table 5.28 Summary of nuclide specific results for groundwater samples from monitoring point SIDA05.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-05115	30 June 2003	13.7	38.5	1.27	152	5.36	5.36	0.629	12.6	9.22	6.28	9.76	2.34
RA-04963	31 March 2003	17.5	64.3	7.29	139	1.84	1.84	0.808	9.48	-4.2	4.64	5.08	8.22
RA-05370	24 November 2003	5.07	14.5	13.6	112	3.82	3.82	0.233	-1.82	17.4	5.46	1.67	8.35
RA-06467	31-May 2005	3.28	4.68	2.95	109	6	6	0.151	6.69	-1.35	2.57	10.1	8.03
RA-06717	28-September 2005	9.38	16.2	1.67	4.47	-	-	0.432	4.3	0.171	1.32	4.86	-
RA-06863	29-November 2005	10.6	22.2	1.62	124	3.39	3.39	0.488	1.78	2.03	2	6.77	5.62
RA-07446	26-July 2006	16.2	104	1.06	67.2	-	9.13	0.744	10.9	-5.19	5.6	9.38	1.06
RA-07312	06-June 2006	16.7	24.8	5.11	77.9	-	2.69	0.769	4.19	5.22	2.28	2.75	-2.83
RA-07662	17-October 2006	5.19	13.8	1.12	61.2	-	0.0334	0.239	18.8	1.25	4.17	10.5	4.95
RA-11123	27 January 2011	42.7	55.4	18	2.52	4.56	4.56	1.97	0.016	9.86	2.4	6.01	<MDA
RA-11431	18 March 2011	7.06	39.1	110	2.26	-	12.4	0.325	3.1	0.38	16	23	1.91
RA-11623	09 June 2011	37.2	42.5	35.7	3.43	0.54	0.54	1.71	0.087	-0.68	10.7	3.4	<MDA
RA-12381	25 November 2011	9.53	60.7	17.1	2.76	1.7	1.7	0.439	14.3	-0.081	1.3	2.1	1.2
RA-13141-02	21 June 2012	23.4	69.2	24.4	2.99	5.15	-0.51	1.08	0.39	0.6	2.3	3.8	< MDA
RA-13376-01	31 July 2012	75.3	128	58.2	1.1	3.04	3.04	3.47	13.7	1.4	7.2	7.01	3.7
RA-13645-01	01 October 2012	18.5	90.2	235	1.69	-	6.8	0.853	6.31	1.5	8.24	8.87	< MDA
RA-13709-01	17 October 2012	62.8	86.4	38	185	0.77	0.77	2.89	7.09	-0.39	10.8	15.7	0.66
RA-14064-02	04 March 2013	35.7	61.8	33.8	1.45	9.54	15.3	1.64	-0.21	-2	1.1	1.1	24.2
RA-14558-02	05 July 2013	14.4	90.6	71.6	3.06	8	8	0.663	13	0.034	1.9	-1.9	0.72
RA-15228-01	22 November 2013	25.2	83.8	74.1	1.3	4.78	4.78	1.16	18.8	-2.6	33.3	14.5	1.64
RA-15477-02	21 February 2014	22.7	46.7	44.8	1.63	13.7	-7.4	1.04	1.8	0.41	8.74	9.36	< MDA
RA-15934-02	30 May 2014	18.1	53.4	40	4.88	18	3.9	0.833	7.4	-0.21	7.95	23	<MDA
RS2015-3591-02	28 October 2015	12.4	40.4	24.4	0.46	4.84	4.84	0.573	37.7	0.37	10.2	5.77	3.86
RS2016-0506-01	08 February 2016	76.9	92.9	19	0.12	15.1	15.1	3.54	0.68	1.3	6.14	24.4	< MDA
RS2018-1044-01	08 March 2018	93	766	20	221	-	-	4.28	0.64	< MDA	11.9	5.6	49.7
RS2018-5260-01	12 September 2018	78.2	595	24.8	149	35.1	< MDA	3.6	11.4	< MDA	8.88	37.1	9.33
RS2019-1417-01	02 April 2019	106	540	53.8	172	42.1	< MDA	4.86	27.1	< MDA	8.88	42.5	51

Table 5.29 Summary of nuclide specific results for groundwater samples from monitoring point SIDA06.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-05115	30 June 2003	64.3	110	0.974	3.84	4.96	4.96	2.96	7.29	0.361	12.5	9.36	-1.13
RA-05370	24 November 2003	51.4	93.3	8.79	6.1	1.68	1.68	2.37	6.9	-2.38	5.93	9.44	1.14
RA-06335	31 March 2005	71.8	140	3.71	6.05	1.57	1.57	3.31	5.63	-0.759	1.98	4.16	2.23
RA-06467	31-May 2005	51.7	96.6	1.7	4.83	2.96	2.96	2.38	7.34	4.14	3.7	4.16	0.0221
RA-06717	28-September 2005	39.1	80.8	3.67	125	-	-	1.8	4.34	-10.8	0.846	0.552	8.77
RA-06863	29-November 2005	45.6	76	8.72	3.93	2.73	2.73	2.15	8.55	0.479	3.03	1.18	4.13
RA-06964	25-January 2006	170	252	5.24	13.7	9.84	9.84	7.82	5.47	0.454	3.7	4.44	5.32
RA-07446	26-July 2006	52.2	100	1.85	3.3	-	5.46	2.4	6.29	-0.183	3.96	5.71	0
RA-07312	06-June 2006	85.7	121	3.62	3.35	-	0.738	3.94	15.2	2.16	6.11	3.67	1.46
RA-07662	17-October 2006	57.7	127	1.2	0	-	0.041	2.66	11	2.43	4.47	5.64	4.64
RA-07997	22-March 2007	46.7	93.5	3.87	3.66	-	-	2.15	2.86	3.24	2.33	1.93	-0.586
RA-08199	14-June 2007	41.2	101	15.3	-0.693	-	-	1.9	11.9	2.32	3.04	12.9	1.57
RA-08850	04-February 2008	727	100	113	3	-	0.048	33.5	11.7	-1.5	9.25	5.41	1.5
RA-11123	27 January 2011	18.1	19.9	12	0.96	15.2	0.89	0.93	2.7	10.3	2.9	2.8	<MDA
RA-11623	09 June 2011	12.9	19.7	29	2.01	2.2	2.2	0.592	2.3	-0.046	6.28	7.3	0.75
RA-12381	25 November 2011	50.6	76.7	24.1	0.27	15.2	-1.6	2.46	18.3	-0.94	2.58	23.1	<MDA
RA-13141-02	21 June 2012	49	92	36	3.45	2.93	-0.22	2.26	18.5	0.49	44	42.2	2.7
RA-13376-01	31 July 2012	70	151	53.5	3.88	4.08	40.8	3.23	18.9	0.86	2.73	2.1	0.74
RA-13645-01	01 October 2012	95.1	186	115	2.21		3.61	4.38	7.2	0.26	6.93	17.8	< MDA
RA-13709-01	17 October 2012	139	183	121	1.26	0.77	2.78	6.41	13	-0.27	6.84	21.8	0.54
RA-14064-02	04 March 2013	54.8	116	28.8	1.8	2.96	2.96	2.52	4	1.1	4.3	6.95	20.9
RA-14558-02	05 July 2013	56.1	86.8	28.7	0.157	2.4	2.4	2.58	5.95	0.038	0.48	7.2	< MDA
RA-15934-02	30 May 2014	7710	7400	41	273	7.36	7.36	355	-9.2	-10	10	27.1	0.92
RS2016-2555-01	10 June 2016	5540	4780	35.3	233	10.3	10.3	255	8.37	< MDA	18.2	6.5	< MDA
RS2016-4964-01	05 November 2016	493	425	71.9	217	10.4	10.4	22.7	8.74	< MDA	9.73	6.4	6.27
RS2018-1045-01	08 March 2018	54.2	384	98.8	2.8	-	-	2.5	19.2	< MDA	16.9	6	2.93

Table 5.30 Summary of nuclide specific results for groundwater samples from monitoring point SIDA07.

Necsa Report Number	Sample Delivery 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
		mBq.L ⁻¹											
RA-05115	30-June 2003	48.4	363	7.81	4.37	31.8	7.52	2.23	3.52	0.385	8.51	2.3	0.0117
RA-04963	31-March 2003	46.6	238	13.4	14.5	35.5	8.26	2.15	12.7	-0.562	13.8	9.18	13.7
RA-05370	24-November 2003	44.9	68.1	17.7	28.2	3.5	3.5	2.07	13.2	5.7	7.98	6.35	1.48
RA-06335	31-March 2005	26.6	105	5.43	12.5	2.83	2.83	1.23	5.73	2.11	5.71	7.3	3.8
RA-06467	31-May 2005	44	380	3.26	13.4	0.442	0.442	2.02	9.73	1.1	4.11	4.16	4.26
RA-06717	28-September 2005	29	344	0.316	13.4	-	-	1.34	1.41	-0.54	1.81	1.48	0.686
RA-06863	29-November 2005	160	179	25.2	58.2	6.12	6.12	7.38	7.13	6.58	33.2	13.5	1.67
RA-06964	25-January 2006	13.2	42.9	12.9	3.6	2.17	2.17	0.606	19.3	-0.34	7.66	10.2	1.17
RA-07446	26-July 2006	33.2	377	0.623	6.06	-	3.95	1.53	3.68	0.364	2.47	2.14	-0.201
RA-07312	06-June 2006	41.4	467	1.69	2.18	-	3.1	1.91	3.7	10.7	3.35	1.65	1.62
RA-07662	17-October 2006	42.8	433	0.64	7.57	-	2.08	1.97	8.12	0.835	1.27	3.47	1.32
RA-07997	22-March 2007	112	307	2.83	73.4	-	-	5.16	3.6	8.44	1.43	1.79	1.98
RA-08199	14-June 2007	892	873	74.1	17.9	-	-	41.1	46.7	3.05	12.5	27.1	-0.541
RA-12176	29 September 2011	27,200	24,200	36.5	15.4	3.23	3.23	1 250	-3.5	20.1	0.46	3.2	78.2
RA-14557-02	05 July 2013	568	545	39.1	16.1	13	0.792	26.1	10.7	4.83	21.9	4	< MDA
RA-15934-02	30 May 2014	47.6	350	27	18.9	18.4	4.54	2.19	0.65	2.65	3.5	13.9	<MDA
RS2015-3591-02	28 October 2015	25.6	333	11.9	22.4	2.23	2.23	1.18	0.4	3.19	1.1	2.8	4
RS2016-2555-01	10 June 2016	68	248	47.2	9.11	7.05	7.05	3.13	6.4	0.26	16.7	5	< MDA
RS2016-4964-01	05 November 2016	30.1	292	64.5	5.59	5.67	5.67	1.39	1.8	< MDA	3.7	5.8	< MDA
RS2016-5538-01	12 December 2016	31.3	322	30	10.9	7.26	7.26	1.44	17.3	0.057	29.1	4.8	< MDA
RS2018-5260-01	12 September 2018	74.3	523	27	171	11.3	11.3	3.42	31.3	< MDA	9.64	6.6	1.2
RS2019-1417-01	02 April 2019	89.6	424	33.3	8.39	8.39	4.13	9.99	< MDA	1.77	4.9	1.1	3.3

Table 5.31 Summary of nuclide specific results for groundwater samples from monitoring point SIDA09.

Necsa Report Number	Sample Delivery 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
RA-14049-02	05 March 2013	3510	3170	19	289	5.3	5.3	161	6.91	18.4	3.27	11.1	24.5
RA-14557-02	05 July 2013	7290	6620	20	370	18.1	0.317	336	10.3	-1.4	8.41	6.12	1.6

Table 5.32 Summary of nuclide specific results for groundwater samples from monitoring point SIDA13.

Necsa Report Number	Sample Delivery 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
RA-12176	29 September 2011	12000	10800	118	103	2.49	2.49	553	12.3	8.3	17.4	11	1.8
RA-15935-02	13 May 2014	2970	2840	33.8	266	7	7	137	14.8	-130	8.17	16.3	1.4
RA-15475-01	21 February 2014	3860	3380	20	723	30.1	7.28	178	19	-120	25.8	18.2	4.65
RS2015-3507-02	23 October 2015	5280	4720	40.6	130	22.5	4.01	243	7.6	6.44	17.7	-4.8	4.6
RS2016-4963-01	07 November 2016	3460	3290	34.1	220	10.6	10.6	159	13.9	< MDA	9.15	5.6	< MDA
RS2016-5538-01	12 December 2016	8050	7300	24	268	21.6	3.9	371	24.9	14.3	15.3	9.45	< MDA
RS2019-1417-01	02 April 2019	57.2	104	28.8	10.1	27.2	< MDA	2.63	9.42	2.18	5.8	2.4	5.3

Table 5.33 Summary of nuclide specific results for groundwater samples from monitoring point SIDA17.

Necsa Report Number	Sample Delivery 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
RS2018-1045-01	08 March 2018	17.7	65.3	91.9	25.5			0.814	45.4	4.83	70.8	1.4	6.15
RS2019-1421-01	02 April 2019	7.54	16.8	9.1	10.3	7.13	< MDA	0.347	4	< MDA	0.58	19.2	0.51

Table 5.34 Summary of nuclide specific results for groundwater samples from various monitoring points (SIDA14, SIDA15, SIDA16, SIDA18, SIDA20, SD39 and SD42).

Necsa Report Number	RS2019-1417-01	RS2019-1421-01	RS2019-1421-01	RS2018-1045-01	RS2019-1417-01	RS2016-0500-01	RS2016-5536-01
Sample Delivery Date	02 April 2019	02 April 2019	02 April 2019	08 March 2018	02 April 2019	09 February 2016	12 December 2016
Sampling Point	SIDA14	SIDA15	SIDA16	SIDA18	SIDA20	SD39	SD42
Radionuclide	mBq.L ⁻¹						
U-238	127	18.8	10.1	41.5	1020	26.2	17.1
U-234	181	21.5	27	94.6	993	68.2	27.7
Th-230	26.1	26.7	78	6.7	29.4	76.3	64.7
Ra-226	9.04	2.19	26.8	16.6	4.52	2.39	4.63
Pb-210	19.4	5.56	9.49	-	17.2	-	4.88
Po-210	< MDA	5.56	< MDA	-	< MDA	4.26	4.88
U-235	5.84	0.866	0.463	1.91	46.9	1.21	0.788
Th-227	8.44	9.01	10	< MDA	17.5	24	9.58
Ra-223	< MDA	< MDA	< MDA	2.2	< MDA	0.71	< MDA
Th-232	5.33	1.7	22.1	4.4	1.9	39.4	4.04
Th-228	7.85	3.84	32.9	9.4	4.5	11	17
Ra-224	< MDA	0.57	4.82	9.33	3.08	0.83	2.4

Table 5.35 Summary of nuclide specific results for groundwater samples from monitoring point SIDA21.

Necsa Report Number	Sample Delivery 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
RA-05115	30-Jun-03	6.1	8.88	27.4	6.49	-16.5	13.1	0.281	19.5	3.38	65	6.46	0.565
RA-04963	31-Mar-03	13	66.2	6.63	10.7	5.75	5.75	0.596	5.4	-0.535	8.75	6.04	9.08
RA-13375-02	31 July 2012	9.49	25.1	88.4	10.5		9.25	0.437	22.4	-2	6.55	4.1	< MDA
RS2018-1045-01	08 March 2018	493	517	74.4	459			22.7	2.4	< MDA	25	22.6	9.07

Table 5.36 Summary of historical nuclide specific data for samples of water collected from underground workings (2003).

Necsa Report Number	RA-04989	RA-05115	RA-05370	RA-04989	RA-05115
Sample Delivery Date	09-Apr-03	30-Jun-03	24-Nov-03	09-Apr-03	30-Jun-03
Field Code	58 L		56L	49L	
	mBq.L ⁻¹				
U-238	11 700	10 700	2 540	14 800	4 280
U-234	10 400	9 660	2 490	13 600	3 580
Th-230	4 090	4 590	42.8	8.44	12.1
Ra-226	132	91.4	64.7	1 190	467
Pb-210	3.66	3.72	1.82	31.2	4
Po-210	3.66	3.72	1.82	18.6	4
U-235	537	494	117	683	197
Th-227	60.6	56.6	1.78	169	16.9
Ra-223	42.8	24	44	112	26.3
Th-232	469	451	3.41	7.02	13.7
Th-228	210	221	1.45	22	2.5
Ra-224	160	124	6.39	3.2	2.42

5.3.5 Radiological Conditions in the Biosphere

The South Deep Gold Mine report radionuclide concentrations in various agricultural commodities (fruits, vegetables and cereal) sourced from local landowners. Table 5.46 summarises the measured radionuclide concentrations, with reference to the Necsa laboratory report number and the date the samples were collected. The respective Necsa radioanalytical laboratory reports are attached as Appendix A.

5.3.6 Environmental Radon

The South Deep Gold Mine periodically measure airborne radon concentrations in the environment, using passive radon gas monitors (RGMs). The RGMs are deployed in sets of two or three in locations in and around the South Deep Gold Mine, as well as near potential receptor locations. Table 5.47 lists the location coordinates and a description of 22 locations used for monitoring airborne radon concentrations.

Figure 5.8 present some of the radon monitoring locations indicated on a map of the South Deep Gold Mine lease area. Location R10, R11, R12, R15 and R16 are not indicated, as these are located some distance from the South Deep Gold Mine, and thus most likely fall outside the area influenced by the Mine.

Monthly measured airborne radon concentrations, in units of Bq.h.m⁻³, is available for 2012, 2015 and 2016. The results are summarised in Table B1 to Table B3, in Appendix B. Table 5.48 summarises the average monthly radon concentrations measured during the most recent campaign conducted in 2016. Results for 2016 are available up to June.

Table 5.37 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 50 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RA-15228-01	22 November 2013	S	878	833	80.2	69.3	2.49	2.49	40.4	27.1	-5.2	13.8	14	2.42
RS2016-2553-01	10 June 2016	S	62.6	95.2	78.1	1.92	6.59	6.59	2.88	23.8	0.17	49.5	6	1
RS2016-2868-01	30 June 2016	S	15.4	31.7	45.3	0.933	9.2	9.2	0.707	4.36	0.25	23.8	5.5	< MDA
RS2016-5294-01	29 November 2016	S	204	280	35.9	39.7	6.72	6.72	9.41	14.3	0.31	2.7	6.9	2.3
RS2016-5620-01	19 December 2016	S	41.2	89.6	75.4	12.4	8.83	8.83	1.9	11	0.17	18.9	6.8	< MDA
RS2017-1096-01	15 March 2017	S	32.2	73.2	42.6	4.13	3.12	3.12	1.48	10	< MDA	9	16.3	< MDA
RS2017-4297-01	05 September 2017	D	58.7	63	37.7	3.51	-	5.86	2.7	5.1	0.087	34.8	7.4	< MDA

Table 5.38 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 90 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RA-15229-01	19 December 2013	S	10,100	8,280	92.6	263		7.43	463	15.9	-33	9.73	18.3	< MDA
RS2016-2553-01	10 June 2016	S	6,170	5,480	164	211	11	11	284	15.4	7.09	19.5	10.7	3.14
RS2016-5294-01	29 November 2016	S	4,780	4,400	18	175	6.04	6.04	220	20.3	< MDA	1.4	6.1	< MDA
RS2016-5620-01	19 December 2016	S	6,470	6140	66.4	216	13.2	13.2	298	32.8	< MDA	5.54	7.75	< MDA

Table 5.39 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 93 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RS2016-1190-01	18 March 2016	S	4,260	3,950	46.4	139	63.1	2.41	196	20	< MDA	11.5	13.4	< MDA
RS2016-5294-01	29 November 2016	S	2,840	2,530	79.4	201	21.8	0.97	131	23.5	0.67	22.7	10.5	1.9
RS2017-4297-01	05 September 2017	D	15	26.4	31.5	6.49	-	4.9	0.692	7.1	< MDA	23.2	14.1	< MDA

Table 5.40 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 94 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RS2016-5620-01	19 December 2016	S	2,860	3,280	38.2	220	4.42	4.42	132	32.4		3.08	8.94	1.9
RS2017-1096-01	15 March 2017	S	94.4	146	26.8	7.26	5.42	5.42	4.34	4.8	< MDA	7.07	11.2	< MDA

Table 5.41 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 95 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RS2016-0500-01	09 February 2016	S	4.61	14.4	4.88	2.5		4.12	0.212	1	7.2	2.16	1.5	1.6
RS2016-1190-01	18 March 2016	S	3,780	3,460	63.2	106	53.8	< MDA	174	16	< MDA	10.6	7.8	1.8
RS2016-2553-01	10 June 2016	S	87.2	118	88.6	3.85	7.26	7.26	4.01	24.1	0.53	26.3	17.3	< MDA
RS2016-2868-01	30 June 2016	S	19.4	27.4	47.9	1.39	7.23	7.23	0.892	3.3	0.97	21.4	9.2	< MDA
RS2016-5294-01	29 November 2016	S	8,480	7,840	23.8	267	20.8	5.65	390	32.2	< MDA	2.69	9.87	0.73
RS2016-5620-01	19 December 2016	S	6,650	8,830	141	252	10.3	10.3	306	17.3	< MDA	31.1	14.1	1
RS2017-1096-01	15 March 2017	S	59.9	193	41	5.08	5.4	5.4	2.76	21.2	< MDA	1.2	8.4	1.7
RS2017-4297-01	05 September 2017	D	30.1	114	42	3.5	-	18.3	1.39	4.4	< MDA	22.1	18.4	0.98

Table 5.42 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 100 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RS2016-1190-01	18 March 2016	S	3,840	3,460	39.6	107	20.4	20.4	177	34.2	1.5	22.1	14.5	< MDA
RS2016-2553-01	10 June 2016	S	6,350	5,260	67.1	166	5.86	5.86	292	13.9	< MDA	13.1	5.3	3
RS2016-5294-01	29 November 2016	S	12,400	11,800	13	197	36.5	< MDA	571	29.1	3.36	1.68	9.29	1.6
RS2016-5620-01	19 December 2016	S	13.9	27.9	36.3	9.81	< MDA	21	0.642	6	0.13	3.3	12	< MDA

Table 5.43 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 105 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RA-15229-01	19 December 2013	S	9,600	7870	51.9	80.3		34.7	442	39.7	13.4	3.9	12.1	3.6
RS2016-1190-01	18 March 2016	S	3,570	3220	18	115	86.5	2.33	164	7.13	10.1	7.41	7.2	< MDA

Table 5.44 Summary of nuclide specific results for samples of service water (S) and drink water (D) collected from 110 Level.

Necsa Report Number	Sample Delivery Date	Use	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	U-235	Th-227	Ra-223	Th-232	Th-228	Ra-224
RA-15477-02	21 February 2014	S	11,500	10,100	41.3	454	43.9	-14	528	35.9	8	4.77	6.09	2.82
RS2016-2553-01	10 June 2016	S	3,680	3,070	40.6	146	5.44	5.44	169	8.5	0.71	4.53	36.2	< MDA
RS2016-2553-01	10 June 2016	S	5,860	5,260	44.9	172	11.8	11.8	270	19.1	64.7	25.8	7.8	1.4
RS2016-2868-01	30 June 2016	S	27.9	30.4	32.6	0.29	6.37	6.37	1.29	11	1.19	6.79	5.1	< MDA
RS2016-5294-01	29 November 2016	S	13,300	12,800	44.8	202	11.7	11.7	612	41.6	< MDA	8.4	7.7	0.91
RS2016-5620-01	19 December 2016	S	37.8	42.2	67.9	6.1	7.17	7.17	1.74	9.1	< MDA	10.7	7.28	< MDA

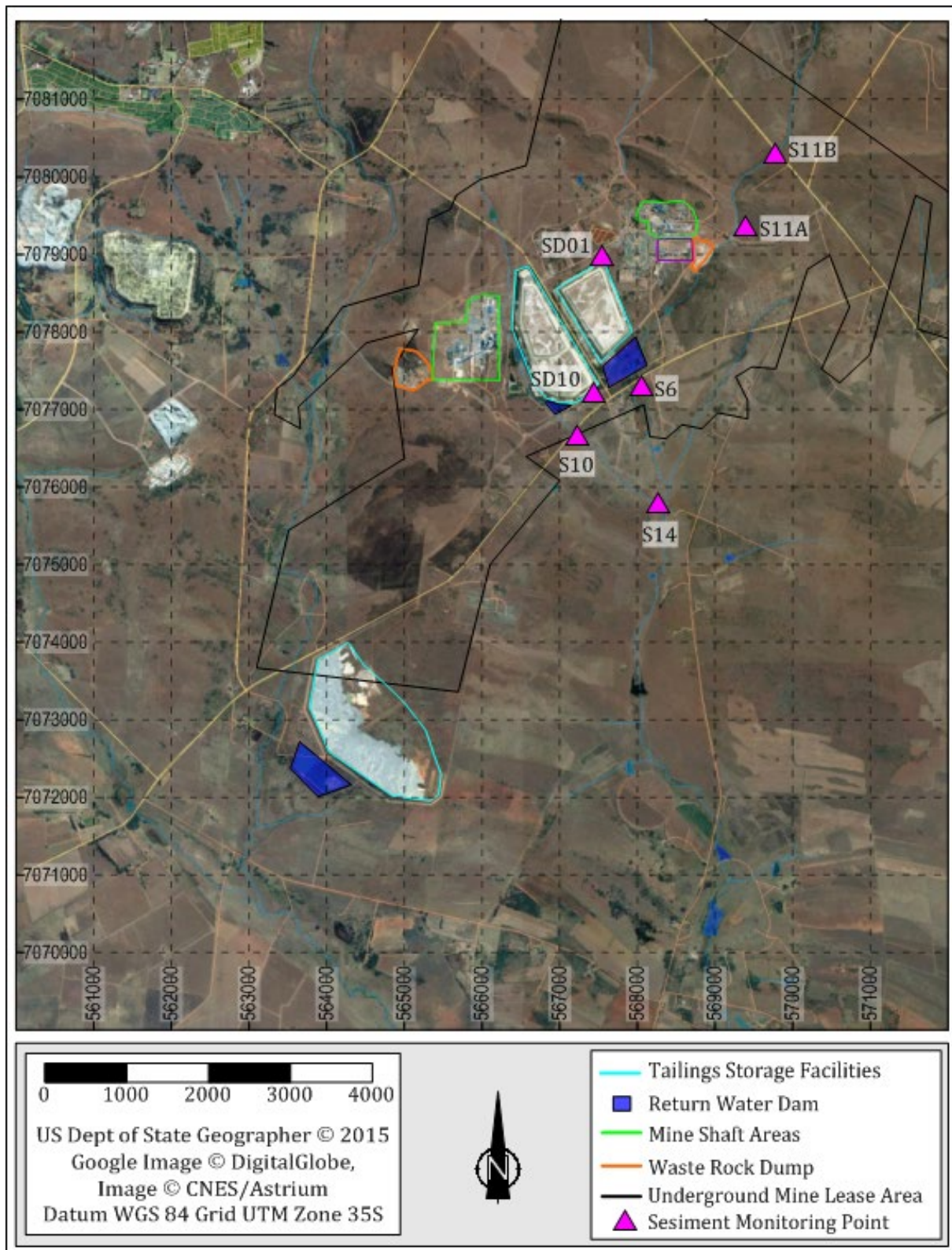


Figure 5.7 Map showing radiological sediment monitoring points in surface water streams at the South Deep Gold Mine.

Table 5.45 Summary of nuclide specific data for sediment samples from surface water streams.

Necsa Report Number	Sample Delivery Date	Field Code	U-238	U-234	Ra-226	Pb-210	U-235	Th-232	Ra-228	Th-228
			Bq.kg-1							
RS2016-0501-01	28 February 2016	S6	2,220	2,240	418	332	102	35.1	46	43
		S10	296	299	218	353	13.6	27	<MDA	30
		S11	2,320	2,340	1,210	893	107	69.8	91	100
		S14	295	298	146	<MDA	13.6	24.4	21	30
RS2015-3508-01	22 October 2015	S6C	331	334	100	219	15.2	45	46	39
		S6S	343	346	154	147	15.8	48.3	<MDA	45
		S10C	111	112	84.6	127	5.11	25.6	<MDA	32
		S10S	103	104	69.4	162	4.75	31.7	<MDA	46
		S11B	4,430	4,470	546	578	204	<MDA	105	58
		S11A	2,460	2,480	450	527	113	37.4	33	55
RA-07445	26 July 2006	SD01	2,700	-	775	924	125	64.6	49.5	56.9
		SD10	551	-	160	200	25.4	27.9		32

Table 5.46 Radionuclide concentrations in agricultural commodities sourced from landowners in the vicinity of the South Deep Gold Mine.

Necsa Report Number	Sample Delivery Date	Field Code	U-238	U-234	Ra-226	Pb-210	Po-210	U-235	Th-232	Ra-228	Th-228
			Bq.kg ⁻¹								
RA-05939	30 September 2004	Maize	0.28			1.85	1.85	0.0129			
RJ2009-0609	30 June 2009	Cabbage	0.0217	0.0219	<MDA	<MDA	0.14	0.001	0.005	<MDA	0.017
RJ2009-0610		Carrots	0.082	0.0827	<MDA	0.18	0.23	0.00378	0.059	0.194	0.0937
RJ2009-0610		Sweet Potatoes	0.029	0.0292	<MDA	<MDA	0.432	0.00133	0.0276	<MDA	0.0000517
RJ2009-0611		Spinach	0.0929	0.0937	0.22	0.843	5.38	0.00428	0.025	0.278	0.0581
RJ2009-0614		Beetroot	0.255	0.257	0.506	0.525	2.11	0.0118	0.209	0.482	0.289
RA-12382	25 November 2011	Spinach 1	0.276	0.279	0.916	0.43	0.155	0.0127	<MDA	0.348	0.08
		Spinach 2	1.06	10.7	1.16	1.52	8.84	0.0487	1.5	0.452	0.16
RA-15482-01	14 February 2014	Tomatoes	0.00778	0.00785	<MDA	<MDA	0.0383	0.000358	0.0392	<MDA	<MDA
RA-15478-01	27 February 2014	Peaches	0.0398	0.0402	<MDA	<MDA	0.533	0.00183	0.308	<MDA	<MDA
		Cabbage	0.0043	0.0043	<MDA	<MDA	0.0943	0.0002	0.335	<MDA	<MDA
		Spinach	0.0513	0.0517	0.49	<MDA	0.135	0.00236	0.19	0.574	0.0771

Table 5.47 Location coordinates and description of radon monitoring locations at the South Deep Gold Mine.

Monitoring Point	Description	Coordinates	
R 1	Orion Peach Farm	-26.437233°	27.6932°
R 2	New tailing dam next to the road SD 10	-26.423867°	27.675833°
R 3	Perskes Modderfontein Veggie Farm	-26.445000°	27.688967°
R 4	Thusanang House No.24	-26.416417°	27.701433°
R 5	Corner of old tailings	-26.416883°	27.681133°
R 6	Old tailings dam road	-26.419617°	27.678317°
R 7	New Slimes dam	-26.425667°	27.671917°
R 8	Elvis Farmhouse	-26.412983°	27.688483°
R 9	Elvis plot	-26.437778°	27.688194°
R 10	Kalbasfontein Tuckshop	-26.495300°	27.684967°
R 11	Elandfontein	-26.391767°	27.560867°
R 12	Hillshaven Primary School	-26.371783°	27.675983°
R 13	Ezulwini Junction	-26.386017°	27.673550°
R 14	Leeu Spruit S11B	-26.396133°	27.698567°
R 15	Hillshaven Flats	-26.368400°	27.663150°
R 16	Waterpan Farm	-26.355633°	27.677150°
R 17	Sewage	-26.418233°	27.687233°
R 18	Smith Farm	-26.424194°	27.694861°
R 19	Doornpoort 2	-26.471833°	27.677454°
R 20	Doornpoort 1	-26.463472°	27.635333°
R 21	TWIN SHAFT	-26.415889°	27.659806°
R 22	WASTE ROCK	-26.404167°	27.691222°

Table 5.48 Monthly average radon activity concentrations measured at the South Deep Gold Mine during the first half of 2016.

Monitoring Point	Jan	Feb	Mar	Apr	May	Jun
	Bq.h.m ⁻³					
R 1	22,700	32,000	24,000	30,333.33	37,333.33	32,744.44
R 2	26,000	26,800	35,311.11	24,088.89	22,333.33	20,333.33
R 3	31,000	30,900	28,000	27,000	31,333.33	26,000
R 4	26,512.92	31,333.33	41,000	20,000	18,316.67	21,812.22
R 5	31,500	25,083.33	23,475	21,000	20,550	28,000
R 6	25,000	26,766.67	32,333.33	26,000	28,000	27,500
R 7	30,000	18,841.11	-	16,560	24,333.33	21,833.33
R 8	23,216.67	27,883.33	32,366.67	25,125.93	25,550	23,333.33
R 9	26,166.67	22,422.22	19,708.89	29,000	30,866.67	26,666.67
R 10	22,550	25,650	19,708.89	26,666.67	28,666.67	28,666.67
R 11	-	21,650	29,000	23,000	24,000	27,666.67
R 12	30,000	18,591.67	23,500	20,000	19,200	23,666.67
R 13	28,400	17,250	38,672.22	19,006.67	19,383.33	16,000
R 14	-	42,500	-	40,333.33	33,666.67	-
R 15	31,000	23,150	33,555.56	16,505	18,983.33	20,744.44
R 16	25,700	26,000	35,000	23,100	25,333.33	26,333.33
R 17	23,288.33	19,525	26,266.67	20,013.33	26,650	22,444.44
R 18	25,750	21,333.33	-	-	17,066.67	25,666.67
R 19	31,000	17,716.67	32,433.33	19,120.33	82,516.67	23,059.26
R 20	25,333.33	19,188.89	34,666.67	18,446.67	20,716.67	23,275
R 21	23,500	25,266.67	29,083.33	20,028.67	23,000	17,416.67
R 22	31,166.67	22,716.67	36,000	19,556.67	20,866.67	18,144.44

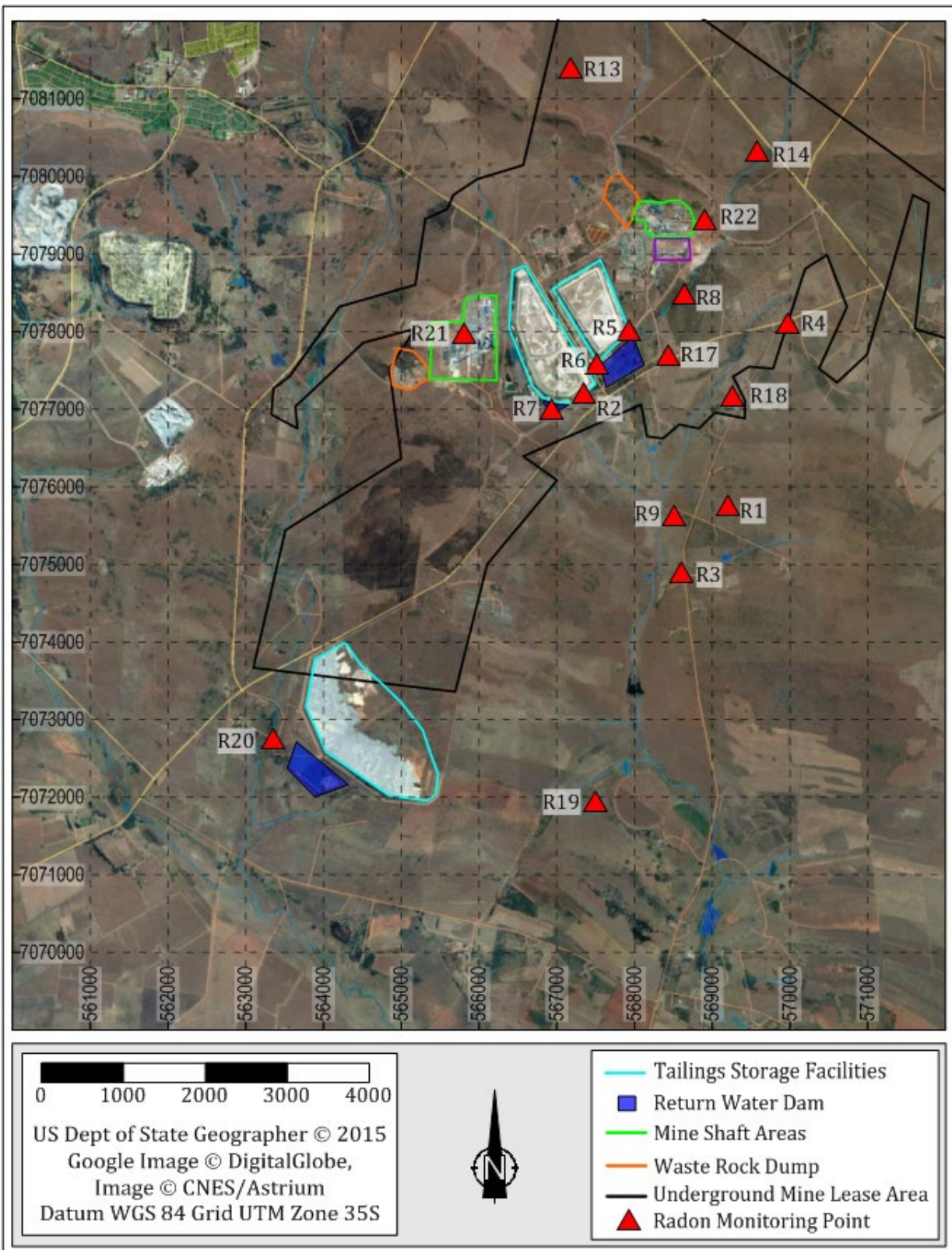


Figure 5.8 Radon monitoring locations at the South Deep Gold Mine.

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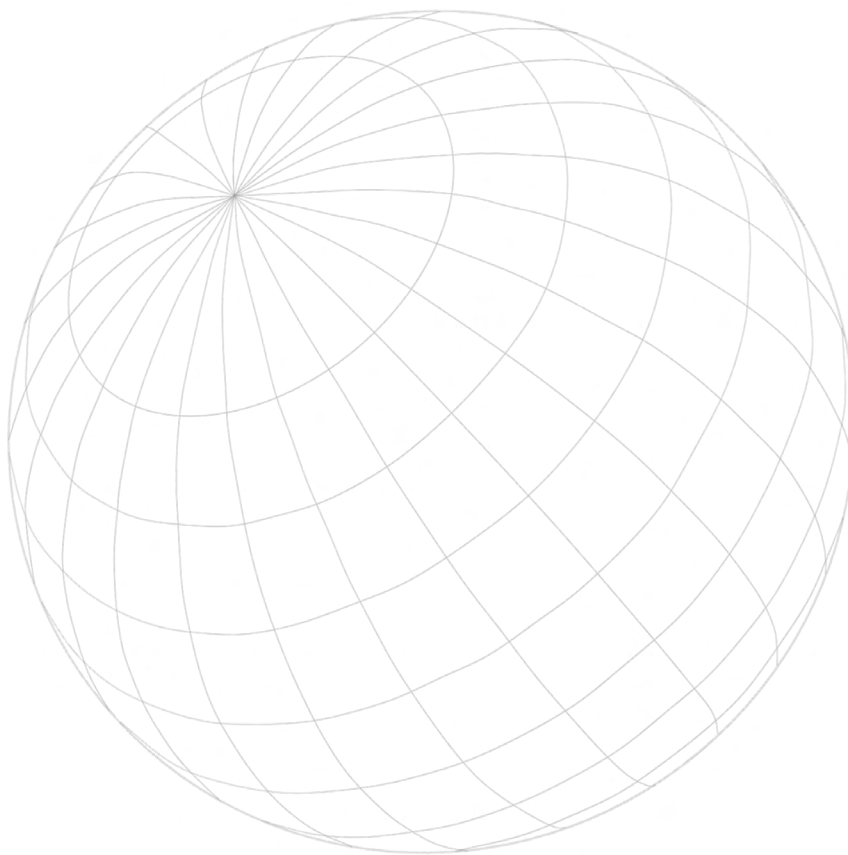
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Appendix A: Full Spectrum Radioanalysis Results of Residue Materials and Environmental Samples

Appendix B: Environmental Radon Monitoring Results

2020 Radiological Public Safety Assessment
of the Gold Fields South Deep Gold Mine:
Mathematical Model Development



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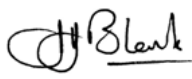
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REVISION TABLE

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LIST OF ACRONYMS

BSS	Basic Safety Standards
Bq	Becquerel
CoR	Certificate of Registration
IAEA	International Atomic Energy Agency
GFI	Gold Fields Limited
ICRP	International Commission on Radiological Protection
JSE	Johannesburg Security Exchange
LL α	Long-Lived Radioactive Dust (Alpha)
MPRD Act	Minerals and Petroleum Resources Development Act
mSv	millisievert
NEA	Nuclear Energy Act (Act No. 46 of 1999)
NNR	National Nuclear Regulator
NNRA	National Nuclear Regulator Act (Act 47 of 1999)
NORM	Naturally Occurring Radioactive Materials
PM ₁₀	Particulate matter less than 10 micron in size
RG	Regulatory Guide
RPP	Radiation Protection Programme
RPS	Radiation Protection Specialist
RPSA	Radiological Public Safety Assessment
TSFs	Tailings Storage Facilities
TSP	Total Suspended Particles
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WRD	Waste Rock Dump
MAP	Mean Annual Precipitation
WLM	Working Level Month
PAEC	Potential Alpha Energy Concentration
EEC	Equilibrium Equivalent Concentration
NUREG	US Nuclear Regulatory Commission

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1 Introduction

1.1 Background

Gold Fields has operated in South Africa since 1887 when Cecil John Rhodes and Charles Rudd formed Gold Fields of South Africa. In 1932, the company began mining the mineral-rich West Rand, where it discovered high-yielding gold deposits. A merger between Gold Fields of South Africa and Gencor in 1998 led to the formation of Gold Fields Limited (GFI). Today, GFI is an unhedged, globally diversified producer of gold that has built on its South African reserves and resources, with a portfolio of eight operating assets and several exploration projects grouped into four regions, namely Australia, Ghana, Peru and South Africa. Gold Fields has a primary listing on the Johannesburg Stock Exchange, with secondary listings on the New York Stock Exchange and the Swiss Exchange.

The only remaining GFI mining operation in South Africa is the South Deep Gold Mine, which conducts gold mining and processing operations in a lease area comprising approximately 4,268 hectares. All required authorisations have been obtained and is in good standing. The conversion of the old order mining right to a new order mining right, as required in terms of the Minerals and Petroleum Resources Development Act (MPRD Act) (Act 28 of 2002) was approved in July 2010.

Geographically, the South Deep Gold Mine is situated in the magisterial districts of Westonaria and Vanderbijlpark in the Gauteng Province of South Africa, some 45 kilometres south-west of Johannesburg (see Figure 1.1). It is accessed *via* the N12 provincial road between Johannesburg and Potchefstroom. Neighbouring towns include Fochville, which is situated 25 km to the west, Carletonville situated about 35 km to the north-west, Westonaria situated 15 km to the north, Randfontein situated 30 km to the north and Vereeniging situated 40 km to the south-east of the South Deep Gold Mine. Figure 1.2 presents a map showing the South Deep Gold Mine relative to major towns and other mining operations, while Figure 1.3 presents the present underground Mining Right Area.

The South Deep Gold Mine has extensive underground workings and surface production facilities, with associated infrastructure that are used to access and extract gold-bearing ore from the Ventersdorp Contact Reefs (VCR) and the Upper Elsburg formation conglomerates of the Witwatersrand Basin (see Figure 1.3). The Upper Elsburg Reefs constitute ~98% of the Mineral Reserve ounces, while the VCR makes up the remaining ~2%. It is estimated that the current Mineral Reserves will be depleted in 2093 (75 years).

The surface production facilities and associated infrastructure include a gold processing plant, backfill and water treatment plants, access and ventilation shaft complexes, tailings storage facilities (TSFs), waste rock dumps (WRDs), return water dams (RWDs), transfer pipelines for water and tailings, and offices.

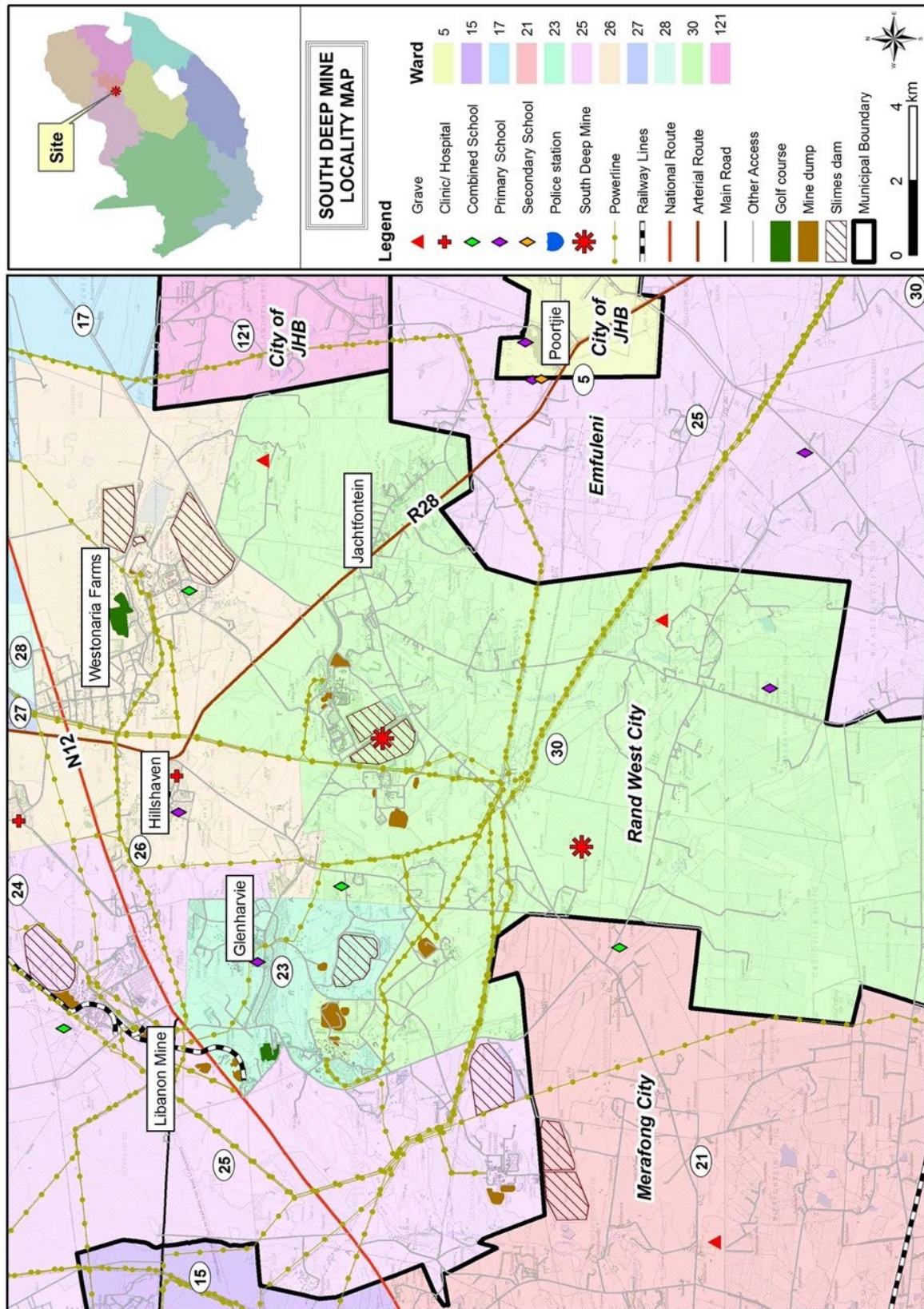


Figure 1.1 Map showing the South Deep Gold Mine is located within the magisterial districts of Westonaria and Vanderbijlpark (Gauteng province), some 45 kilometres south-west of Johannesburg (Equispectives, 2020).

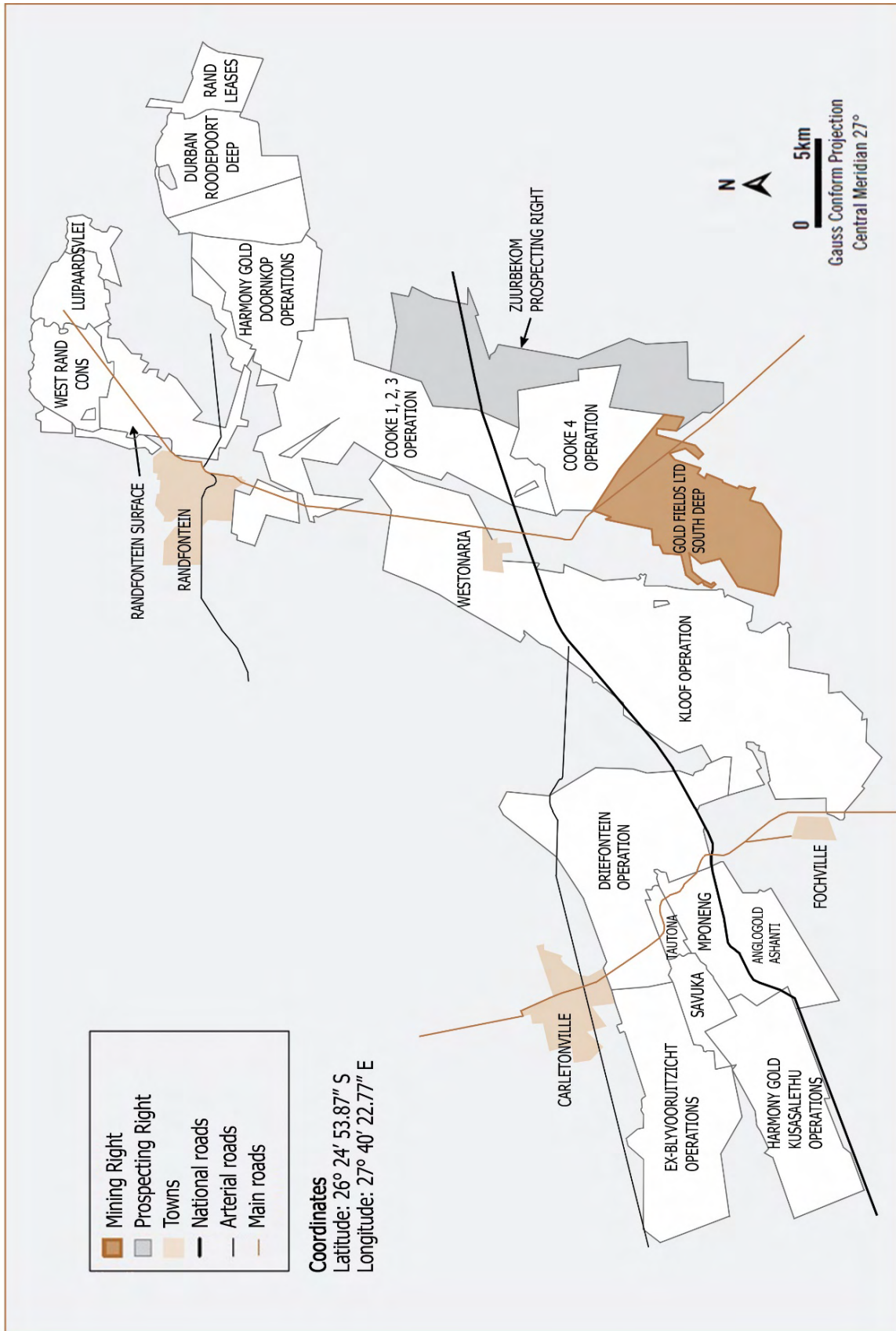


Figure 1.2 Map showing the South Deep Gold Mine relative to major towns and other nearby mining operations.

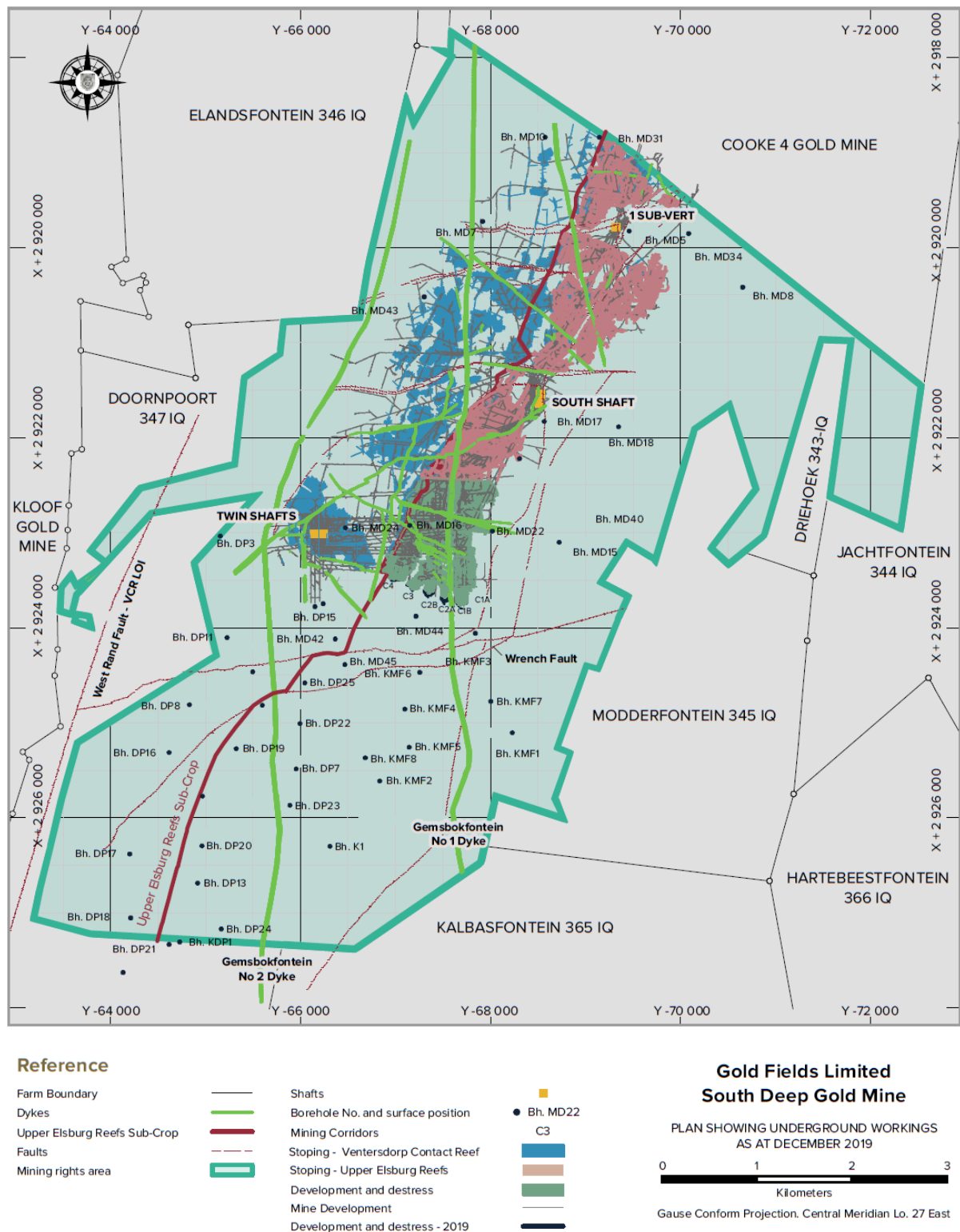


Figure 1.3 Map showing the present Mining Right Area and scope of the South Deep Gold Mine operations.

1.2 Naturally Occurring Radionuclides

Naturally occurring radionuclides associated with the uranium, thorium and actinium decay series are associated in varying degrees with the gold-bearing reefs of the Witwatersrand Basin. These naturally occurring radionuclides are present in ore brought to the surface for processing and consequently was carried through to the mineral processing residues that are now stored on the surface as tailings or sand facilities. These materials and residues that contain naturally occurring radionuclides are generally referred to as Naturally Occurring Radioactive Materials (NORM) (IAEA, 2007).

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). 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 other wastes.

Industries such as NORM generating mining and mineral processing operations and associated facilities and activities thus have the potential to alter the natural background radiation, and potentially increase radiation exposure to human beings and the environment, by:

- Moving naturally occurring radionuclides from inaccessible locations to locations where humans are present and can be exposed;
- Concentrating naturally occurring 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).

1.3 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 safety 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”.

Gold Fields holds a Certificate of Registration (CoR-18) granted by the NNR in terms of Section 22 of the NNRA for the South Deep Gold Mine. Under the regulatory process administered by the NNR and in line with internationally accepted radiation protection and management practices, a CoR

holder must submit an updated Radiological Public Safety Assessment (RPSA) regularly (every 3 to 5 years) to retain the nuclear authorisation. The purpose of these revisions is to reflect on regulatory and operational changes incurred during this period and to assess the radiological consequences of these changes to members of the public. At the same time, new information that became available on the current operation can be incorporated into the RPSA and the associated public Radiation Protection Programme (RPP) can be revised and updated accordingly. Collectively, this ensures that the protection of members of the public against exposure to ionizing radiation-induced by facilities and activities incorporated within the scope of the CoR is in line with the national safety standards.

The current radiological public safety assessment for the South Deep Gold Mine was performed and submitted to the NNR in 2017 (Van Blerk and Potgieter, 2017). AquiSim Consulting (Pty) Ltd (AquiSim) was appointed as Radiation Protection Specialist (RPS) to update the 2017 Radiological Public Safety Assessment of the South Deep Gold Mine in accordance with the provision, requirements, and guidelines provided by the NNR (hereafter referred to as the 2020 South Deep Gold Mine RPSA).

1.4 Purpose of the Report

Figure 1.4 is a schematic overview of the safety assessment framework used for the 2020 South Deep Gold Mine RPSA. It is a systematic approach, consisting of several logical and interrelated steps. A detailed description of the methodology is presented in the *Assessment Context* report (Aquisim, 2020a). Consistent with the safety assessment framework and technical approaches therein, the purpose of this report is to translate the conceptual models developed for each scenario and associated public exposure condition into mathematical equations or expressions as appropriate.

As illustrated in Figure 1.4, this process, together with the implementation of these mathematical models into the appropriate computational software (i.e., computer model) is a logical extension of the definition and justification of public exposure conditions and is further supported with input from the *Process Level* modelling.

1.5 Scope and Structure of the Document

The main objective of the 2020 South Deep Gold Mine RPSA is to demonstrate with confidence to the NNR and other stakeholders that members of the public residing near the South Deep Gold Mine are not exposed to levels of ionizing radiation above the compliance criteria set for public exposure. Viewed from this perspective, the purpose of the 2020 South Deep Gold Mine RPSA was defined as follows in the *Assessment Context* report (Aquisim, 2020a):

To assess the radiological safety to members of the public from conditions induced by the South Deep Gold Mine in a comprehensive, systematic, and transparent manner that is consistent with the NNRA and NEA, as well as with NNR requirements, guidance, and regulations.

The safety assessment framework (see Figure 1.4) is based on a general methodology developed by the international community to conduct post-closure radiological safety assessments of near-surface radioactive waste disposal facilities (generally referred to as the ISAM methodology) (IAEA, 2004). The framework is systematic and structured in nature and sufficiently general for application to mining and mineral processing facilities.

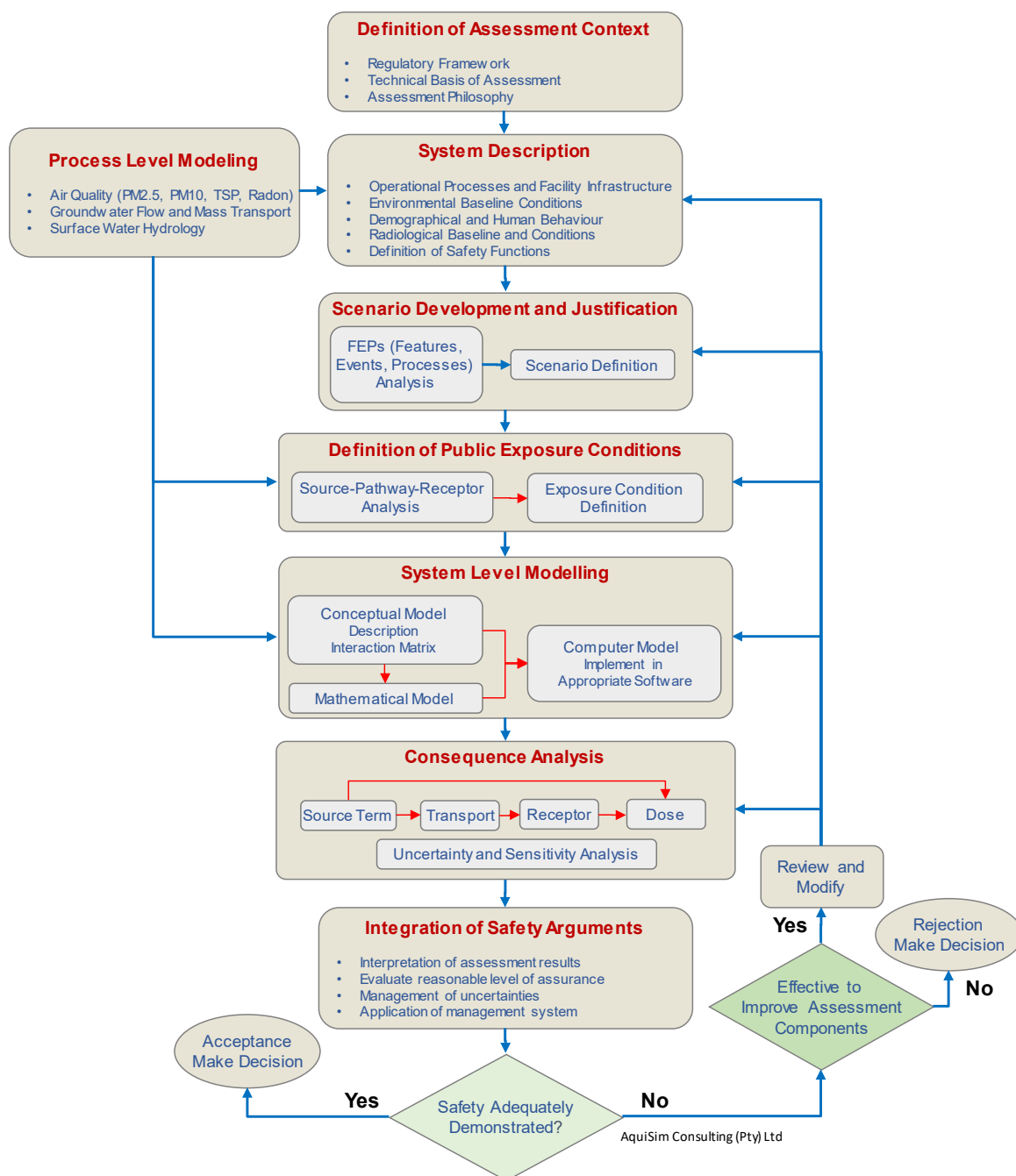


Figure 1.4 Schematic illustration of the safety assessment framework, within which the 2017 South Deep Gold Mine RPSA is performed (Aquisim, 2020a).

The conceptual and mathematical models developed for a specific component of an environmental system are closely related. Mathematical models translate the assumptions of the conceptual

model into mathematics, which might be sets of coupled algebraic, differential and/or integral equations with appropriate initial and boundary conditions defined over a specified domain. These equations are solved using computer software (or a computer model) to define the temporal and spatial dependence of the quantities of interest (such as radionuclide concentrations and doses to humans).

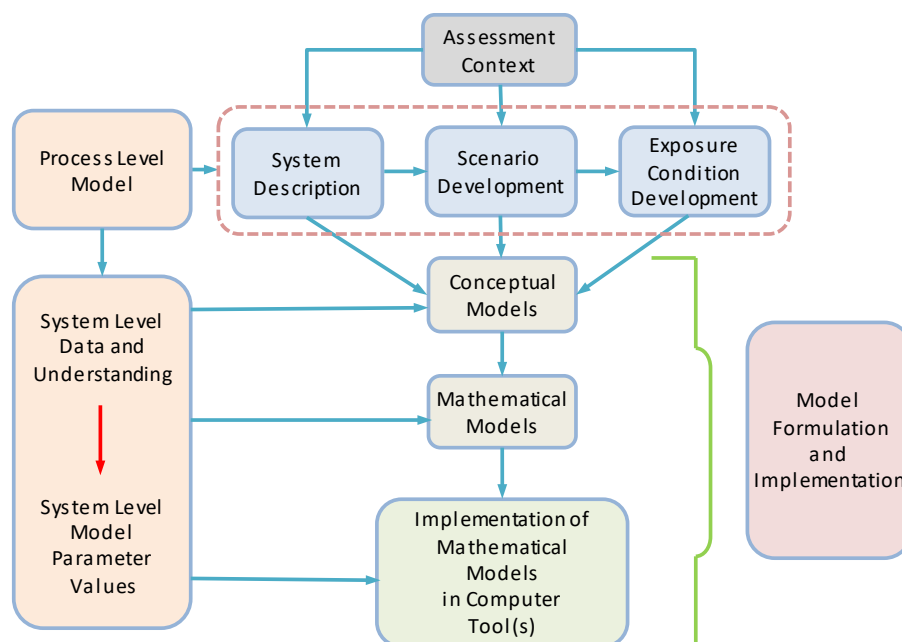
Conceptual models for the public exposure conditions defined for the 2020 South Deep Gold Mine RPSA is presented in the *Development and Justification of Public Radiation Exposure Conditions* report (Aquisim, 2020b). The scope of this report is consequently limited to the development and presentation of appropriate mathematical models for these exposure conditions and the implementation of these models in the appropriate software. Specify and justify model parameter values required to solve the mathematical models is an integral part of the model development process (see Figure 2.1). The report, therefore, concludes with the specification and justification of general and exposure condition-specific parameter values. The report is structured as follows.

This report is structured as follows:

- Section 2 discusses the process to implement the mathematical models in appropriate computer software for calculation purposes as part of the consequence analysis step.
 - Section 3 presents a *System Level* model implementation of the groundwater pathway, which for this assessment was implemented in Ecolego.
 - Section 4 describes the mathematical equations or expressions necessary to calculate the release and distribution of radioactivity into the accessible environment, as required for the different conceptual models, as well as the equations necessary to calculate the radiological consequences in term of a total effective dose.
 - Section 5 specifies and justifies the general and exposure condition-specific model parameter values for the equations presented in Section 4.
-

2.1 General

The safety assessment framework presented in Figure 1.4, depicts model development as consisting of several individual steps, the result is the implementation of the conceptual and associated mathematical models in appropriate computer software or tools, often referred to as a *computer model*. These steps relative to other elements in the assessment framework are depicted in Figure 2.1, which emphasises the fact that model development and implementation for a specific set of scenarios and exposure conditions are subject to the current understanding of the system with a continuous feed of model parameter values.



The assessment framework makes provision for the use of *Process Level* models and *System Level* models (see Figure 1.4). The purpose of this section is to discuss the role and purpose of *Process Level* (Section 2.2) and *System Level* models (Section 2.3) in the model formulation and implementation process. Model implementation for the 2020 South Deep Gold Mine RPSA is presented in Section 2.4.

2.2 Process Level Modelling

2.2.1 General

The release and subsequent migration of naturally occurring radionuclides into and through the environment as a function of time and space are governed by complex partial differential equations. Due to their complexity and lack of analytical solutions, numerical methods are often required to solve these equations. *Process Level* models are process and pathway-specific (e.g., atmospheric, surface water and groundwater) and generally performed at a high level of detail. For this reason, specialists are often used to perform the required *Process Level* modelling.

The level of information and system behaviour understanding that can be generated through *Process Level* modelling are significant, which underlines its importance in the overall safety assessment framework. While this enables a detailed consideration of environmental processes, it also requires considerable resources to develop and execute these models. For this reason, it is often (at least at present) not viable to use *Process Level* modelling in integrated radiological safety assessment analysis.

Figure 1.4 shows that within the assessment framework, *Process Level* modelling provides input into the system description, as part of the overall understanding of the system behaviour. It also assists with the definition and justification of scenarios and public exposure conditions, especially in terms of understanding the spatial and temporal impact of particulates and contaminants released and distributed into the environment.

2.2.2 Groundwater Pathway

Characterising the groundwater pathway using *Process Level* modelling comprises two steps. During the first step, one-, two-, or three-dimensional conceptual and numerical models are developed to characterise the groundwater flow regime. Depending on site-specific conditions, the groundwater flow regime may comprise the unsaturated and saturated zones. The unsaturated flow regime is defined as a function of the gravimetric pressure conditions and the moisture content of the unsaturated stratigraphic layers, subject to infiltration from the surface.

The saturated groundwater flow regime provides a spatial and temporal distribution of groundwater levels (known as the piezometric head distribution), subject to the interaction of features such as surface water bodies, water divides, and geological structures (e.g., faults, dykes), as well as any stresses imposed on the system (e.g., recharge or abstraction of groundwater). This enables the derivation of the spatial and temporal distribution of the groundwater flow directions and associated Darcy velocities.

With the groundwater flow regime characterised, the next step is to develop accompanying one-, two-, or three-dimensional conceptual and numerical mass transport models to characterise the transient leaching and migration of contaminants into the wider environment. Most often, the two steps are coupled, during which the solution of the groundwater flow equation is used as input to solve the mass transport equation.

In addition to the solution of the groundwater flow equation, the solution of the mass transport equation also requires the time-dependent source term release rate of contaminants from the

groundwater pathway sources into the underlying aquifer. The output is the spatial and temporal distribution and evolution of a contaminant plume on a grid that enables its representation as an isopleth map. This represents the *integrated contribution* from all relevant groundwater pathway sources over the timescale and area of concern.

The radiological impact of naturally occurring radionuclides through the groundwater pathway is generally a slow and retarded process, and even more so in the presence of a substantial unsaturated zone. This is due to the adsorption properties of the radionuclides and geosphere and the simulation times required for the long-lived radionuclides associated with the U-238, U-235, and Th-232 decay chains. The radiological impact is thus only visible after simulations of tens to thousands of years. For this reason, *Process Level* modelling of the groundwater pathway is often limited to conservative inorganic elements such as SO₄, or Cl, which represents the development of a contaminant plume without the absorption or reaction with the porous or fractured matrix.

2.2.3 Atmospheric Pathway

A similar approach to the groundwater pathway is used to characterise the behaviour of the atmospheric pathway. In this case, a numerical air dispersion model is developed to simulate the release and distribution of particulate matter or gases (e.g., radon or thoron) from the atmospheric pathway sources into the wider environment. The local atmospheric airflow field is subject to the prevailing meteorological conditions (e.g., wind, precipitation, barometric pressure, humidity, and temperature) as well as natural or human-induced topographical differences of the area. The meteorological conditions and thus the airflow field may vary on an hourly basis, between day and night, seasonally, or annually, which make quantifying the behaviour of the atmospheric pathway a very dynamic process.

Coupled with the atmospheric airflow field, is the subsequent dispersion of particulate matter or gases. This requires the quantification of the source term release rate from the various point and area sources, followed by the dispersion simulation of particles or gases into the environment as a function of time.

At least three quantities are of importance from a radiological perspective as far as particulate matter is concerned. The first is the airborne dust concentration, which is associated with a fraction smaller than 10 µm (or PM₁₀). This represents the inhalable (respirable) part of the released dust. The second is the fraction larger than 10 µm (TSP, or Total Suspended Particles). This fraction is what will be deposited into the environment. The third quantity is the release and subsequent dispersion of radon (or thoron) gas. The output is the spatial and temporal distribution of PM₁₀, airborne radon or thoron, and TSP on a grid that enables its representation as an isopleth map. This represents the *integrated contribution* from all relevant atmospheric pathway sources over the area of concern.

The radiological impact through the atmospheric pathway is dependent on the naturally occurring radionuclide composition of the individual sources and their relative contribution to the total dust or gas load. While this can be treated as part of the integrated modelling process, it is more effectively treated as a separate process outside the *Process Level* modelling step due to the number of radionuclides associated with the U-238, U-235, and Th-232 decay chains that have to be included in the *Process Level* model.

2.3 System Level Modelling

The aim of *System Level* modelling within the safety assessment framework is to integrate as many as possible of the system components into an integrated model, with the radiological impact in terms of a total effective dose as an endpoint. During the process, relevant information and input values are abstracted from the *Process Level* modelling in support of the *System Level* model.

A compartment model approach is often used for this purpose to represent the migration and fate of contaminants in the environment. According to Little *et al.* (2003), the use of a compartment model approach places two main constraints on the mathematical representation of a total system.

The first constraint is that the system must be discretised into a series of compartments. Using the compartment modelling approach, a system may be represented by breaking it down into compartments that can correspond to the components identified in the conceptual model. It is assumed that, as soon as a contaminant enters a compartment, instantaneous mixing occurs so that there is a uniform concentration over the whole compartment. Each compartment must be chosen to represent a system component for which this assumption is reasonable.

The second constraint is that processes resulting in the transfer of contaminants from one compartment to another need to be expressed as transfer coefficients that represent the fraction of the activity in a compartment transferred from that compartment to another per unit time. The mathematical representation of the intercompartmental transfer processes takes the form of a matrix of transfer coefficients that allow the compartmental amounts to be represented as a set of first-order linear differential equations.

For the i^{th} compartment, the rate at which the inventory of radionuclides in a compartment change with time is given by (Little *et al.*, 2003):

Equation 1

$$\frac{dN_i}{dt} = \left(\sum_{j \neq i} \lambda_{ji} N_j + \lambda_N M_i + S_i(t) \right) - \left(\sum_{j \neq i} \lambda_{ij} N_i + \lambda_N N_i \right)$$

where i and j indicate compartments, N and M are the amounts (Bq) of radionuclides N and M in a compartment (M is the precursor of N in a decay chain). $S(t)$ is a time-dependent external source of radionuclide N (Bq y⁻¹). Transfer and loss rates are represented by λ . λ_N is the decay constant for radionuclide N (y⁻¹) and λ_{ji} and λ_{ij} are transfer coefficients (y⁻¹) representing the gain and loss of radionuclide N from compartments i and j . For simplicity, the above equation assumes a single parent and daughter. However, compartmental modelling software such as Ecolego® allows the representation of multiple parents and daughters.

The solution of the matrix of equations given above provides the time-dependent inventory of each compartment. Assumptions for compartment sizes then result in estimates of concentrations in the corresponding media, from which doses/intakes can be estimated.

The *System Level* modelling for this assessment is implemented in Ecolego® Version 7 (<https://www.ecolego.se/>), with a clear distinction between the sources, pathways and receptors. For this purpose, an abstraction of information from the *Process Level* model is needed in terms of pathway-specific parameter values. Ecolego® uses a compartment model approach to represent the migration and fate of contaminants in the environment. The system is discretised into a series of compartments and sub-compartments that correspond to the components identified in the conceptual model. It is assumed that as soon as a contaminant enters a compartment, instantaneous mixing occurs so that there is a uniform concentration over the whole compartment.

Note that it is not always possible or practical to include all system components into one *System Level* model. The contribution from the atmospheric pathway, for example, is dynamic and the radiological impact to members of the public may be from the first day of operation (i.e., present-day operational conditions). The contribution of the groundwater pathway, on the other hand, is slow and the potential radiological impact may only occur in the far future (e.g., hundreds of years from now). The timescales of concern, over which the potential radiological impact to members of the public may occur are thus different. For this reason, separate *System Level* models are often developed to evaluate the contribution from the atmospheric and groundwater pathways.

2.4 Model Implementation for the 2017 South Deep Gold Mine RPSA

2.4.1 General

Presented here is a brief overview of the model formulation and implementation approach for the 2020 South Deep Gold Mine RPSA. Consistent with the public exposure conditions defined for the assessment in the *Definition and Justification of Scenarios and Public Exposure Conditions* report (Aquisim, 2020b), the contribution of the atmospheric and groundwater pathway to a total effective dose is required. For this purpose, a combination of *Process Level* and *System Level* modelling is used, with the groundwater and atmospheric pathways considered separately (i.e., decoupled).

2.4.2 Groundwater Pathway

An integrated *Process Level* model that describes the groundwater flow regime and mass transport for the entire South Deep Gold Mine are not available at present. A quantitative interpretation of the groundwater flow regime and contaminant dispersion potential was presented in the *System Description* report (Aquisim, 2020c), based on available information from specialist reports. The information presented may include groundwater flow directions and the associated groundwater flow velocities (Darcy velocities) under steady-state conditions, as well as contaminant concentrations and predicted migration of contaminants in groundwater as a function of time. However, the model does not specifically address radionuclides as a potential contaminant in groundwater.

The coupled *System Level* model to quantify the contribution of the groundwater pathway is described in Section 3. It considers the potential leaching of radionuclides from the groundwater sources, the downward migration of the contaminants through the unsaturated zone to the

underlying aquifer, the mixing of contaminants with passing groundwater, and the migration of the contaminant plume through the aquifer to a receiving water body (e.g., river) or borehole.

The postulated groundwater flows direction and associated Darcy velocities serves as input into the *System Level* model. The *System Level* model provides as output the time-dependent breakthrough curve of naturally occurring radionuclides at a point of interest (in units of Bq.L⁻¹). The *System Level* model can thus be coupled with the various dose models to calculate the radiological impact through the groundwater pathway.

2.4.3 Atmospheric Pathway

Model implementation for the atmospheric pathway consists of a *Process Level* model based on the prevailing meteorological conditions and the source term release rates from the atmospheric pathway sources to provide the following as output:

- The spatial distribution (at grid points) of the annual average airborne dust concentration (PM₁₀) in the atmosphere (in units of µg.m⁻³);
- The spatial distribution (at grid points) of the annual average dust deposition rate of Total Suspended Particulates (TSP) into the environment (in units of mg.m⁻².day⁻¹); and
- The spatial distribution (at grid points) of the annual average airborne radon and thoron concentrations (in units of Bq.m⁻³).

The development of the *Process Level* model for the atmospheric pathway was done as part of an independent specialist study by ParcScientific (Parc Scientific, 2020). Parc Scientific (2020) describes the relevant conceptual, mathematical, and numerical models to quantify the above parameter values. The description of these models will not be repeated here.

One limitation of the atmospheric pathway *Process Level* model (at present) is that it is time-independent, and only represents the results for a given source term as input values. For this reason, the results are presented as annual averages, or as maximums. A *System Level* model for the atmospheric pathway may not be subject to these limitations. However, a *System Level* model will not be able to provide the spatial resolution a *Process Level* model provides.

The spatial distribution of the annual average airborne radon concentrations can be used directly to assess the contribution of radon and thoron inhalation to a total effective dose. The spatial distribution of PM₁₀ and TSP still must be multiplied with the radionuclide activity concentrations associated with the different sources. If the total contribution is from one source, then it is a simple case of multiplying the PM₁₀ (µg.m⁻³) and TSP (mg.m⁻².day⁻¹) values with the radionuclide specific activity concentration (Bq.g⁻¹) to get the radionuclide specific airborne activity concentration (µBq.m⁻³) and deposition rate (mBq.m⁻².day⁻¹).

If the contribution is from multiple sources, the relative contribution of each source to the PM₁₀ and TSP concentrations still must be multiplied with the radionuclide specific activity concentration of each source. The resulting values are summed over all sources to get the total radionuclide specific airborne activity concentration and deposition rate. The output from this process can be coupled with the dose models to calculate the radiological impact through the atmospheric pathway.

2.4.4 Dose Assessment Models

The processes described above are used to quantify the radionuclide specific activity concentrations in different environmental compartments (e.g., atmosphere or underlying aquifer). These radionuclides may be further transferred and distributed to other biosphere compartments (e.g., surface water, surface soils, crops, grass, sediments, animal products, etc.). Human interaction with these compartments will result and contribute to a total effective dose, subject to assumptions and their human behavioural conditions (e.g., the ingestion of crops or animal products or groundwater as a source of food or water). The dose models used for this purpose is presented in detail in Section 4.



3 System-Level Model for the Groundwater Pathway

3.1 General

The purpose of the *System Level* model for the groundwater pathway is to quantify the migration of radionuclides released from the relevant sources, through the underlying geosphere as a function of time. It assumes that the groundwater flow regime is well characterised using a *Process Level* modelling approach or - as a minimum - that a well-justified conceptual model exists that can be used to derive groundwater flow directions and associated Darcy velocities.

The section is structured as follows. Section 3.2 presents a conceptual understanding of the groundwater migration processes included in the *System Level* model. This is followed by a more detailed discussion of each of the possible compartments associated with the groundwater pathway. This includes the source term (Section 3.3), the unsaturated zone beneath the source (Section 3.4), the mixing zone (Section 3.5) in the saturated zone (Section 3.6) beneath the source (and unsaturated zone), the discharge of contaminated water to an abstraction borehole (Section 3.7), and the discharge of contaminated water to a river (Section 3.8).

3.2 Conceptual Understanding of the Groundwater Migration Processes

Figure 3.1 to Figure 3.3 present simplified representations of the groundwater pathway for different site-specific conditions. Viewed simplistically, the main components of the groundwater system are a source, an unsaturated zone of limited thickness, a saturated zone, a mixing zone between clean and contaminated water in the aquifer, and a receptor of groundwater contamination that could be in the form of an abstraction borehole or a surface water body such as a river or a lake. The source as used here could be a contaminated soil layer with a relatively limited thickness and lateral extent, a surface stockpile facility (e.g., Tailings Storage Facility or Waste Rock Dump) with a relatively large lateral extent and thickness, or a below-grade layer of contaminated waste material.

It is assumed that radionuclides contained in the source are released following the infiltration and dissolution of precipitation into and through the source. The radionuclides that leach from the source migrates vertically through the unsaturated zone towards the groundwater table (i.e., interface between the unsaturated and saturated zone). Upon entering the aquifer (saturated zone), mixing between contaminated and uncontaminated water will occur, after which the radionuclides migrate along with the groundwater flow path towards the downstream borehole or surface water body. Steady-state flow conditions are assumed for radionuclide migration. The processes consider advection, hydrodynamic dispersion, radioactive decay, and radionuclide sorption by the soil matrix. For the latter, instantaneous and reversible sorption described by a linear isotherm (also known as a K_d -model or sorption distribution coefficient) is assumed. Figure 3.1 is a conceptual representation of a source term with limited thickness and lateral extent, with a thick aquifer system that underlies the source, whereas Figure 3.2 and Figure 3.3 represents a shallow (thin) aquifer system and a relatively large lateral extent source term.

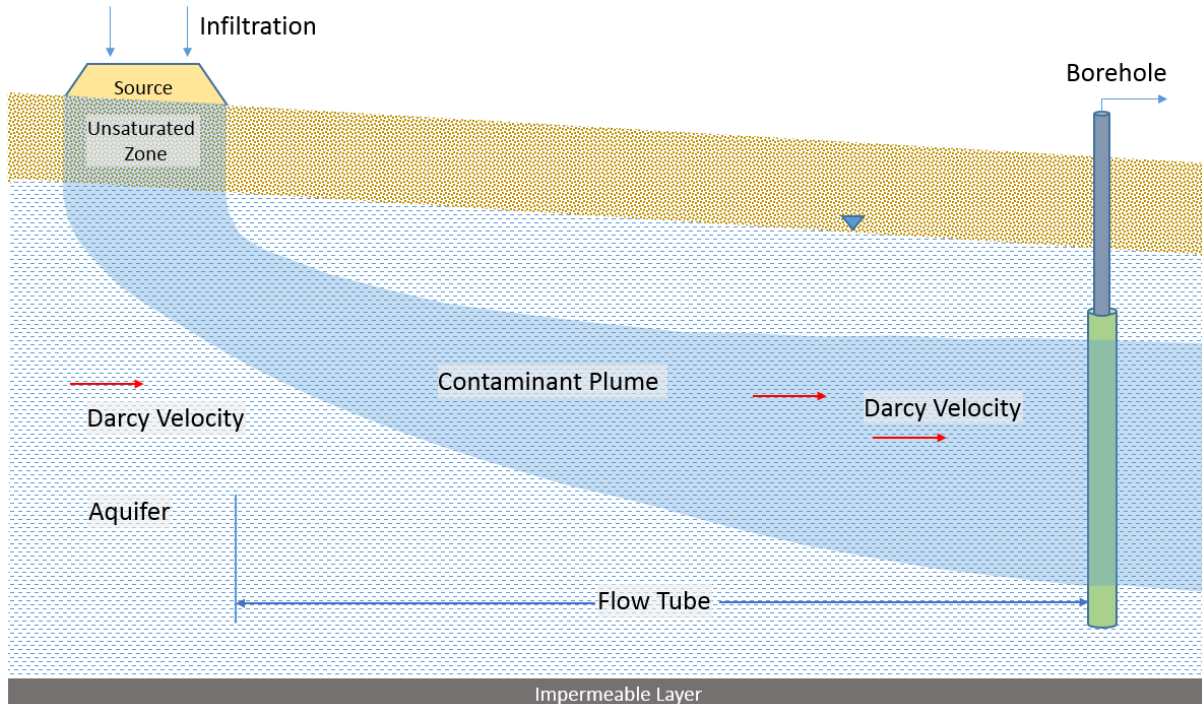


Figure 3.1 Schematic representation of the groundwater system to calculate the migration of radionuclides through a deep (thick) aquifer system and a relatively small lateral extent source term, with an abstraction borehole as a receptor.

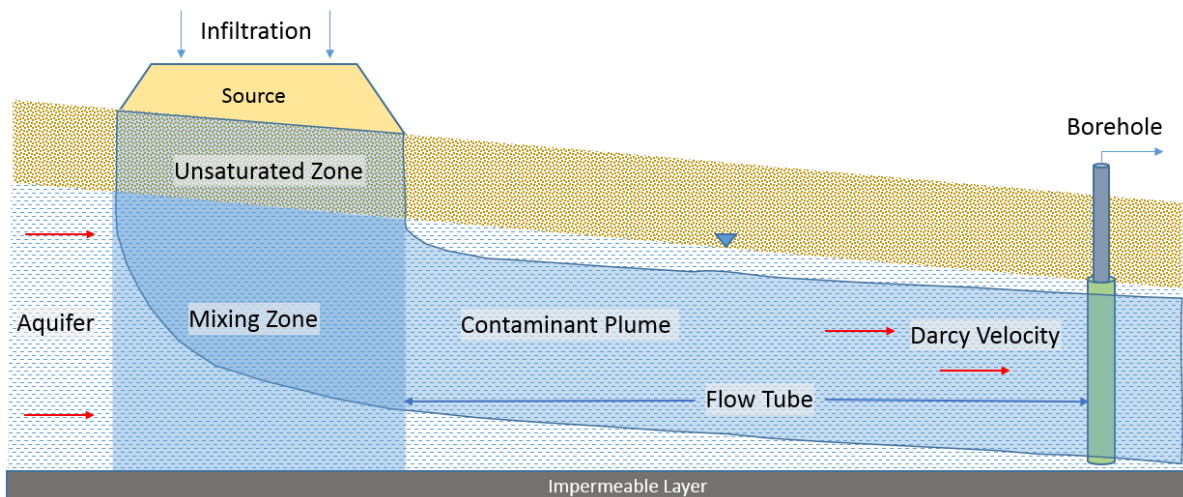


Figure 3.2 Schematic representation of the groundwater system to calculate the migration of radionuclides through a shallow (thin) aquifer system and a relatively large lateral extent source term, with an abstraction borehole as a receptor.

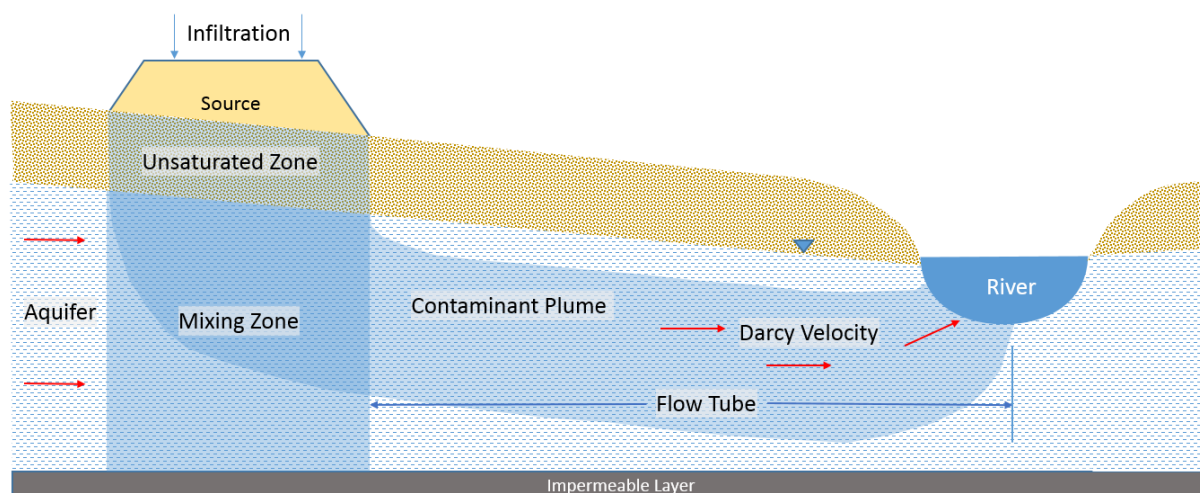


Figure 3.3 Schematic representation of the groundwater system to calculate the migration of radionuclides through a shallow (thin) aquifer system and a relatively large lateral extent source term, with a river as a receptor.

3.3 Source Term Model

Radionuclides present in a surface stockpile or a repository of contaminated water will migrate into its immediate surroundings and the subsurface of the ground at large, under the influence of molecular diffusion and hydrodynamic dispersion caused by infiltrating surface water. The rate of migration—commonly referred to as the *source term*—is one of the most important quantities to know in an assessment of this nature.

One certain property of the source term is that it must be related to the rate at which the nuclides leach from the source, i.e., the *flux* of dissolved nuclides. Advanced mathematical models based on the hydrodynamic dispersion equation can be used to describe this flux mathematically (Botha, 1996). However, some parameters required for this purpose is difficult to determine in the field, while some of the functions in the equation are generally unknown. Most of the methods used to compute the source term in radioactive waste disposal assessments, for example, therefore usually represent the source term as a mathematical function with adjustable parameters, or even as a constant.

The source term compartment represents the leaching of radionuclides from the source (e.g., TSF) to the unsaturated zone beneath the source or, in the absence of an unsaturated zone, directly to the saturated zone (aquifer). Figure 3.4 is a simple representation of the source and the most important parameters. The infiltration rate (m.y^{-1}) is assumed to be constant and equal to a fraction of the Mean Annual Precipitation (MAP). A variable infiltration rate over the lifetime of the facility would also require the moisture content in the source to vary. The source term model makes provision for the infiltrating water to contain radionuclide specific activity concentrations (Bq.m^{-3}).

If the source has a relatively thin vertical extent (thickness), then the source can be represented as a single compartment with homogeneous properties. If the source consists of layers of

materials with different properties, then the source term implemented in Ecolego may be represented as multiple compartments with different properties. A variation of the latter might be when the top layer does not contain naturally occurring radionuclides but serve as a cover layer. Note that the source layer(s) may be located above grade or below grade.

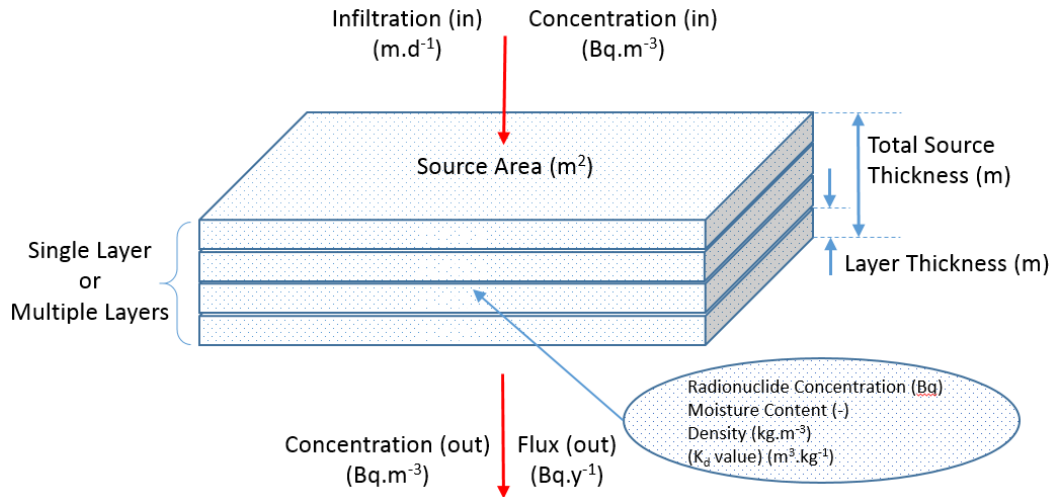


Figure 3.4 Conceptual representation and associated parameters values for the source term model.

Figure 3.4 shows that the source term model is a function of the radionuclide specific activity concentration (Bq), the volumetric moisture content ($\text{m}^3.\text{m}^{-3}$), the dry bulk density of the source material ($\text{kg}.\text{m}^{-3}$), and the radioelement specific distribution coefficient or K_d -value ($\text{m}^3.\text{kg}^{-1}$). The advective transfer coefficient in Equation 1 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 (2004) and Baes and Sharp (1983):

Equation 2

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

where I_w is the infiltration rate to the source layer ($\text{m}.\text{y}^{-1}$), 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 3

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

where, ρ_w is the soil bulk density in the source ($\text{kg}.\text{m}^{-3}$) and $K_{d,w}$ is the sorption distribution coefficient in the source ($\text{m}^3.\text{kg}^{-1}$). For multiple layers with different properties, the transfer coefficient is defined for each layer with the values of its associated parameters. Figure 3.4 shows that the output from the source term model is the radionuclide concentration ($\text{Bq}.\text{m}^{-3}$) or flux ($\text{Bq}.\text{y}^{-1}$) leaving the compartment.

A further variation of the conceptual model presented above is where the source has a significant vertical extent such as in the case of a TSF. Representing the source as a single compartment does not account for the dispersive fluxes within the source, which might be of importance for a thicker source. For this configuration, it is proposed that the migration of radionuclides from the source is represented using the Transport Block in Ecolego. The Transport Block divides the single compartment into several sub-compartments. The number of compartments **N** is determined automatically considering the accuracy of approximation of the advection-dispersion terms.

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, 2004):

Equation 4

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

where α_L is the longitudinal dispersivity (m) and H_i is the compartment thickness. Note that the transfer coefficient in Equation 4 represents the dispersion of radionuclides between the compartments in both directions.

3.4 Unsaturated Zone

The unsaturated zone compartment (if present) simulated radionuclide transport through that part of the geosphere between the source and the groundwater table (i.e., saturated zone), accounting for the advection, dispersion, radioactive decay and sorption. The unsaturated zone may vary from a few metres to tens of metres. Figure 3.5 is a simplified representation of the unsaturated 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 source (see Section 3.3). This means that under unsaturated flow conditions the associated moisture content is also constant in time. The radionuclide concentration (Bq.m⁻³) of water (moisture) entering the unsaturated zone is equal to the concentration flowing from the source.

It is assumed that the unsaturated zone is represented as one compartment of known thickness. The Transport Block in Ecolego is used to divide the single compartment into several sub-compartments **N**. The number of compartments **N** is determined automatically considering the accuracy of approximation of the advection-dispersion terms.

Figure 3.5 shows that the unsaturated zone model is a function of the volumetric moisture content (m³.m⁻³) and the dry bulk density of the unsaturated zone (kg.m⁻³), the radioelement specific distribution coefficient or K_d -value (m³.kg⁻¹) for the unsaturated soils, as well as the dispersivity (m). The advective and dispersive transfer coefficients in Equation 1 that represents the transfer and loss of radionuclides from the unsaturated zone to the saturated zone (aquifer) is similar to those presented in Equation 2 to Equation 4, except that it is for the unsaturated zone parameter values.

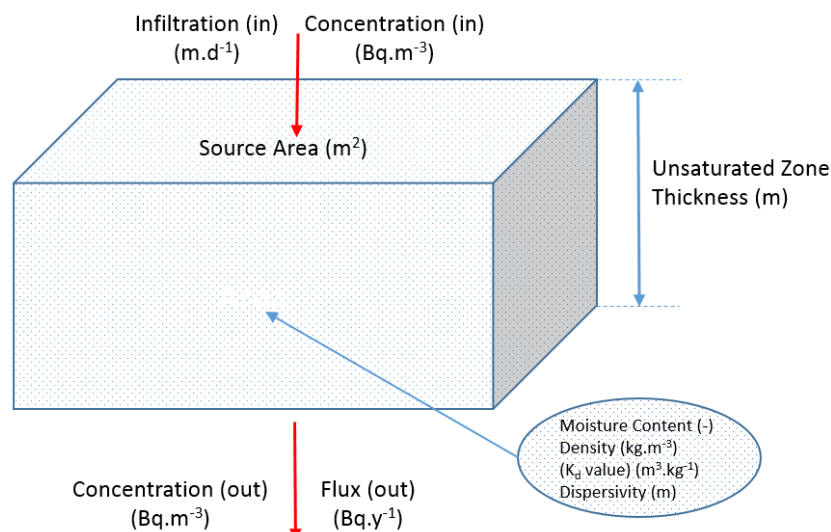


Figure 3.5 Conceptual representation and associated parameters values for the unsaturated zone model.

3.5 Aquifer Mixing

The aquifer mixing compartment simulates the aquifer zone immediately below the source. Contaminated water leaching from the source and the unsaturated zone (if present) will enter the saturated zone (aquifer) (i.e., infiltration flux). This water will be subject to mixing and dilution with clean (uncontaminated) water in the aquifer. It serves thus as a transition zone between the unsaturated zone and the aquifer. This compartment, therefore, transfers vertical transport in the unsaturated zone to the horizontal transport in the aquifer, the latter of which will be represented by a flow tube. This transition compartment is especially needed in cases where the source has a large aerial extent, while the aquifer has a relatively small thickness. It is assumed that groundwater coming into this compartment upstream from the source is uncontaminated (i.e., the radionuclide concentration is zero).

Figure 3.6 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 (see Section 3.4). 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) (see Section 3.6).

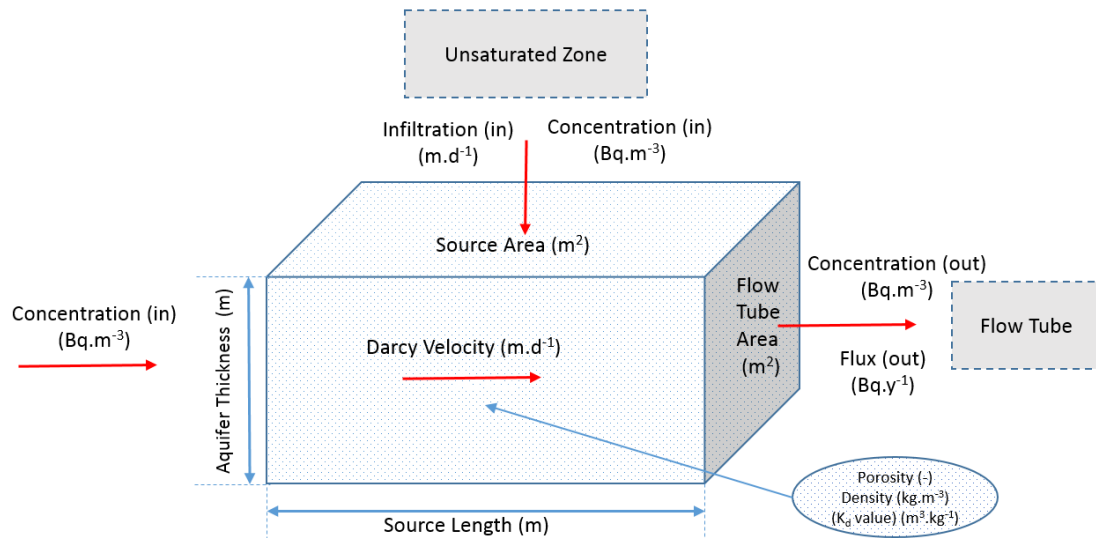


Figure 3.6 Conceptual representation and associated parameters values for the aquifer mixing zone model.

Figure 3.6 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 radioelement specific distribution coefficient or K_d -value ($\text{m}^3.\text{kg}^{-1}$) for the aquifer.

3.6 Aquifer (Saturated Zone)

The aquifer compartment simulates radionuclide transport in the saturated zone (flow tube), accounting for the advection, dispersion, radioactive decay, and sorption. Figure 3.7 is a simplified representation of the aquifer and the most important parameters. It is assumed that the aquifer is represented as one compartment of known dimensions, which is defined by the aquifer thickness, the area of the flow tube, and the length of the flow tube. The latter is defined by the distance to a receptor point (e.g., borehole or river). The Transport Block in Ecolego is used to divide the single compartment into several sub-compartments N . The number of compartments N is determined automatically considering the accuracy of approximation of the advection-dispersion terms.

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 (see Section 3.7) or discharge in the river (see Section 3.8).

Figure 3.6 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 ($\text{m}^3.\text{kg}^{-1}$) for the aquifer, and the dispersivity (m). The advective and dispersive transfer coefficients in Equation 1 that represents the transfer and loss of radionuclides from the aquifer is similar to those presented in Equation 2 to Equation 4, except that it is for the aquifer parameter values.

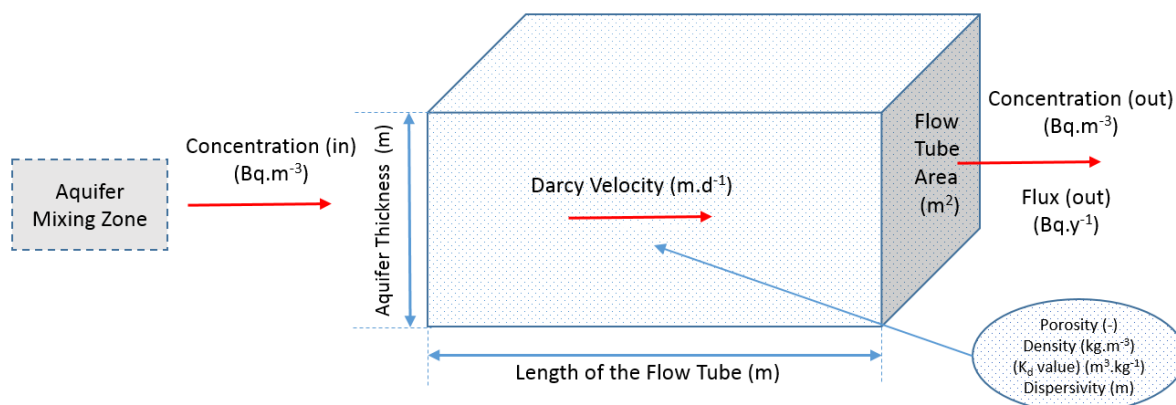


Figure 3.7 Conceptual representation and associated parameters values for the aquifer (saturated zone) model.

Note that the implementation of several aquifer models in Ecolego can be used to simulate a groundwater flow system with varying hydraulic and/or sorption properties.

3.7 Borehole Abstraction

The borehole abstraction module calculates radionuclide concentration in groundwater pumped from a borehole. It is assumed that some fraction of the borehole intersects the contaminated groundwater plume in the flow tube originating from the source, while the other part of the borehole intersects uncontaminated "background" groundwater. Figure 3.8 is a simplified representation of the borehole abstraction module and the most important parameters.

The concentration of the water abstracted from the borehole is simplistically taken as the sum of the flow tube concentration (Bq.m^{-3}) multiplied with 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.

Note that the conceptual representation presented above is conservative. Under site-specific conditions, abstracted groundwater from a borehole will draw water from uncontaminated areas and the contaminated water will consequently be diluted further.

3.8 River Discharge

The river discharge model accounts for the discharge of contaminated groundwater into a surface water body such as a river. This will result in the mixing of contaminated groundwater with uncontaminated river water. Figure 3.9 is a simplified representation of the river discharge module and the most important parameters.

The model assumes an incoming radionuclide concentration (Bq.m^{-3}) of groundwater equal to the concentration in the aquifer (flow tube). The contaminated water is then mixed with incoming surface water with known radionuclide concentration (assumed to be zero), and an incoming flow rate ($\text{m}^3.\text{y}^{-1}$).

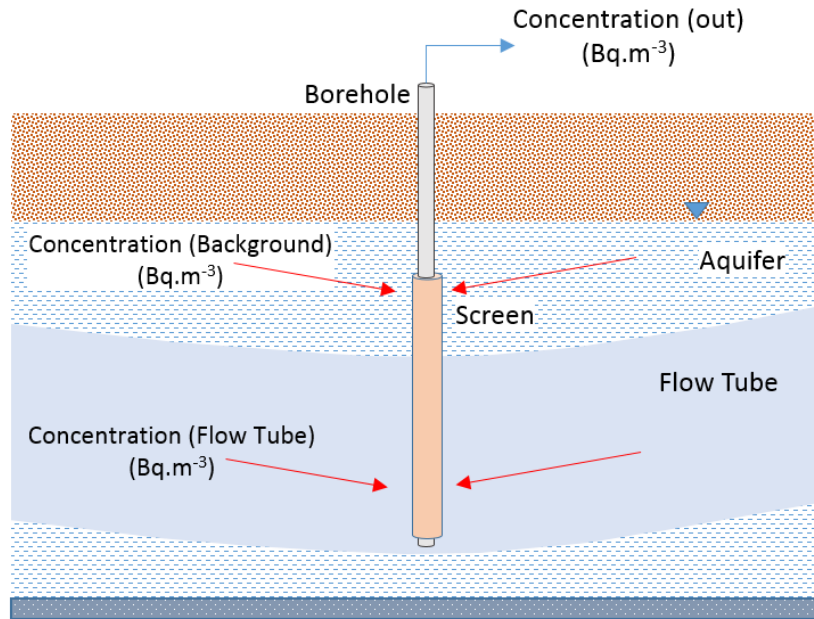


Figure 3.8 Conceptual representation and associated parameters values for the borehole abstraction model.

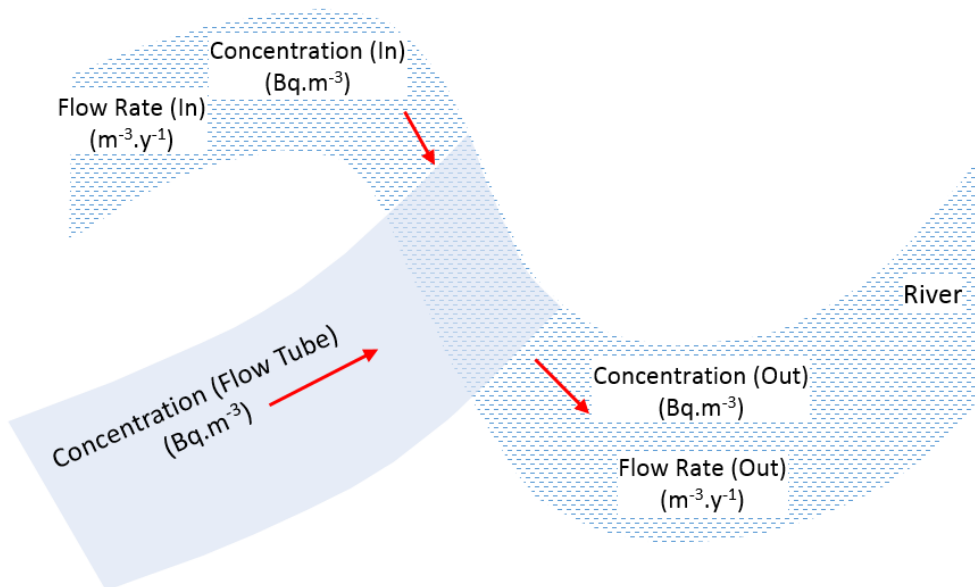


Figure 3.9 Conceptual representation and associated parameters values for the river discharge model.

The resulting flow rate in the river after the point of discharge is the sum of the incoming river flow rate and the incoming groundwater flow rate. The latter is defined as the product of the Darcy velocity and flow tube area. The resulting concentration in the river after the point of discharge is defined as follows:

$$Conc_{River,out} = \frac{Conc_{River,in} \cdot FlowRate_{River,in} + Conc_{FlowTube,in} \cdot DarcyVel \cdot Area_{FlowTube}}{FlowRate_{River,out}}$$

Following a *System Level Modelling* approach, the conceptual models require mathematical models or expressions to represent the environmental pathways and the biosphere analysis. The purpose of the environmental pathway analysis is to quantify the release and distribution of radioactivity through and into the environment. The purpose of the biosphere analysis is to quantify the dose contributions for the different exposure conditions.



4 Mathematical Expressions for Biosphere Analysis

4.1 General

The purpose of this section is to describe the mathematical equation and expressions necessary to evaluate the contribution of the biosphere to the total effective dose. The biosphere analysis assumes an input from the atmospheric or aquatic pathway analysis. The mathematical models required for this purpose is in the form of ordinary differential equations, supplemented with simple algebraic mathematical expressions as required. The following mathematical models and expressions are presented in this section:

- Calculation of the soil activity concentration as it will change with time due to deposition and irrigation (Section 4.2);
- Calculation of the concentration in crops (Section 4.3) and pasture (Section 4.4);
- Calculation of the concentration in animal products (Section 4.5);
- Calculation of the airborne radon concentration released from a surface source, both indoor and outdoor (Section 4.6); and
- Calculation of the total effective dose to members of the public due to direct ingestion of contaminated water, soil, fish, secondary crop and animal products, direct inhalation of contaminated airborne dust ($LL\alpha$) and radon gas, as well as from external exposure to contaminated air, soil, and water (Section 4.7).

Note that not all these equations may apply to the public exposure conditions developed for the 2020 South Deep Gold Mine RPSA but are presented here in the interest of transparency and completeness.

4.2 Soil Activity Concentration

The radionuclide concentration 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 radionuclide concentration in the soil rooting zone with time.

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

Equation 5

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

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, $Area$ (m²) 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 6

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

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, and 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 7

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

where $Rate_{dep}$ (Bq.m⁻².y⁻¹) is the deposition rate on the soil layer and $Area$ (m²) is the area of the soil layer. I_{rrig} (Bq.y⁻¹) is calculated by:

Equation 8

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

where $C_{water,irr}$ (Bq.m⁻³) is the radionuclide concentration in nearby irrigation water and $Rate_{irr}$ (m³.m⁻².y⁻¹) is the irrigation rate for the area. $\lambda_{Eros,DZ}$ (y⁻¹) is calculated by:

Equation 9

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

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 10

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

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 11

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

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

Equation 12

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

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

Equation 13

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

where I_{nfil} (m³.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, $\varepsilon_{soil,RZ}$ (m³.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 14

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

where $K_{d\ soil,RZ}$ (m³.kg⁻¹) is the distribution coefficient for the soil rooting zone. Similarly, $\lambda_{Leach,DZ}$ (y⁻¹) is calculated by:

Equation 15

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

where $\varepsilon_{soil,DZ}$ (m³.m⁻³) is the porosity of the soil rooting zone and Ret_{DZ} (-) is the retardation factor for the deep soil zone that can be calculated by:

Equation 16

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

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 17

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

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 18

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

4.3 Concentration in Crops

Soil contaminated with radionuclides could be used to grow crops. Crops potentially ingested by humans (e.g., vegetables, grains, or fruits) can become contaminated through several processes, which include deposition of dust, irrigation with contaminated water, internal transfer processes between the soil and the crops, and root uptake processes. The activity concentration in a crop (C_{crop} , in $Bq.kg^{-1}$) can be calculated using the following equation:

Equation 19

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

where C_{water} is the radionuclide concentration in the water ($Bq.m^{-3}$), C_{soil} is the radionuclide concentration in the soil ($Bq.kg^{-1}$) (see Equation 6), 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} are the crop growth days 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 ($\text{kg}\cdot\text{m}^{-2}$, 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 19 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 $Int_{crop} f_{growth} C_{water} I_{rate}$.

4.4 Concentration in Pasture

The concentration in the pasture is calculated using an equation similar to Equation 19, but without the food preparation loss term. The activity concentration in pasture (C_{past} , in $\text{Bq}\cdot\text{kg}^{-1}$) can be calculated using the following equation:

Equation 20

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

where C_{water} is the radionuclide concentration in the water ($\text{Bq}\cdot\text{m}^{-3}$), C_{soil} is the radionuclide concentration in the soil ($\text{Bq}\cdot\text{kg}^{-1}$), CF_{past} is the soil to pasture concentration factor ($\text{Bq}\cdot\text{kg}^{-1}$ fresh weight per $\text{Bq}\cdot\text{kg}^{-1}$ 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 ($\text{m}\cdot\text{y}^{-1}$) and Dep_{rate} is the deposition rate of airborne contaminants ($\text{Bq}\cdot\text{m}^{-2}\cdot\text{y}^{-1}$). Y_{past} is the pasture yield ($\text{kg}\cdot\text{m}^{-2}$, 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 Ing_{past} is the consumption rate of pasture by the animals ($\text{kg}\cdot\text{d}^{-1}$ fresh weight of pasture).

4.5 Concentration in Animal Products

The concentration in the animal product (C_{Anm}) can be calculated using the following equation:

Equation 21

$$C_{Anm} = CF_{Anm} [C_{past} CR_{Ap} + C_{water} CR_{Aw} + C_{soil} CR_{Asoil} + C_{sed} CR_{Ase}]$$

where CF_{Ann} 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_{Aseed} 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 22

$$C_{milk} = CF_{milk} [C_{past} CR_{Ap} + C_{water} CR_{Aw} + C_{soil} CR_{Asoil} + C_{sed} CR_{Aseed}]$$

where CF_{milk} is the concentration factor for the animal milk (d.L^{-1}), and the remaining parameters are listed above.

4.6 Equations to Calculate Airborne Radon Concentrations

4.6.1 General

Presented here are the equations to calculate the airborne radon concentration released from a mineralised stockpile facility (e.g., TSF, waste rock, ore stockpiles or leach residue), as well as the subsequent radon concentration in the air above such a facility.

4.6.2 Radon Release from Mineralised Stockpile Facility

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 radon 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 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 of the stockpile facility 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 23

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

where E is the emanation coefficient of the material (unitless) assumed to be 0.2, λ is the decay constant for Rn-222 ($2.06E-06 \text{ s}^{-1}$), 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 24

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

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 $1.10E-05 \text{ m}^2.\text{s}^{-1}$. 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 25

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

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 23 that requires this parameter ($\tanh \frac{z_r}{L_r}$), changes 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 ($>10 \text{ m}$) 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 covering layer on the radon flux of the facility is given by (IAEA, 2013):

Equation 26

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

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

4.6.3 Radon Concentration in Open Air

The associated airborne radon concentration at the surface of the stacked source material ($C_{Rn,air}$, $\text{Bq}\cdot\text{m}^{-3}$) can be approximated by the following equation:

Equation 27

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

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

4.7 Equations to Calculate the Total Effective Dose

4.7.1 General

Given the conceptual models for the public exposure conditions developed for the 2020 South Deep Gold Mine RPSA, equations for the following exposure pathways are needed:

- Effective dose rate from the ingestion of contaminated water, fish or soil;
- Effective dose rate from the ingestion of contaminated secondary crops (e.g., leafy and root vegetables, fruit, cereal);
- Effective dose rate from the ingestion of contaminated secondary animal products (e.g., meat, milk, eggs);
- Effective dose rate from external exposure to contaminated air, soil, and water; and
- Effective dose rate from the inhalation of contaminated airborne dust and radon gas.

4.7.2 Water Ingestion

The effective dose rate from the ingestion of contaminated water ($ED_{ing,water}$, in $\mu\text{Sv}\cdot\text{y}^{-1}$) 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 28

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

where C_{water} is the radionuclide concentration in the water ($\text{Bq}\cdot\text{m}^{-3}$), DC_{ing} is the dose coefficient for ingestion ($\mu\text{Sv}\cdot\text{Bq}^{-1}$), and CR_{water} is the individual annual water consumption rate ($\text{m}^3\cdot\text{y}^{-1}$).

4.7.3 Fish Ingestion

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

Equation 29

$$ED_{ing, fish} = C_{water} DC_{ing} B_p CR_{fish}$$

where C_{water} is the radionuclide concentration in the water (Bq.m^{-3}), DC_{ing} is the dose coefficient for ingestion ($\mu\text{Sv.Bq}^{-1}$), B_p (bioaccumulation factor) B_p is the ratio of the activity concentration in fish tissue to that in water ($\text{m}^3.\text{kg}^{-1} \text{ Bq.kg}^{-1}$ wet weight fish per Bq.m^{-3} water), and CR_{fish} is the individual annual fish consumption rate.

4.7.4 Soil Ingestion

The effective dose rate from the ingestion of contaminated soil ($ED_{ing, soil}$, in $\mu\text{Sv.y}^{-1}$) is calculated from measured or modelled radionuclide concentrations in the soil (e.g., using Equation 6, as required), multiplied with appropriate ingestion dose coefficients and soil consumption rates, and is given by:

Equation 30

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

where C_{soil} is the radionuclide concentration in the water (Bq.kg^{-1}), DC_{ing} is the dose coefficient for ingestion ($\mu\text{Sv.Bq}^{-1}$), and CR_{soil} is the individual annual soil consumption rate (kg.y^{-1}).

4.7.5 Secondary Crop Ingestion

The effective dose rate from the ingestion of contaminated crops ($ED_{ing, crop}$, in $\mu\text{Sv.y}^{-1}$) (e.g. fruit, cereals, leafy or root vegetables) is calculated as a summation of measured or modelled (using Equation 19) radionuclide concentrations of the secondary crop, multiplied with appropriate ingestion dose coefficients and crop consumption rates, and is given by:

Equation 31

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

where C_{crop} is the radionuclide concentration in the crop (Bq.kg^{-1}), DC_{ing} is the dose coefficient for ingestion ($\mu\text{Sv.Bq}^{-1}$), and CR_{crop} is the individual annual crop consumption rate (kg.y^{-1}).

4.7.6 Animal Product Ingestion

The effective dose from the ingestion of contaminated animal products ($ED_{ing,Anm}$, in $\mu\text{Sv.y}^{-1}$) (e.g. beef, mutton, pork, poultry, and eggs) is calculated from measured or modelled (using Equation 19) radionuclide concentrations of the secondary animal product, multiplied with appropriate ingestion dose coefficients and animal product ingestion rates, and is given by:

Equation 32

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

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

Equation 33

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

where C_{milk} is the radionuclide concentration in the animal product (Bq.L^{-1}), CR_{milk} is the individual annual milk consumption rate (L.y^{-1}), and DC_{ing} is the dose coefficient for ingestion ($\mu\text{Sv.Bq}^{-1}$).

4.7.7 External Gamma Irradiation: Water

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

Equation 34

$$ED_{Ext_w} = C_{water} DC_{ext_w} EP_w$$

where C_{water} is the radionuclide concentration in the water (Bq.m^{-3}), DC_{ext_w} is the dose coefficient for external gamma irradiation in water ($\mu\text{Sv.h}^{-1}$ per Bq.m^{-3}), and EP_w is the annual human exposure period to contaminated water (h.y^{-1}).

4.7.8 External Gamma Irradiation: Air

The effective dose from external exposure to contaminated air (ED_{Ext_a} , in $\mu\text{Sv.y}^{-1}$) is calculated from measured or simulated airborne radionuclide concentrations, multiplied with appropriate dose conversion coefficients for external gamma irradiation in air, and the period exposed to the

air. The external (cloud immersion) dose can be calculated using the following equation:

Equation 35

$$ED_{ext_air} = C_{air} DC_{ext_a} EP_a$$

where C_{air} is the radionuclide concentration in the air ($Bq.m^{-3}$), DC_{ext_w} is the dose coefficient for external gamma irradiation in the air ($\mu Sv.h^{-1}$ per $Bq.m^{-3}$), and EP_w is the annual human exposure period to contaminated air ($h.y^{-1}$).

4.7.9 External Gamma Irradiation: Soil

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

Equation 36

$$ED_{ext_soil} = C_{soil} DC_{ext_s} EP_s$$

where C_{soil} is the radionuclide concentration in the soil ($Bq.kg^{-1}$), DC_{ext_s} is the dose coefficient for external gamma irradiation to soil ($\mu Sv.h^{-1}$ per $Bq.kg^{-1}$), and EP_s is the annual human exposure period to contaminated air ($h.y^{-1}$).

4.7.10 Inhalation of LLα

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

Equation 37

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

where $C_{LL\alpha}$ is the airborne activity concentration for LLα in the air ($Bq.m^{-3}$), DC_{inh} is the dose coefficient for inhalation ($\mu Sv.Bq^{-1}$), EP_h is the human exposure (occupancy) period to the LLα airborne concentration ($h.y^{-1}$), and BR_h is the human air breathing rate ($m^3.h^{-1}$).

4.7.11 Inhalation of Airborne Radon

There seems to be no international consensus on the calculation of doses from inhaled radon decay products (Kozak, 2007). ICRP (1993) has recommended that the model of the human respiratory tract should not normally be used for calculating doses from radon decay products for

the assessment of risks. Radon gas is not absorbed or deposited in the lung and does not provide a dose through the inhalation pathway. The primary concern related to inhalation of radon gas is the dose received from short-lived progeny (Kozak, 2007). Radon daughters produced in the air quickly attach to aerosols and respiratory surfaces (Kozak, 2007). Consequently, concentrations of progeny are typically somewhat lower than their equilibrium concentrations. The departure from equilibrium is commonly called the equilibrium factor, F , which relates the alpha energy of the mixture of daughters to the alpha energy of an equilibrium mixture (Kozak, 2007). The radon inhalation dose (ED_{Inh_Rn} , $\mu\text{Sv.y}^{-1}$) can also be calculated using the following equation:

Equation 38

$$ED_{Inh_Rn} = C_{Rn} EP_h DC_{Rn}$$

where C_{Rn} is the airborne radon concentration (Bq.m^{-3}), EP_h is the human exposure (occupancy) period to the airborne radon (h.y^{-1}), and DC_{Rn} is the radon inhalation dose coefficient (mSv.h^{-1} per Bq.m^{-3}) (see Table 5.8).



5 Parameter Values

5.1 General

The purpose of this section is to summarise and discuss the biosphere parameter values needed for the mathematical equations and expressions presented in Section 4. Ideally, the parameter values used in an assessment should be based on site-specific conditions and human behavioural characteristics. This is seldom possible, which means that the analysis has to resort to literature values, supplemented with guidance provided by the NNR in RG-002 (NNR, 2013).

It should be noted that the equations presented in Section 4 do not claim to be the *only* and *right* representation of the biosphere system processes. Conceptually, one may view these processes in more than one way. Similarly, the parameter values presented in this section is one of a set derived from literature and judged to be appropriate for the assessment. In the absence of site-specific values, the analyst has no alternative but to resort to literature values or values from similar (or analogue) sites to perform the consequence analysis.

The section is structured in the following manner. Section 5.2 presents radionuclide and element dependent data, while Section 5.3 presents conversion factors that can be used to calculate the radiological dose to members of the public from the uptake of radioactivity from the environment. Section 5.4 presents the environmental transfer factors for soil to plants and animal feed to animal products. Section 5.4 presents biosphere parameter values related to the distribution of radioactivity to plants, animals, soil, and water. Section 5.6 presents the human habits parameters values related to ingestion, inhalation, and external exposure, as well as variations in the parameter values as applicable to the different exposure conditions defined for the 2020 South Deep Gold Mine RPSA.

5.2 Radionuclide and Element Dependent Data

It follows from the *Assessment Context* report (Aquisim, 2020a) that the contaminants of concern are those naturally occurring radionuclides and their progeny associated with the U-238, Th-232 and U-235 decay series. These decay series and their radiological properties are illustrated schematically in Figure 5.1 and listed in Table 5.1 to Table 5.3.

Where applicable, radioactive decay and decay product in-growth are considered in the assessment. This serves the dual purpose of avoiding overly conservative results, in the case of slower transport processes, as well as accounting for impacts related to the radioactive decay products. Where analytical results on the radioactive decay products are not available, the following secular equilibrium assumptions between parent and progeny are applied:

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

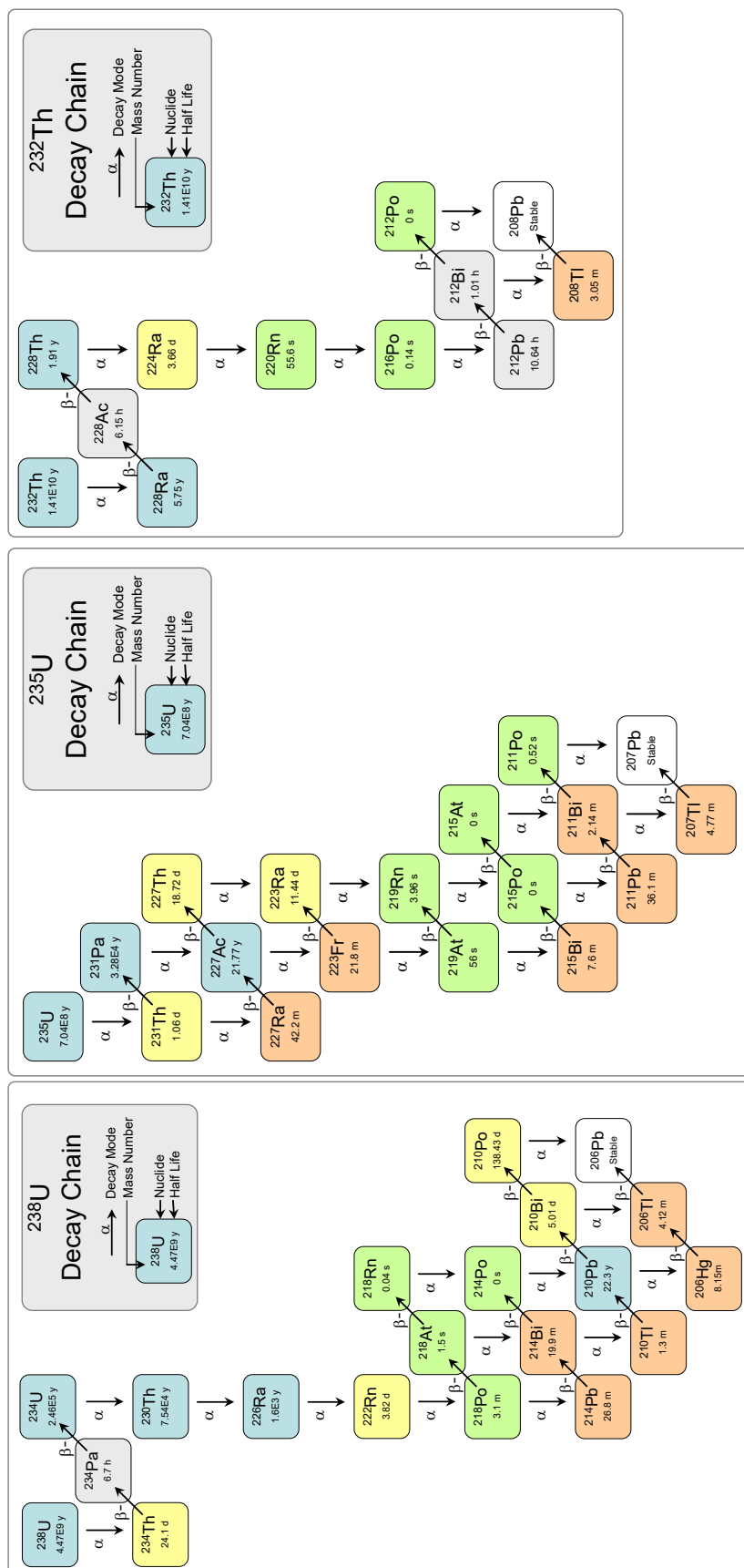


Figure 5.1 Schematic illustrations of the U-238, U-235, and Th-232 decay chains.

Table 5.1 Radiological properties for the Actinium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Unit	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 5.2 Radiological properties for the Thorium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Unit	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
Thorium	Th-228	α	1.913E+00	y	3.623162E-01	1.913100E+00	3.623162E-01	228.03	3.032544E+16
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

Table 5.3 Radiological properties for the Uranium decay chain of radionuclides.

Element	Radionuclide	Decay Mode	Half-Life	Unit	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

5.3 Dose Conversion Factors

5.3.1 General

The estimation of the **total effective 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. Calculation of the internal effective dose contribution requires an indication of the unit rate of activity intake (product of activity concentration in the material ingested or inhaled, and the associated ingestion or inhalation rate) and an estimate of the dose per unit intake of activity (see Section 4).

In addition to ingestion and inhalation, radioactivity may also enter the body through the skin, which constitutes external gamma 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 the outside. This situation is in contrast with the intake of radionuclides by inhalation or ingestion, where the radiations are emitted inside the body.

5.3.2 Internal Exposure

The International Commission on Radiological Protection (ICRP) has developed biokinetic and dosimetry models to derive effective dose conversion factors to calculate the effective dose per unit intake of activity through ingestion and inhalation. These models use a compartmental modelling approach to determine the distribution of cumulated radionuclides within the body, taking account of physical half-life; that is, to calculate the number of decays in different regions of the body. The resulting effective dose conversion factors (in units of Sv.Bq⁻¹) are published in ICRP Publication 72 (ICRP, 1996).

As indicated in the *Assessment Context* report (Aquisim, 2020a), the most pertinent national guidance currently available for conducting prior and operational radiological public safety assessments for mining and mineral processing operations is RG-002 (NNR, 2013). This regulatory 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 documents (IAEA, 2014). The dose conversion factors published in RG-002, make a distinction between the different age groups listed in Table 5.4.

Generally, the populations evaluated for radiation exposure are made up of individuals with a range of ages. The specific ages that dose conversion factors are published for are therefore taken to apply to age group ranges, which include these specified ages. Table 5.4 lists the age groups to which the age-specific dose conversion factors can be applied.

Table 5.5 and Table 5.6 list the effective inhalation and ingestion dose conversion factors, respectively, for the radionuclides presented in Section 5.2 and as published in RG-002.

Table 5.4 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	Age Group Used in the Assessment
New-born	From 0 to 1 year of age	0 to 2 years
1 Year	From 1 year to 2 years	
5 Year	More than 2 years to 7 year	2 year to 7 year
10 Year	More than 7 years to 12 years	7 year to 12 years
15 Year	More than 12 years to 17 years	12 years to 17 years
Adult	More than 17 years	Adults

Table 5.5 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 5.6 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

5.3.3 External Exposure

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 independent of the age of the person exposed and the conversion factors are, therefore, age-independent. Table 5.7 lists the external exposure dose conversion factors for the radionuclides presented in Section 5.2 as presented 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.

Table 5.7 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.s ⁻¹ .Bq ⁻¹ .m ⁻²	Sv.s ⁻¹ .Bq ⁻¹ .m ⁻³	Sv.s ⁻¹ .Bq ⁻¹ .m ⁻³
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

5.3.4 Radon Inhalation

According to the IAEA Basic Safety Standard (BSS) (IAEA, 1996), the annual dose conversion factor for radon¹ is given by:

¹ Ratio of PAEC (Potential Alpha Energy Concentration) and EEC (Equilibrium Equivalent Concentration) of Radon.

$$\frac{5.56 \times 10^{-6} \text{ mJ.m}^{-3}}{\text{Bq.m}^{-3}}$$

Assuming the UNSCEAR worldwide occupancy factor of 0.8 indoors and 0.2 outdoors, and equilibrium factors of 0.4 and 0.8 for indoor and outdoor exposure respectively, the annual indoor and outdoor exposure to radon progeny per unit radon concentration is given by:

$$\frac{1.56 \times 10^{-2} \text{ mJ.h.m}^{-3}}{\text{Bq.m}^{-3}} \text{ or } \frac{7.83 \times 10^{-3} \text{ mJ.h.m}^{-3}}{\text{Bq.m}^{-3}}$$

The dose conversion convention for effective dose per unit exposure to radon progeny to members of the public is given by (IAEA, 1996):

$$\frac{1.1 \text{ mSv}}{\text{mJ.h.m}^{-3}}$$

The combined annual indoor and outdoor radon inhalation dose conversion factor (DCF_{Rn}) is then:

Equation 39

$$\frac{(1.72 \times 10^{-2} \text{ mSv} + 8.61 \times 10^{-3} \text{ mSv})}{\text{Bq.m}^{-3}} \text{ or } \frac{2.57 \times 10^{-2} \text{ mSv}}{\text{Bq.m}^{-3}} \text{ or } \frac{25.7 \mu\text{Sv}}{\text{Bq.m}^{-3}}$$

Table 5.8 lists the parameter values necessary to derive the radon inhalation dose conversion factor using indoor and outdoor exposure periods of 7,000 and 1,760 hours per annum, respectively.

Table 5.8 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				

5.4 Environmental Transfer Factors

5.4.1 General

The environmental transfer factors presented here include the transfer of activity from soil to plants, or from plants to animal products, or the accumulation of activity in fish. It also includes the adsorption of activity onto soil particles, or the distribution coefficient (also known as the K_d -value).

5.4.2 Soil to Plant Uptake Factors

The transfer of radionuclides from soil to plants is commonly described by the transfer factor, F_v , defined as:

The ratio of the dry weight concentration in the plant to the dry weight concentration in the specified soil. For fruit, F_v is the concentration ratio of the wet weight concentration in the fruit to the dry weight concentration in the soil.

The transfer 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. Table 5.9 compares the concentration factors from soil to crops as prescribed in RG-002 (NNR, 2013) to various literature values. RG-002 presents some values for different soil groups. In all cases, the value for 'all' soils was taken for comparison to literature values. Comparison of the values listed in Table 5.9 shows that the values prescribed by RG-002 are conservative and often represents the upper end in a range of values. The values from RG-002 is obtained from the most recent literature resource and are used in the analysis. Where data for specific nuclides are not available from RG-002, the values from Staven *et al.* (2003) are used.

5.4.3 Animal Feed to Animal Products Transfer Factors

Table 5.10 compares the transfer factors from animal feed to animal products (e.g., meat, milk, poultry and eggs) prescribed in RG-002 (NNR, 2013) to various literature values. The transfer of radionuclides from an animal feeds to milk is commonly described by using the transfer coefficient F_m defined as:

The fraction of the animal's total daily intake of a radionuclide that is transferred to each litre of milk per day.

The values for milk listed in Table 5.10 taken from RG-002 apply to cow milk only. However, the values from other references may be applied to cow, goat, and sheep milk.

The transfer of radionuclides from animal feed (pasture, grass, forage) to edible animal products are commonly described by using the transfer coefficient F_f defined as:

The fraction of the animal's total daily intake of a radionuclide that is transferred to each kg of flesh at equilibrium or at the time of slaughter.

Table 5.9 Soil to secondary crop transfer 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, 2001)
8.3E-04	1.8E-04	4.9E-03	1.0E-03	1.1E-05	1.1E-04	1.1E-04	(De Beer, <i>et al.</i> , 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 <i>et al.</i> , 1999)
1.7E-03	3.6E-04	9.8E-03	2.0E-03	2.4E-04	9.4E-05	9.4E-05	(Staven <i>et al.</i> , 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, 2001)
2.2E-03	4.8E-05	7.8E-03	1.6E-03	1.8E-05	1.8E-04	1.8E-04	(De Beer, <i>et al.</i> , 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 <i>et al.</i> , 1999)
3.0E-03	8.5E-05	5.0E-04	1.5E-03	1.8E-03	8.8E-05	8.5E-05	(Staven <i>et al.</i> , 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, <i>et al.</i> , 2002)
7.2E-04	4.5E-05	1.1E-03	1.8E-03	2.2E-04	4.5E-05	4.5E-05	(Staven <i>et al.</i> , 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, 2001)
1.1E-03	2.9E-05	1.0E-03	4.0E-03	4.4E-04	4.4E-04	4.4E-04	(De Beer, <i>et al.</i> , 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 <i>et al.</i> , 1999)
1.2E-03	3.1E-05	1.1E-03	4.3E-03	2.1E-03	2.0E-05	2.0E-05	(Staven <i>et al.</i> , 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 <i>et al.</i> , 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, 2001)
2.3E-02	1.1E-02	8.0E-02	1.1E-03	2.0E-02	2.0E-02	2.0E-02	(De Beer, <i>et al.</i> , 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 <i>et al.</i> , 1999)
8.3E-03	1.8E-03	4.9E-02	1.0E-02	1.2E-03	4.7E-04	4.7E-04	(Staven <i>et al.</i> , 2003)
Average Crop Transfer Factors							Reference
2.7E-03	3.9E-04	1.0E-02	4.0E-03	1.3E-03	1.2E-04	1.2E-04	(Staven <i>et al.</i> , 2003)
(1) Transfer 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 is specifically for maize. (4) The animal feed from grain is for maize stalks and roots, which are commonly used as animal feed.							

Table 5.10 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 Factors 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, 2001)
3.4E-04	9.0E-04	9.4E-04	4.0E-04	5.0E-03	5.0E-03	5.0E-03	(De Beer, <i>et al.</i> , 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 <i>et al.</i> , 1999)
3.0E-04	4.0E-05	9.0E-04	4.0E-04	5.0E-03	4.0E-05	4.0E-04	(Staven <i>et al.</i> , 2003)
Transfer Factors 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, 2001)
4.0E-04	1.7E-06	1.3E-03	2.0E-04	1.0E-03	1.0E-03	1.0E-03	(De Beer, <i>et al.</i> , 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 <i>et al.</i> , 1999)
4.0E-04	5.0E-06	1.3E-03	2.6E-04	3.4E-04	5.0E-06	2.0E-05	(Staven <i>et al.</i> , 2003)
Transfer Factors 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, <i>et al.</i> , 2002)
1.0E+00	6.0E-03	3.0E-02	8.0E-01	2.3E+00	6.0E-03	6.0E-03	(Staven <i>et al.</i> , 2003)
Transfer Factors 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 <i>et al.</i> , 2002)
1.0E+00	4.0E-03	3.1E-01	1.0E+00	7.0E+00	4.0E-03	4.0E-03	(Staven <i>et al.</i> , 2003)

The beef values listed in Table 5.10 are for all types of beef products but may also be applied to pigs, goats, horses, and game animal products. The poultry values may be applied to all types of poultry. The values from RG-002 are used in the analysis. Where transfer coefficients for specific elements or animal products are not available from RG-002, values from Staven *et al.* (2003) are used.

5.4.4 Fish Bioaccumulation Factor

Under equilibrium conditions, the incorporation of radioactivity into fish can be expressed as the bioaccumulation factor B_p defined as:

The ratio of the activity concentration in fish tissue to that in water, which is expressed as Bq.kg⁻¹ wet weight fish per Bq.kg⁻¹ (or L⁻¹) water (units of L.kg⁻¹).

The activity concentration in fish tissue refers to the edible portion (muscle) of the fish wet mass. Table 5.11 lists the bioaccumulation factors compiled from various references. Table 5.11 shows that RG-002 values are different from older literature values. However, RG-002 values are used in the assessment. Where data for specific nuclides are not available from RG-002, the values from Staven *et al.* (2003) are used.

Table 5.11 Concentration factors from contaminated water to fish in L.kg⁻¹ compiled from various sources.

Concentration Factors for Freshwater Fish (L.kg ⁻¹)							Reference
U	Th	Ra	Pb	Po	Pa	Ac	
0.96	6	4	25	36	-	-	RG-002
10	100	50	300	50	10	30	(IAEA, 2001)
10	100	50	300	50	10	-	(IAEA, 1994)
2 to 50	30 - 10 ⁴	10 - 200	100 - 300	10 - 500	-	-	(IAEA, 1994)
10	30	50	200	50	50	800	(Penfold <i>et al.</i> , 1999)
10	100	50	300	50	10	25	(Staven <i>et al.</i> , 2003)

5.4.5 Distribution Coefficients (K_d-values)

Table 5.12 lists soil distribution coefficients for selected radionuclides published in RG-002 (NNR, 2013). For comparison, the list includes the range of values (minimum, maximum and geometric mean) from a literature review of radioactive material in the soil as published by the Argonne National Laboratory (Yu *et al.*, 1993). The comparison shows that the value of the distribution coefficient can vary significantly and that the values from RG-002 are on the more conservative lower end of the spectrum indicating higher radionuclide mobility in a groundwater system, for example.

Table 5.12 Soil distribution coefficients (K_d-values) for the elements of concern (NNR, 2013; Yu *et al.*, 1993).

Element	RG-002	Comparative Values			
		Sand	Loam	Clay	Resrad Default
	K _d -values (m ³ .kg ⁻¹)				
Th	1.9	3.2	3.3	5.8	60
Ra	2.5	0.5	36	9.1	0.07
U	0.2	0.35	0.02	1.6	0.05
Pb	2	0.27	16	0.55	0.1
Po	0.21	0.15	0.4	3	1.58
Pa	2	0.55	1.8	2.7	0.05
Ac	1.7	0.45	1.5	2.4	0.02

5.5 Biosphere Characteristics

5.5.1 Plant Parameters

Table 5.13 lists the data and parameter values required to calculate the interception and translocation of radionuclide to crops and pasture following deposition of dust and irrigation water onto the crops and pasture, as well as the transfer of radionuclides in the soil and as contamination on the crops and pasture, to the internal parts of the crops as plants. Also listed in Table 5.13 is the data and parameters values required to calculate the reduction of radionuclides on crops and pasture (e.g., weathering rates, and through food preparation).

Table 5.13 Parameters used in describing radionuclide uptake in plants and crops.

Parameter	Unit	Root	Leafy	Fruit	Cereal	Forage	Grain	Hay
Crop Yield	kg.m ⁻²	2.4	2.9	2.4	0.4	1.9	0.7	1.9
Growing Period	Days	90	45	90	90	30	90	45
Translocation Factor	-	0.1	1	0.1	0.1	1	0.1	1
Fraction loss due to food Preparation	-	0.9	0.9	0.9	0.9	0.0	0.0	0.0
Weathering rates	y ⁻¹	18	18	18	18	18	18	18
Crop Interception Factor	-	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Soil contamination of crop	-	0.002	0.001	0.004	0.003	0.001	0.001	0.001
Mass Interception Factor	m ⁻² .kg ⁻¹	0.3	0.3	0.3	3	3	3	3

5.5.2 Animal Habit Parameters

Table 5.14 compares the animal water, soil and fodder consumption rates for beef, sheep/goat/pig and poultry prescribed in RG-002 (NNR, 2013) to various literature values. Table 5.14 shows that the RG-002 values are realistic and within the ranges of values published in the literature.

Table 5.14 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, 2001)
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 <i>et al.</i> , 1999)
20 to 100	10 to 25	-	(IAEA, 1994)
50 to 60	25	0.5	
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, 1994)
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, 1994)
0.3	0.15	0.01	

5.5.3 Soil Concentration

Depending on the nuclide specific decay constant and the distribution coefficients used to calculate the soil concentration, it will take tens to thousands of years before equilibrium conditions exist concerning activity concentrations in soil following deposition or irrigation. Table 5.15 lists the constant parameter values required to evaluate Equation 5 to Equation 18 for

different areas of application (e.g., cropland, garden, open land, or pasture). Other parameters required to evaluate these equations include the soil distribution coefficients (K_d -values) listed in Table 5.12, soil to plant transfer factors listed in Table 5.9 and the nuclide specific decay constants listed in Table 5.1 to Table 5.3. A distinction is made between the root zone of the soil and the deep zone.

Table 5.15 Constant parameter values necessary to calculate the soil concentration as a result of the deposition of contaminated dust or irrigating with contaminated water (Beyeler *et al.*, 1999; IAEA, 2003).

Description		Units	Cropland	Garden	Open land	Pasture
Area		m ²	1	1	1	1
Bioturbation		kg.m ⁻² .y ⁻¹	8.2	8.2	8.2	8.2
Erosion Rate of Soils		kg.m ⁻² .y ⁻¹	0.108	0.108	0.108	0.108
Infiltration Rate into the Topsoil Layer		m.y ⁻¹	0.3	0.3	0.3	0.3
Irrigation Rate into the Topsoil Layer		m ³ .m ⁻² .y ⁻¹	0.3	0.3		0.3
Number of Crops Harvested per year		y ⁻¹	1	1		1
Root Soil Zone						
Moisture Content		m ³ .m ⁻³	0.25	0.25	0.25	0.25
Dry Bulk Density		kg.m ⁻³	1800	1800	1800	1800
Porosity		-	0.3	0.3	0.3	0.3
Depth of Soil		m	0.3	0.3	0.3	0.3
Distribution Coefficient (K _d -value)	Ac	m ³ .kg ⁻¹	0.45	0.45	0.45	0.45
	Pa		0.55	0.55	0.55	0.55
	Pb		0.27	0.27	0.27	0.27
	Po		0.15	0.15	0.15	0.15
	Ra		0.5	0.5	0.5	0.5
	Rn		0	0	0	0
	Th		3.2	3.2	3.2	3.2
	U		0.35	0.35	0.35	0.35
Deep Soil Zone						
Moisture Content		m ³ .m ⁻³	0.25	0.25	0.25	0.25
Dry Bulk Density		kg.m ⁻³	1800	1800	1800	1800
Porosity		-	0.3	0.3	0.3	0.3
Depth of Soil		m	0.3	0.3	0.3	0.3
Distribution Coefficient (K _d -value)	Ac	m ³ .kg ⁻¹	0.45	0.45	0.45	0.45
	Pa		0.55	0.55	0.55	0.55
	Pb		0.27	0.27	0.27	0.27
	Po		0.15	0.15	0.15	0.15
	Ra		0.5	0.5	0.5	0.5
	Rn		0	0	0	0
	Th		3.2	3.2	3.2	3.2

5.6 Human Habit Parameters

5.6.1 Human Ingestion Rates

To quantify the contribution that ingestion of contaminated water, food and animal products makes to the total effective dose, require assumptions regarding the rate at which these products are consumed. RG-002 (NNR, 2013) proposes age-specific ingestion rates for water, soil and various agricultural products.

Table 5.16 compares the RG-002 values against ranges of ingestion rates for adult members of the public published in NUREG-5512 Vol. 4 (Haaker *et al.*, 1999). The comparison shows that the values prescribed in RG-002 fall within the range of literature values and are appropriately scaled to the South African population. However, the value for grain ingestion prescribed by RG-002 is excessively high. This grain ingestion value is based on the reliance of a large proportion of the South African population on maize meal as a staple food. Although this may be the case and the value may be appropriate to reflect this dietary phenomenon in some areas, it is unlikely that this amount of maize will be sustainable from a single source on an annual basis.

Table 5.16 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

The intention of the ingestion rates, as used in the calculation of the effective dose received through the ingestion of farm produce, is to reflect the intake of these foodstuffs obtained from the contaminated source. Often the entire annual ingestion rate of a commodity or product is used as it may not be unreasonable to assume that that amount may be obtained from a single source. This is admittedly a conservative assumption and is made in the interest of protecting members of the public. Considering this, it is unreasonable to expect that one person may be able to obtain as much as 250 kg of maize (dry weight) per year from a single contaminated source. This equates to 0.7 kg of maize per day. Given that in the order of 0.17 kg (or 250 ml) dry weight maize is enough for 2 meals per day, this means that 0.7 kg equates to 8 meals (conservatively) per day. This means that this consumption rate (viewed conservatively) is about 4 times to 5 times too high, if no other food is consumed, and that the member of the public consumes maize twice a day for 365 days per year.

When one starts to consider a family of four adults that grow a few maize plants in their home garden or a community of few tens of people receiving their share of maize grown in a community garden, this figure becomes unrealistic and unsustainable on an annual basis. For this assessment, it is thus assumed that a member of the public obtains no more than 10% of his or her annual intake of grain (25 kg for adults) from a local field or garden where these may have become contaminated.

Table 5.17 lists the ingestion rates for the different age groups as derived from the adult values presented in RG-002. The values for the other age groups are taken as a percentage of the adults' annual ingestion rate according to the values listed in the first row of Table 5.17. Where values for specific agricultural products are not available from RG-002, the values listed under the 'Average' column in Table 5.16 are used. The adjusted ingestion rate for grain, as discussed above, is applied.

Table 5.17 Ingestion rates for different age groups as defined from the adult ingestion rates in Table 5.16.

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 ⁽¹⁾		2.11E+01	2.64E+01	3.17E+01	4.49E+01	5.28E+01
Leafy Vegetables ⁽¹⁾		8.56E+00	1.07E+01	1.28E+01	1.82E+01	2.14E+01
Root Vegetables ⁽¹⁾		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

(1) Values taken as the average values in NUREG-5512 Vol. 4 (see Table 5.16) since RG-002 does not specify default values.

5.6.2 Inhalation Parameters

The inhalation dose is directly linear to the breathing rate and exposure period (see Section 4.7.10). Table 5.18 lists breathing rates for different age groups as specified in RG-002. The values are from ICRP Publication 101 (ICRP, 2006).

5.6.3 Occupancy Factors for External Exposure

Members of the public may incur an external gamma radiation dose from exposure to contaminated soil (ground shine), as well as from immersion in the contaminated air (cloud shine) or water. The radiation dose from all these external exposure pathways is linearly dependent on the occupancy factor, i.e., the period that members of the public are exposed to the contaminated water, air, or soil.

Table 5.18 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 - 7 years	8.88
7 to 12 years	15.36
12 to 17 years	20.16
Adults	22.08

Occupancy factors are, therefore, derived that specify the amount of time members of the public spend on an annual basis at certain activities. These activities are assumed to take place on or near the contaminated media and can thus be used to estimate the period members of the public will be exposed to the media. Table 5.19 summarises the age group-specific annual occupancy factors, as proposed in RG-002 (NNR, 2013).

Table 5.19 Occupancy factors taken from RG-002 (NNR, 2013).

Activity	0 to 2 Years	2 to 7 Years	7 to 12 Years	12 to 17 Years	Adult
Time spent indoors	7,914	7,775	7,568	7,665	7,050
Time spent outdoors	846	985	1,192	1,095	1,710
Playing on contaminated soil	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

5.7 Specific Parameter Values for each Exposure Condition

5.7.1 General

The parameter values presented in the previous sections are general and suitable for most public exposure conditions defined for a radiological public safety assessment. Table 5.20 summarises the default parameter values that may influence the characteristics of site-specific public exposure conditions.

The definition of exposure conditions for the 2020 South Deep Gold Mine RPSA assumed specific conditions that may be different from the default values. The purpose of this section is to define and highlight these differences for each exposure condition.

5.7.2 Residential Area Exposure Condition

The purpose of the Residential Area Exposure Condition as defined in the *Definition and Justification of Public Exposure Conditions* report (Aquisim, 2020b) is to evaluate the radiological consequences to members of the public living in urban residential areas near the South Deep Gold Mine.

Table 5.20 Summary of default parameter values that may influence the characteristics of a site-specific public exposure condition.

Default Parameter Values								
Parameter		Unit	Value	Age Groups				
				0 to 2 Years	2 to 7 Years	7 to 12 Years	12 to 17 Years	Adult
Occupancy Factors								
Indoor Exposure Period (Total)		h.y ⁻¹		7914	7775	7568	7665	7050
Outdoor Exposure Period (Total)				846	985	1192	1095	1710
	Exposure Period in Garden	h.y ⁻¹		84.6	98.5	238.4	273.75	427.5
	Exposure Period on Cropland			84.6	98.5	238.4	273.75	427.5
	Exposure Period on Pasture			84.6	98.5	238.4	273.75	427.5
	Exposure Period on Open land			84.6	98.5	238.4	273.75	427.5
Water Immersion								
	Bathing	h.y ⁻¹		60.8	91.3	121.7	121.7	91.3
	Swimming			19.2	27.4	30.2	27.8	9.0
Inhalation Rates		m ³ .h ⁻¹		0.22	0.37	0.64	0.84	0.95
Reduction Factor		-	1					
Shielding Factor		-	1					
Ingestion Rates								
Water		L.y ⁻¹		240	300	360	510	600
Milk				48	60	72	102	120
Soil								
Soil Total Intake		kg.y ⁻¹		0.0148	0.0185	0.0222	0.03145	0.037
	Garden	kg.y ⁻¹	Propor tional	0.0049	0.0062	0.0074	0.0105	0.0123
	Cropland			0.0049	0.0062	0.0074	0.0105	0.0123
	Pasture			0.0049	0.0062	0.0074	0.0105	0.0123
Grain		kg.y ⁻¹		10.0	12.5	15.0	21.3	25.0
Fruit				21.1	26.4	31.7	44.9	52.8
Leafy Vegetables				8.6	10.7	12.8	18.2	21.4
Root Vegetables				17.8	22.3	26.8	37.9	44.6
Meat (beef)				12.0	15.0	18.0	25.5	30.0
Meat (mutton)				10.0	12.5	15.0	21.3	25.0
Meat (pork)				8.0	10.0	12.0	17.0	20.0
Poultry				20.0	25.0	30.0	42.5	50.0
Eggs				6.0	7.5	9.0	12.8	15.0
Freshwater Fish				10.0	12.5	15.0	21.3	25.0

The exposure conditions presented here consider an exposure group living in formal or informal residential areas near the South Deep Gold Mine. This means that the exposure condition relates to any of the nearby residential areas for the parameter values and assumptions included in the description of the exposure condition.

Table 5.21 summarises the exposure parameters specific to the Residential Area Exposure Condition. The main contributor to a total effective dose for the Residential Area Exposure Condition is from the atmospheric and associated secondary pathways, through the following routes of exposure:

- External gamma radiation from cloud shine and ground shine (following deposition);
- Internal exposure from the incidental ingestion of garden soil (100% of the published consumption rate in Table 5.20);
- Internal exposure from the ingestion of fruits and vegetables (50% of annual consumption rate in Table 5.20), as well as chicken and eggs (50% of annual consumption rate in Table 5.20); and
- Internal exposure from the inhalation of airborne radon and LL α dust.

Table 5.21 Summary of Residential Area Exposure Condition parameter values assumed for the 2020 South Deep Gold Mine RPSA.

Default Parameter Values								
Parameter	Unit	Value	Age Groups					
			0 to 2 Years	2 to 7 Years	7 to 12 Years	12 to 17 Years	Adult	
Occupancy Factors								
Indoor Exposure Period (Total)		h.y ⁻¹		7914	7775	7568	7665	7050
Outdoor Exposure Period (Total)				846	985	1192	1095	1710
	Exposure Period in Garden	h.y ⁻¹		846	985	1192	1095	1710
Inhalation Rates		m ³ .h ⁻¹		0.22	0.37	0.64	0.84	0.95
Reduction Factor		-	1					
Shielding Factor		-	1					
Ingestion Rates								
Soil (Total)		kg.y ⁻¹		0.0148	0.0185	0.0222	0.03145	0.037
	Garden	kg.y ⁻¹		0.0148	0.0185	0.0222	0.03145	0.037
Fruit				10.55	13.2	15.85	22.45	26.4
Leafy Vegetables				4.3	5.35	6.4	9.1	10.7
Root Vegetables				8.9	11.15	13.4	18.95	22.3
Poultry				10	12.5	15	21.25	25
Eggs				3	3.75	4.5	6.4	7.5

5.7.3 Commercial Agricultural Exposure Condition

The purpose of the Commercial Agricultural Exposure Condition as defined in the *Definition and Justification of Public Exposure Conditions* report (Aquisim, 2020b) is to evaluate the radiological consequences to members of the public practising agricultural farming near the South Deep Gold Mine. This means that this exposure condition relates to any farming activity for the conditions and assumptions included in the description of the exposure condition. Table 5.22 summarises the exposure parameters specific to the Commercial Agriculture Exposure Condition.

The main contributor to a total effective dose for the Commercial Agricultural Exposure Condition is from the atmospheric (i.e., the ambient air conditions), aquatic, and associated secondary pathways and includes the following:

- External gamma radiation from cloud shine (airborne LL α and Radon);

- External gamma radiation from topsoil contaminated through atmospheric deposition of LLα or irrigation with contaminated water;
- External gamma radiation from bathing and swimming in contaminated water;
- Internal exposure from the incidental ingestion of contaminated soil (100% of annual consumption rate in Table 5.20), contaminated water (100% of annual consumption rate in Table 5.20), poultry, eggs, meat (beef & mutton), milk, cereal, fruits and vegetables (100% of annual consumption rate in Table 5.20); and
- Internal exposure from the inhalation of airborne radon and LLα dust.

Table 5.22 Summary of Commercial Agriculture Exposure Condition parameter values assumed for the 2020 South Deep Gold Mine RPSA.

Default Parameter Values								
Parameter	Unit	Value	Age Groups					
			0 to 2 yr.	2 to 7 yr.	7 to 12 yr.	12 to 17 yr.	Adult	
Occupancy Factors								
Indoor Exposure Period (Total)		h.y ⁻¹		7914	7775	7568	7665	7050
Outdoor Exposure Period (Total)				846	985	1192	1095	1710
	Exposure Period in Garden	h.y ⁻¹		676.8	788	596	219	342
	Exposure Period on Cropland			84.6	98.5	298	438	684
	Exposure Period on Pasture			84.6	98.5	298	438	684
Water Immersion								
	Bathing	h.y ⁻¹		60.8	91.3	121.7	121.7	91.3
	Swimming			19.2	27.4	30.2	27.8	9.0
Inhalation Rates		m ³ .h ⁻¹		0.22	0.37	0.64	0.84	0.95
Reduction Factor		-	1					
Shielding Factor		-	1					
Ingestion Rates								
Water		L.y ⁻¹		240	300	360	510	600
Milk				38.4	48	57.6	81.6	96
Soil (Total)		kg.y ⁻¹		0.0148	0.0185	0.022	0.031	0.037
	Garden	kg.y ⁻¹		0.01036	0.00925	0.0111	0.00629	0.0074
	Cropland			0.00222	0.004625	0.00555	0.01258	0.0148
	Pasture			0.00222	0.004625	0.00555	0.01258	0.0148
Grain		kg.y ⁻¹		10	12.5	15	21.3	25
Fruit				21.1	26.4	31.7	44.9	52.8
Leafy Vegetables				8.6	10.7	12.8	18.2	21.4
Root Vegetables				17.8	22.3	26.8	37.9	44.6
Meat (beef)				12	15	18	25.5	30
Meat (mutton)				10	12.5	15	21.3	25
Poultry				20	25	30	42.5	50
Eggs				6	7.5	9	12.8	15

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Yu, C., C. Loureiro, J.-J. Cheng, L. G. Jones, Y. Y. Wang, Y. P. Chia, and E. Faillace (1993), Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil, *Report ANL/EAIS-8*, Argonne National Laboratory.

Tailings and Milled Ore Materials from the South Deep Gold Mine

RadioAnalysis Building 1600 P O Box 582 Pretoria 0001 Telephone: + 27 12 305 5527 Facsimile: + 27 12 305 5944 Contact: Ms BC Tshabalala Company: Southdeep Joint Venture Address: Placer Dome Western Areas Joint P O Box 57 Western Areas 1780 Date: 6 June 2014 Report number: RA-15466-01 Pages: 3 Your reference: 49000092345 Analysis Report Radioactivity analysis of solids Compiled by: D Kotze <i>[Signature]</i> Checked by: M Buys <i>[Signature]</i> The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.	Report number: RA-15466-01 Page 2 of 3 1. SERVICE Analysis solid samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series. Number of samples received: 2 The samples were received on: 19 February 2014 2. SAMPLE PREPARATION AND ANALYSIS <table border="1"><thead><tr><th>Method</th><th>Description</th><th>Completed</th><th>Assayer</th><th>Verified by</th></tr></thead><tbody><tr><td>WIN-114</td><td>Dry sample, mill to homogenise</td><td>11/03/2014</td><td>E Mothlabane</td><td>J Smit</td></tr><tr><td>WIN-138</td><td>Gross alpha/beta analysis</td><td>12/05/2014</td><td>S May</td><td>E Nhlapo</td></tr><tr><td>WIN-167</td><td>U and Th by neutron activation analysis</td><td>20/05/2014</td><td>A Sathekge</td><td>N Seaga</td></tr><tr><td>WIN-101</td><td>²²⁶Ra, ²²⁸Ra, ²³²Th, ⁴⁰K by gamma analysis</td><td>23/04/2014</td><td>Z Gaven</td><td>N Seaga</td></tr><tr><td>WIN-158</td><td>²¹⁰Pb by low energy gamma analysis</td><td>17/04/2014</td><td>T Mkwanezi</td><td>N Seaga</td></tr></tbody></table> 3. RESULTS 3.1 Results are attached as an appendix to this report. 3.2 Results report are related only to sample portions tested. 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty. 4. QUALITY ASSURANCE 4.1 The compiler is the Technical Expert for all the methods. 4.2 The compiled report is checked by a person other than the compiler for accuracy of data transcription. 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.	Method	Description	Completed	Assayer	Verified by	WIN-114	Dry sample, mill to homogenise	11/03/2014	E Mothlabane	J Smit	WIN-138	Gross alpha/beta analysis	12/05/2014	S May	E Nhlapo	WIN-167	U and Th by neutron activation analysis	20/05/2014	A Sathekge	N Seaga	WIN-101	²²⁶ Ra, ²²⁸ Ra, ²³² Th, ⁴⁰ K by gamma analysis	23/04/2014	Z Gaven	N Seaga	WIN-158	²¹⁰ Pb by low energy gamma analysis	17/04/2014	T Mkwanezi	N Seaga
Method	Description	Completed	Assayer	Verified by																											
WIN-114	Dry sample, mill to homogenise	11/03/2014	E Mothlabane	J Smit																											
WIN-138	Gross alpha/beta analysis	12/05/2014	S May	E Nhlapo																											
WIN-167	U and Th by neutron activation analysis	20/05/2014	A Sathekge	N Seaga																											
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²³² Th, ⁴⁰ K by gamma analysis	23/04/2014	Z Gaven	N Seaga																											
WIN-158	²¹⁰ Pb by low energy gamma analysis	17/04/2014	T Mkwanezi	N Seaga																											

Report number: RA-15466-01

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg	BEFORE			AFTER		
Field code	Leach Feed Comp.			SD Residue Comp.		
Lab code	RA-15466X001			RA-15466X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	578	29	0.46	678	34	0.52
²³⁴ U	583	30	0.46	683	35	0.52
²²⁶ Ra	588	15	19	668	16	18
²¹⁰ Pb	1900	20	280	922	45	120
²³⁵ U	26.6	1.3	0.021	31.2	1.6	0.024
²³² Th	30.5	1.5	3.3	37.6	1.7	3.4
²²⁸ Ra	31.0	6.7	20	26.2	7.4	23
²²⁸ Th	14	4.7	47	28	12	32
⁴⁰ K	137	24	65	141	26	71
Gross alpha	5240	250	340	7080	290	350
Gross beta	2090	30	41	2660	30	44

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **23 December 2015**
Report number: **RS2015-3509-01**
Pages: **3**
Your reference: **4900102214**

Analysis Report

Radioactivity analysis of composite sample

Compiled by: **MJ Raven**

Checked by: **N Seaga**

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Report number: RS2015-3509-01

Page 2 of 3

1. SERVICE

Analysis of solid composite samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of sample(s) received: 2

The sample(s) were received on: 2015/10/22

Purchase order received on: 2015/10/15

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry sample, mill to homogenise	2015/10/28	E Motlhabane	O Mathekg
WIN-138	Gross alpha/beta analysis	2015/11/17	MS May	E Nhlapo
WIN-167	U and Th by neutron activation analysis	2015/12/18	A Sathekge	N Seaga
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	2015/12/01	R Gaven	N Seaga
WIN-158	²¹⁰ Pb by low energy gamma analysis	2015/11/17	R Senosi	N Seaga

**Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results report are related only to sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

3.4 ²³⁴U activity was derived from the ²³⁸U activity, by using natural isotopic ratio

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods.
- The individual test reports are available upon request

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Report number: RS2015-3509-01

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg

Field code	BEFORE			AFTER		
	Value	Unc.	MDA	Value	Unc.	MDA
Lab code	RS2015-3509X001			RS2015-3509X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	690	7	0.37	675	7	0.39
²³⁴ U	696	7	0.37	681	7	0.39
²²⁶ Ra	655	27	43	< MDA		40
²¹⁰ Pb	973	48	130	933	42	100
²³² U	31.8	0.3	0.017	31.1	0.3	0.018
²³² Th	36.2	1.3	2.0	35.2	1.3	2.5
²²⁸ Ra	60.2	17.8	52	< MDA		79
²²⁸ Th	23	6.0	130	< MDA		100
⁴⁰ K	170	84	270	3760	210	300
Gross alpha	6110	1110	2100	5880	1070	2000
Gross beta	3050	150	200	2650	140	200

Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **15 April 2016**
Report number: **RS2016-0504-01**
Pages: 3
Your reference: **4900103660**

Analysis Report

Radioactivity analysis of soil

Compiled by: **MJ Raven**

Checked by: **N Seaga**

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Report number: **RS2016-0504-01**

Page 2 of 3

1. SERVICE

Analysis of solid samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of sample(s) received: 2

The sample(s) were received on: 2016-02-08

Purchase order received on: 2016-02-09

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry sample, mill to homogenise	2016/02/11	E Motlhabane	L Seshoka
WIN-138	Gross alpha/beta analysis	2016/03/29	MS May	E Nhlapo
WIN-167	U and Th by neutron activation analysis	2016/04/04	A Sathekge	N Seaga
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	2016/04/04	R Gaven	A Sathekge
WIN-158	²¹⁰ Pb by low energy gamma analysis	2016/04/06	M Rapetsoa	N Seaga

*Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results report are related only to sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

3.4 ²³⁴U activity was derived from the ²³⁸U activity, by using natural isotopic ratio

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- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

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Report number: RS2016-0504-01

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg

Field code	Southdeep Comp			Southdeep Leach		
Lab code	RS2016-0504X001			RS2016-0504X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	684	22	0.35	651	21	0.36
²³⁴ U	690	22	0.35	656	21	0.36
²²⁶ Ra	645	28	41	633	26	46
²¹⁰ Pb	1120	50	140	952	49	130
²²⁸ U	31.5	1.0	0.016	30.0	0.9	0.017
²³² Th	31.9	0.7	1.6	29.0	0.7	1.7
²²⁸ Ra	< MDA		110	< MDA		99
²²⁸ Th	33	17	130	61	19	140
⁴⁰ K	< MDA		420	< MDA		420
Gross alpha	7110	1160	2000	7640	1200	2000
Gross beta	2700	140	220	2720	150	230

Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **20 July 2016**
Report number: **RS2016-2550-01**
Pages: **3**
Your reference: **4900105467**

Analysis Report

Radioactivity analysis of soil

Compiled by: **MJ Raven**

Checked by: **A Sathekge**

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Report number: **RS2016-2550-01**

Page 2 of 3

1. SERVICE

Analysis of soil samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of sample(s) received: 2

The sample(s) were received on: 2016-06-10

Purchase order received on: 2016-06-13

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry sample, mill to homogenise	2016-06-22	E Motlhabane	O Mathekga
WIN-138	Gross alpha/beta analysis	2016-07-11	MS May	E Nhlapo
WIN-167	U and Th by neutron activation analysis	2016-07-05	Z Ntuli	A Sathekge
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	2016-07-19	R Gaven	A Sathekge
WIN-158	²¹⁰ Pb by low energy gamma analysis	2016-07-19	M Rapetsoa	A Sathekge

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Results report are related only to sample portions tested.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.
- 3.4 ²³⁴U activity was derived from the ²³⁸U activity, by using natural isotopic ratio

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.
 - Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
 - Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods.
 - The individual test reports are available upon request
- 4.3 The compiler is the Technical Expert for all the methods.
- 4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: **RS2016-2550-01**

Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg

Field code	Composite			Residue		
Lab code	RS2016-2550X001			RS2016-2550X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	688	17	0.52	621	15	0.53
²³⁴ U	693	17	0.52	626	15	0.53
²²⁶ Ra	685	27	40	642	29	50
²¹⁰ Pb	1250	90	220	1170	80	210
²³² U	31.7	0.8	0.024	28.6	0.7	0.024
²³² Th	31.8	2.3	11	28.9	2.3	11
²²⁸ Ra	< MDA		90	< MDA		100
²²⁸ Th	< MDA		120	< MDA		150
⁴⁰ K	< MDA		380	< MDA		420
Gross alpha	6500	1110	1900	5280	1020	1900
Gross beta	2620	140	200	2590	140	190

Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("**< MDA**") will be indicated.
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4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Waste Rock Material from the South Deep Gold Mine

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Date: **22 April 2015**
Report number: **RS2015-0179-01**
Pages: **3**
Your reference: **RS2015-0179**

Analysis Report

Radioactivity analysis of solids

Compiled by: **N Seaga**

Checked by: **PM Moletsane**

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Report number: **RS2015-0179-01**

Page 2 of 3

1. SERVICE

Analysis of solid samples for radionuclides in the uranium and thorium decay series.
Number of samples received: 5
Date samples received: 26 February 2015

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry sample, mill to homogenise	13/03/2015	E Motlhabane	O Mathekga
WIN-167	U and Th by neutron activation analysis	22/04/2015	A Sathekge	N Seaga
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	22/04/2015	A Sathekge	N Seaga

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Results report are related only to sample portions tested.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
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 - Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods.
 - The individual test reports are available upon request
- 4.3 The compiler is the Technical Expert for all the methods.
- 4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: **Rs2015-0179-01** Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS
Activity concentrations of nuclides in solid samples
Unit: Bq/kg

Field code Lab code	SD1 RS2015-0179x001			SD2 RS2015-0179x002			SD3 RS2015-0179x003			SD4 RS2015-0179x004			SD5 RS2015-0179x005		
	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	643	26	0.43	4520	180	0.43	67.4	3.0	0.43	11.6	0.7	0.43	12.7	0.8	0.44
²³⁴ U	649	26	0.44	4560	180	0.43	68.0	3.0	0.43	11.7	0.7	0.44	12.8	0.8	0.44
²²⁶ Ra	457	26	47	1020	40	59	60.0	10.9	29	< MDA		37	< MDA		39
²³⁴ U	29.6	1.2	0.020	208	8	0.020	3.10	0.14	0.020	0.535	0.033	0.020	0.586	0.035	0.020
²³² Th	45.8	2.0	4.4	119	9	5.8	59.6	2.0	4.3	8.28	0.45	1.5	8.97	0.45	1.4
²²⁶ Ra	51	20	60	< MDA		140	< MDA		86	< MDA		68	< MDA		67
²³⁰ Th	34	13	140	110	25	180	51	12	100	< MDA		83	< MDA		100
⁴⁰ K	190	100	330	230	110	370	655	100	250	< MDA		320	200	82	260

**Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

Notes:

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2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1) . The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Vegetable and Fruit Products from the South Deep Gold Mine

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Date: **10 December 2009**
Report number: **Final**
Pages: **3**
Our reference: **RJ2009-0609**
Your reference: **4500272919**

Analysis Report

Radioactivity analysis of cabbage


Compiler: **D Kotze**
Technical signatories: **J Smit, S Seema**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RJ2009-0609** Report number: **Final** Page **2** of **3**

1. SERVICE

Analysis of a cabbage sample for selected radionuclides in the uranium and thorium decay series.
The samples were received on 30 June 2009.

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020311	Dry, shred, ash of plant material	WIN-109,-118	25/08/2009	Edward
060331	Uranium and thorium by neutron activation analysis	WIN-167	03/08/2009	N Seaga
050222	²¹⁰ Pb, ²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	WIN-101	25/08/2009	M Willemsse
020332	Microwave digestion of solids	WIN-178	19/11/2009	A Mamaila
050331	²¹⁰ Po by alpha spectrometry	WIN-129	19/11/2009	A Mamaila

3. RESULTS

3.1 Results are attached as an appendix to this report.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: **RJ2009-0609** Report number: **Final** Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg fresh weight

Field code	Cabbage		
Lab code	RJ2009-0609X001		
Nuclide	Value	Unc.	MDA
²³⁸ U	0.0217	0.0036	0.0081
²³⁴ U	0.0219	0.0037	0.0081
²²⁶ Ra	< MDA		0.00028
²¹⁰ Pb	< MDA		0.19
²¹⁰ Po	0.140	0.043	0.043
²³⁵ U	0.00100	0.00017	0.00037
²³² Th	0.0050	0.0016	0.014
²²⁸ Ra	< MDA		0.11
²²⁸ Th	0.017	0.0035	0.020
⁴⁰ K	67.0	1.2	0.19

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
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Report of Analysis

Reference: Job Code: **RA 05939**
Report: **Final**
Pages: **7**
Date issued: **Wednesday, 1 December 2004**

Radioactivity Analysis of Maize

Client: Company: **Placer Dome Western Area Joint Venture**
Contact: **Mr C. Malebanye**
Authorisation: **Order No: WDS47258**
Laboratory: Compiler: **Ntombi Segoe**
Technical: **Marja Raven, Jackie Smit, Bernadette Hendry,**
Signatories: **Teresa Coetzee and Valencia Makuba**

The validity of these results were verified by technical signatories. The views and opinions of authors expressed herein do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job Code: RA 05939	Report: Final	Page 2 of 7
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1. SERVICE SUMMARY

One maize sample was received for analysis of its radioactivity content. The radionuclides of interest are NORM's (Naturally Occurring Radioactive Materials) and typically include uranium (^{238}U , ^{235}U), thorium (^{232}Th , ^{230}Th), radium (^{226}Ra , ^{228}Ra), as well as ^{210}Pb , ^{210}Po and ^{40}K . Besides the nuclide-specific analyses, the sample was also analysed for its gross activity content.

2. SAMPLE RECEIVED

The sample was received for analysis on Thursday, 30 September 2004. The samples was coded for laboratory use and both field descriptions and laboratory codes are reported.

Necsa code	Field Description	Sample material	Sample Condition
5939x001	Unmarked	Maize	Good and dry

3. SAMPLE PREPARATION AND ANALYSES

3.1. Initial sample preparation

(a) Dry, mill and homogenise animal tissue

Product: 020312

Performed on: 30 September 2004

Method: RA-WIN-113/119

Assayer: Hamilton Tyukala

The sample was further dried overnight at 105 °C and then milled and homogenised the following day, after a cooling off period.

3.2. Analysis of solid samples

(a) Gross $\alpha\beta$ -activity counting of solids

Product: 030311

Performed on: 08 October 2004

Method: RA-WIN-138

The sample was adjusted to a specific sample geometry and counted on a low background gas-flow proportional counter for 5 to 6 hours per sample.

(b) Uranium/Thorium analysis of solids

Product: 060331

Performed on: 09 November 2004

Method: RA-WIN-167

Assayer: Ntsoaki Seaga

The sub-sample of 200 mg each was weighed out in specially designed irradiation capsules and irradiated in the SAFARI Research Reactor for 20 seconds each, together with element standards. The uranium concentration ($\mu\text{g/g}$) is determined by Delayed Neutron Counting (DNC). The sample was counted again after a cooling-off period of approximately 7 days on a well-type HPGe gamma detector for determination of the thorium concentration ($\mu\text{g/g}$). These concentration values are then converted to the respective activity concentrations (Bq/kg).

Job Code: RA 05939	Report: Final	Page 3 of 7
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(c) Radium analysis of solids

Product: 050141

Performed on: 08 November 2004

Method: RA-WIN-101

The sample was counted on a low-background high energy HPGe gamma-spectrometry system for 24 hours per sample. The spectral data is analysed for the radionuclides ^{226}Ra , ^{228}Ra , ^{228}Th and ^{40}K and the activity results reported in Bq/kg .

(d) $^{210}\text{Pb}/^{210}\text{Po}$ analysis

Product: 090821

Performed on: 29 November 2004

Method: RA-WIN-129

Assayer: Botle Leiee

Polonium is pre-concentrated from the liquid by two separate direct extractions on silver and α -particle spectrometry detection in a low-background counting facility.

3.3 Quality Assurance

All analytical methods are validated and documented in the RadioAnalysis Quality System, which is based on ISO/IEC Standard 17025. The RadioAnalysis Laboratory is accredited for, inter alia, method RA-WIN-101 (Testing Laboratory T0111).

3.4 Data reduction and evaluation

Data is evaluated against the regulatory requirements and recommendations are made where relevant.

4. ANALYTICAL RESULTS

- The analytical results are presented as appendices to this report.
- The reported uncertainty is a probable error calculated mainly from the counting statistics, and is not the normal standard deviation on replicate analyses.

5. REMARKS AND OBSERVATIONS

- Results reported only apply to samples received by RadioAnalysis. It is assumed that the sampling procedure, normally performed by the client, is representative of the source matrix. Further sample preparation done by RadioAnalysis only improves the homogeneity of the sample(s) received.
 - The format for reporting of results (see Appendix 1 and 2) can be explained as follows:

X: which is the measured value, and can be negative if the value is close to or even below the minimum detection limit;

Sx: the probable error, which is calculated from counting statistics and gives an indication of the uncertainty in the result (sometimes also reported as " $X \pm Sx$ ");

MDA: The minimum detectable activity, which is the detection limit of the method and specific sample matrix (sometimes also reported as "< MDA").
 - It should be emphasised that gross $\alpha\beta$ -activity measurements are merely meant to screen samples for their total activity. The measured activities differ from the true activity due to the energy of the α - and β -particles involved, as well as the density of the matrix concerned.
- Note that the gross $\alpha\beta$ -activity results are expressed in Bq.g^{-1} , whereas the nuclide-specific results are expressed in Bq.kg^{-1} .

Job Code: **RA 05939** Report: **Final** Page **4** of **7**

5.4 A conservative approach has been followed to obtain the possible yearly dose if the individual fish source(s) would be used as the only fish source available to the adult population. The results are reported in Appendix 2. Equilibrium with the respective mother/daughter nuclides are assumed for those radionuclides not analysed for.

For the short-lived nuclides such assumptions are acceptable, but for ²²⁷Ac and ²³¹Pa these assumptions are not entirely accurate. ²²⁷Ac and ²³¹Pa were accepted to be in equilibrium with ²³⁸U. For a more thorough dose evaluation, these nuclides need to be analysed for as well.

The NNR Licensing Guide LG-1032, Rev 0 refers to an annual screening assessment criterion of 25 µSv for a specific pathway, taking into consideration also the contribution from other pathways, so that an overall criterion of 250 µSv is followed.

For the specific food source (maize) reported on, given the conservative approach mentioned above, the total minimum dosage is around 90 µSv per annum, with the contribution from ²¹⁰Pb, ²¹⁰Po and ²²⁶Ra the highest. A requirement now would be to determine the actual use of the individual food source and evaluate the maximum intake volume per year by members of the public.

5.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years. We do not take responsibility for electronic versions of this report, nor do we guarantee the correct transfer of electronic data from our laboratory to the client.

Job Code: **RA 05939** Report: **Final** Page **5** of **7**

APPENDIX 1:

Radionuclide:	Sample activity in Bq/kg		
	5939x001 Unmarked Maize		
	X	Sx	MDA
U-238 decay series			
U-238	0.28	0.222	0.85
Ra-226			5.5
Pb-210	1.85	0.96	1.6
Po-210	1.85	0.96	1.6
U-235 decay series			
U-235	0.0129	0.0102	0.039
Th-232 decay series			
Th-232			1.3
Ra-228			8.4
Th-228			6.1
K-40	160	16	45
Gross α-activity [Bq/g]	0.281	0.04	0.1
Gross β-activity [Bq/g]	0.487	0.013	0.022
[Uranium] in µg/g	0.0227	0.018	0.069
[Thorium] in µg/g			0.32

Note: Take Pa-231 = Ac-227 = Th-227

Note: Take Ra-228 = Ac-228 = Th-228

Job Code: **RA 05939** Report: **Final** Page **6** of **7**

APPENDIX 2:

Fish at an intake of: 25 kg per annum

IAEA 115:

Radionuclides

5939x001

X

MDA

U-238 Series

U-238	0.315	0.95
Th-234	0.0238	0.072
U-234	0.343	1
Th-230	1.47	4.4
Ra-226		38
Pb-214		0.019
Bi-214		0.015
Pb-210	31.9	28
Bi-210	0.06	0.053
Po-210	55.4	49

U-235 Series

U-235	0.0152	0.046
Th-231	0.00011	0.00033
Pa-231	0.229	0.69
Ac-227	0.355	1.1
Th-227	0.00287	0.0087
Ra-223	0.0323	0.098
Pb-211	5.81E-05	0.00018

Th-232 Series

Th-232		7.4
Ra-228		140
Ac-228		0.09
Th-228		11
Ra-224		9.9
Pb-212		0.91
Bi-212		0.039

Total $\mu\text{Sv/a}$ 90.1 300

Job Code: **RA 05939** Report: **Final** Page **7** of **7**

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Date: **23 July 2012**
Report number: **Final**
Pages: **04**
Our reference: **RA-12382**
Your reference: **4500432684**

Analysis Report

Radioactivity analysis of solids


Compiler: **D Kotze**
Technical signatories: **J Smit, M Raven, E Nhlapo, S Seema**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-12382** Report number: **Final** Page 2 of 4

1. SERVICE

Analysis of solid samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 25 November 2011

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020131	Dry sample, mill to homogenise	WIN-114	01/12/2011	E Mothlabane
030311	Gross alpha/beta analysis	WIN-138	28/12/2011	JJ van der Walt
060331	Uranium and thorium by neutron activation analysis	WIN-167	08/02/2012	N Seaga
050222	Gamma-spec, broad energy quantitative	WIN-101	24/04/2012	D Matshidiso
090821	Po-210 by Radiochemical Separations, in liquids	WIN-129	27/03/2012	D Matshidiso

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
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- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: **RA-12382** Report number: **Final** Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg

Field code	Spinach 1			Spinach 2		
	RA-12382X001			RA-12382X002		
Lab code						
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	0.276	0.019	0.023	1.06	0.06	0.045
²³⁴ U	0.279	0.019	0.023	1.07	0.06	0.045
²²⁶ Ra	0.916	0.186	0.56	1.16	0.36	1.1
²¹⁰ Pb	0.43	0.15	0.48	1.52	0.27	0.79
²¹⁰ Po	0.155	0.048	0.043	8.84	0.65	0.065
²³⁵ U	0.0127	0.0009	0.0010	0.0487	0.0026	0.0021
²³² Th	< MDA		4.2	1.5	0.33	2.2
²²⁸ Ra	0.348	0.066	0.21	0.452	0.110	0.34
²²⁸ Th	0.080	0.023	0.082	0.16	0.046	0.16
⁴⁰ K	98.1	2.2	0.89	110	3	1.8
Gross alpha	-7.3	4.5	18	-6.1	9.3	35
Gross beta	96.3	1.4	1.5	139	2	3.0

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: **RA-12382** Report number: **Final** Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Spinach 1	RA-12382X001	1600	510	360	300	370	250
Spinach 2	RA-12382X002	18000	7200	4700	3400	3200	2700

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ²³⁰Th (= ²³⁰Th) ²²⁶Ra up to ²¹⁰Pb (= ²¹⁰Pb) ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb)
²³⁵U up to ²¹¹Pb (= ²¹¹Pb) ²²⁸Th to ²¹²Bi (= ²¹²Bi)
²²⁸Ra and ²²⁸Ac (= ²²⁸Ra) ²²⁸Th to ²¹²Bi (= ²¹²Bi)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.

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Date: **10 December 2009**
Report number: **Final**
Pages: **3**
Our reference: **RJ2009-0611**
Your reference: **450027917**

Analysis Report

Radioactivity analysis of spinach


Compiler: **D Kotze**
Technical signatories: **J Smit, M Raven, S Seema**

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Job reference: **RJ2009-0611** Report number: **Final** Page 2 of 3

1. SERVICE

Analysis of spinach for selected radionuclides in the uranium and thorium decay series.
The samples were received on 30 June 2009

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020311	Dry, shred, ash of plant material	WIN-109,-118	09/07/2009	Edward
060331	Uranium and thorium by neutron activation analysis	WIN-167	03/08/2009	N Seaga
050141	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	WIN-101	25/08/2009	M Willemsse
050221	²¹⁰ Po by alpha spectrometry	WIN-158	19/11/2009	A Mamaila

3. RESULTS

3.1 Results are attached as an appendix to this report.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: **RJ2009-0611** Report number: **Final** Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg fresh weight

Field code	T1FieldCode1		
Lab code	RJ2009-0611X001		
Nuclide	Value	Unc.	MDA
²³⁸ U	0.0929	0.0143	0.030
²³⁴ U	0.0937	0.0144	0.030
²²⁶ Ra	0.22	0.074	0.24
²¹⁰ Pb	0.843	0.089	0.22
²¹⁰ Po	5.38	0.43	0.067
²²⁶ U	0.00428	0.00066	0.0014
²³² Th	0.025	0.0088	0.071
²²⁸ Ra	0.278	0.030	0.093
²²⁸ Th	0.0581	0.0039	0.018
⁴⁰ K	129	2	0.18

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **10 December 2009**
Report number: **Final**
Pages: **3**
Our reference: **RJ2009-0614**
Your reference: **4500270126**

Analysis Report

Radioactivity analysis of beetroot

Compiler: **D Kotze**

Technical signatories: **J Smit, S Seema**

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Job reference: **RJ2009-0614** Report number: **Final** Page 2 of 3

1. SERVICE

Analysis of a beetroot sample for selected radionuclides in the uranium and thorium decay series.
The sample was received on 30 June 2009.

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020311	Dry, shred, ash of plant material	WIN-109,-118	09/07/2009	Edward
060331	Uranium and thorium by neutron activation analysis	WIN-167	03/08/2009	N Seaga
050222	²¹⁰ Pb, ²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	WIN-101	25/08/2009	M Willems
020332	Microwave digestion of solids	WIN-178	19/11/2009	A Mamaila
050331	²¹⁰ Po by alpha spectrometry	WIN-129	19/11/2009	A Mamaila

3. RESULTS

3.1 Results are attached as an appendix to this report.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
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Job reference: **RJ2009-0614** Report number: **Final** Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg fresh weight

Field code	Beetroot		
Lab code	RJ2009-0614X001		
Nuclide	Value	Unc.	MDA
²³⁸ U	0.255	0.024	0.034
²³⁴ U	0.257	0.024	0.034
²²⁶ Ra	0.506	0.114	0.34
²¹⁰ Pb	0.525	0.107	0.33
²¹⁰ Po	2.11	0.24	0.063
²³⁵ U	0.0118	0.0011	0.0015
²³² Th	0.209	0.010	0.054
²²⁸ Ra	0.482	0.040	0.11
²²⁸ Th	0.289	0.014	0.026
⁴⁰ K	132	3	0.24

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
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Date: **03 December 2009**
Report number: **Final**
Pages: **3**
Our reference: **RJ2009-0610**
Your reference: **4500272914**

Analysis Report

Radioactivity analysis of carrots

Compiler: **D Kotze**

Technical signatories: **J Smit, M Raven, S Seema,**

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Job reference: **RJ2009-0610** Report number: **Final** Page 2 of 3

1. SERVICE

Analysis of carrots for selected radionuclides in the uranium and thorium decay series.
The samples were received on 30 June 2009.

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020311	Dry, shred, ash of plant material	WIN-109,-118	09/07/2009	Edward
060331	Uranium and thorium by neutron activation analysis	WIN-167	03/08/2009	N Seaga
050222	²¹⁰ Pb, ²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	WIN-101	25/08/2009	M Willemsse
020332	Microwave digestion of solids	WIN-178	19/11/2009	A Mamaila
050331	²¹⁰ Po by alpha spectrometry	WIN-129	19/11/2009	A Mamaila

3. RESULTS

3.1 Results are attached as an appendix to this report.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
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Job reference: **RJ2009-0610** Report number: **Final** Page **3** of **3**

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: **Bq/kg fresh weight**

Field code	Carrots		
Lab code	RJ2009-0610X001		
Nuclide	Value	Unc.	MDA
²³⁸ U	0.0820	0.0083	0.013
²³⁴ U	0.0827	0.0083	0.013
²²⁶ Ra	< MDA		0.29
²¹⁰ Pb	0.18	0.071	0.23
²¹⁰ Po	0.230	0.060	0.049
²³⁵ U	0.00378	0.00038	0.00059
²³² Th	0.0590	0.0035	0.018
²²⁸ Ra	0.194	0.030	0.094
²²⁸ Th	0.0937	0.0054	0.019
⁴⁰ K	105	2	0.19

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor $k = 1$). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **10 December 2009**
Report number: **Final**
Pages: **3**
Our reference: **RJ2009-0610**
Your reference: **4500272914**

Analysis Report

Radioactivity analysis of sweet potatoes

Compiler: **D Kotze**

Technical signatories: **J Smit, M Raven**

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Job reference: **RJ2009-0610** Report number: **Final** Page 2 of 3

1. SERVICE

Analysis of sweet potatoes for selected radionuclides in the uranium and thorium decay series.
The samples were received on 30 June 2009.

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020311	Dry, shred, ash of plant material	WIN-109,-118	09/07/2009	Edward
060331	Uranium and thorium by neutron activation analysis	WIN-167	03/08/2009	N Seaga
050222	²¹⁰ Pb, ²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	WIN-101	25/08/2009	M Willems
020332	Microwave digestion of solids	WIN-178	19/11/2009	A Mamaila
050331	²¹⁰ Po by alpha spectrometry	WIN-129	19/11/2009	A Mamaila

3. RESULTS

3.1 Results are attached as an appendix to this report.

4. QUALITY ASSURANCE

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Job reference: **RJ2009-0610** Report number: **Final** Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg fresh weight

Field code	Sweet Potatoes		
Lab code	RJ2009-0610X001		
Nuclide	Value	Unc.	MDA
²³⁸ U	0.0290	0.0057	0.014
²³⁴ U	0.0292	0.0058	0.014
²²⁶ Ra	< MDA		0.00038
²¹⁰ Pb	< MDA		0.00027
²¹⁰ Po	0.432	0.090	0.054
²³⁵ U	0.00133	0.00026	0.00064
²³² Th	0.0276	0.0028	0.017
²²⁶ Ra	< MDA		0.00016
²²⁸ Th	0.0000517	0.0000055	0.000026
⁴⁰ K	0.115	0.002	0.00025

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **23 October 2014**
Report number: **RA-15482-01**
Pages: **4**
Your reference: **4900094528**

Analysis Report

Radioactivity analysis of Tomatoes

Compiled by: **D Kotze** *pp Louw*

Checked by: **J Smit** *J Smit*

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Report number: **RA-15482-01**

Page 2 of 4

1. SERVICE

Analysis of solid samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 1

The samples were received on: 14 February 2014

Purchase order received: 25 February 2014

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry sample, mill to homogenise	18/03/2014	E Mothlabane	J Smit
WIN-138	Gross alpha/beta analysis	09/07/2014	MS May	E Nhlapo
WIN-167	U and Th by neutron activation analysis	31/03/2014	A Sathekge	N Seaga
WIN-101	Gamma spec broad energy 210Pb, 226Ra, 228Th, K-40	12/05/2014	A Sathekge	N Seaga
WIN-178	Microwave digestion	12/05/2014	T Kota	A Rasutha
WIN-129	²¹⁰ Po Radiochemical separations	12/05/2014	T Kota	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results report are related only to sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: RA-15482-01

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg

Field code	Sample 1 Tomatoes		
Lab code	RA-15482X001		
Nuclide	Value	Unc.	MDA
²³⁸ U	0.00778	0.00227	0.0027
²³⁴ U	0.00785	0.00229	0.0027
²²⁶ Ra	< MDA		0.037
²¹⁰ Pb	< MDA		0.16
²¹⁰ Po	0.0383	0.0172	0.032
²³⁵ U	0.000358	0.000104	0.00012
²³² Th	0.0392	0.0037	0.021
²²⁸ Ra	< MDA		0.076
²²⁸ Th	< MDA		0.021
⁴⁰ K	67.2	2.8	0.24
Gross alpha	-26	3.9	14
Gross beta	69.6	1.0	0.38

Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-15482-01

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
Sample 1 Tomatoes	RA-15482X001	56	20	14	14	22	8.1

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ²³⁰Th (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb)
²³⁵U up to ²¹¹Pb (= ²³⁵U)
²²⁸Ra and ²²⁸Ac (= ²²⁸Ra) ²²⁸Th up to ²¹²Bi (= ²²⁸Th)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.

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Date: **14 July 2014**
Report number: **RA-15478-01**
Pages: **4**
Your reference: **4900076995**

Analysis Report

Radioactivity analysis of Vegetables

Compiled by: **I Louw** *I Louw*

Checked by: **J Smit** *J Smit*

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Report number: **RA-15478-01**

Page 2 of 4

1. SERVICE

Analysis of solid samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 3

The samples were received on: 27 February 2014

P/O received: 31 March 2014

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry sample, mill to homogenise	07/04/2014	E Mthlabane	J Smit
WIN-138	Gross alpha/beta analysis	25/06/2014	MS May	E Nhlapo
WIN-167	U and Th by neutron activation analysis	30/05/2014	A Sathekge	N Seaga
WIN-101	²¹⁰ Pb, ²²⁶ Ra, ²²⁸ Th, ⁴⁰ K by gamma analysis	30/05/2014	A Sathekge	N Seaga
WIN-129	²¹⁰ Pb by Radiochemical Separation	02/07/2014	T Kota	N Seaga

*Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Results report are related only to sample portions tested.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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- 4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: RA-15478-01

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides

Unit: Bq/kg

Field code	Peaches Samp 1			Cabbage Samp 2			Spinach Sample 3		
Lab code	RA-15478X001			RA-15478X002			RA-15478X003		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	0.0398	0.0030	0.0048	0.0043	0.0023	0.0083	0.0513	0.0056	0.012
²³⁴ U	0.0402	0.0030	0.0048	0.0043	0.0023	0.0084	0.0517	0.0056	0.012
²²⁶ Ra	<MDA		0.62	<MDA		0.90	0.49	0.16	0.52
²¹⁰ Pb	<MDA		0.37	<MDA		0.53	<MDA		0.41
²¹⁰ Po	0.533	0.170	0.16	0.0943	0.0424	0.067	0.135	0.035	0.12
²³⁵ U	0.00183	0.00014	0.00022	0.00020	0.00010	0.00038	0.00236	0.000026	0.00056
²³² Th	0.308	0.010	0.031	0.335	0.014	0.062	0.019	0.041	0.23
²²⁸ Ra	<MDA		0.21	<MDA		0.32	0.574	0.070	0.20
²²⁸ Th	<MDA		0.068	<MDA		0.099	0.0771	0.0090	0.044
⁴⁰ K	50.3	1.3	0.43	83.9	2.1	0.63	85.4	2.9	0.46
Gross alpha	4.01	0.35	1.0	6.41	0.59	1.7	10.8	0.9	2.4
Gross beta	67.4	0.7	0.066	101	1	0.12	102	1	0.15

Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("<MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("<MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-15478-01

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Peaches Samp 1	RA-15478X001	500	190	130	110	150	76
Cabbage Samp 2	RA-15478X002	230	73	55	61	110	34
Spinach Sample 3	RA-15478X003	430	120	92	110	190	46

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ²³⁴Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Pb (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) ²³⁵U and ²³¹Pa (= ²³⁵U)
²³²Th up to ²²⁸Th (= ²³²Th) ²²⁸Ra and ²²⁸Ac (= ²²⁸Th) ²²⁸Th up to ²¹²Bi (= ²²⁸Th) ²²⁶Ra up to ²¹⁰Pb (= ²²⁶Ra)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.

Sediment Materials from the South Deep Gold Mine

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Date: **18 May 2016**
Report number: **RS2016-0501-01**
Pages:
Your reference: **4900103658**

Analysis Report

Radioactivity analysis of sediment

Compile by: **MJ Raven**

Checked by: **N Seaga**

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Report number: **RS2016-0501-01**

Page 2 of 3

1. SERVICE

Analysis of solid samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium series.

Number of sample(s) received: 6

Date sample(s) received: 2016-02-08

Purchase order received: 2016-02-09

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry, mill and homogenise samples	2016-02-16	E Motlhabane	L Seshoka
WIN-138	Gross alpha/beta analysis on solids	2016-03-28	S May	E Nhlapo
WIN-167	Uranium/Thorium by neutron activation analysis	2016-04-04	A Satheke	N Seaga
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma spectrometry	2016-04-06	R Gaven	A Satheke
WIN-158	²¹⁰ Pb by low energy gamma spectrometry	2016-05-09	M Rapetsoa	N Seaga

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results reported relate only to the sample portions analysed.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

3.4 ²³⁴U activity was derived from the ²³⁸U activity, by using natural isotopic ratio.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: RS2016-0501-01

APPENDIX 1: ANALYTICAL RESULTS
Activity concentrations of nuclides in solid samples
Unit: Bq/kg

Field code Lab code	Doornkop		S6		S10		S11 [†]		S14		TSF DP	
	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.
²³⁸ U	35.2	1.4	2220	70	296	10	2320	70	295	10	33.2	1.3
²³⁴ U	35.5	1.4	2240	70	299	10	2340	70	298	10	33.5	1.3
²²⁶ Ra	21	8.9	28	26	218	19	1210	50	146	13	46.7	11.6
²¹⁰ Pb	< MDA		332	86	353	58	893	102	< MDA		< MDA	
²³⁴ U	1.62	0.06	102	3	0.016	0.4	0.015	107	3	0.016	1.53	0.06
²³² Th	27.2	0.6	35.1	0.9	2.3	27.0	69.8	1.2	2.3	24.4	30.2	0.6
²²⁶ Ra	< MDA		71	46	66	< MDA	98	91	36	110	< MDA	
²²⁸ Th	32	8.0	99	43	170	30	100	31	210	30	23	8.8
⁴⁰ K	180	77	240	310	316	102	< MDA	660	170	73	276	87
Gross alpha	2240	240	4510	460	1100	1620	11700	1600	2180	250	1880	230
Gross beta	343	25	4580	80	85	1150	5530	210	839	32	332	24

*Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

- Notes:
1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
 2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
 3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
 4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **23 March 2016**
Report number: **RS2015-3508-01**
Pages:
Your reference: **4900099507**

Analysis Report

Radioactivity analysis of sediment

Compile by: **MJ Raven**

Checked by: **N Seaga**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Report number: **RS2015-3508-01**

Page 2 of 3

1. SERVICE

Analysis of sediment samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium series.

Number of sample(s) received: 6

Date sample(s) received: 2015-10-22

Date purchase order received: 2015-11-22

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry, mill and homogenise samples	2015/12/03	E Motlhabane	O Mathekga
WIN-138	Gross alpha/beta analysis on solids	2016/03/08	S May	E Nhlapo
WIN-167	Uranium/Thorium by neutron activation analysis	2016/01/29	A Sathekge	N Seaga
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma spectrometry	2016/02/16	R Gaven	A Sathekge
WIN-158	²¹⁰ Pb by low energy gamma spectrometry	2016/01/22	R Senosi	A Sathekge

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results reported relate only to the sample portions analysed.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

3.4 ²³⁴U activity was derived from the ²³⁸U activity, by using natural isotopic ratio.

4. QUALITY ASSURANCE

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4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Page 3 of 3

Report number: **RS2015-3508-01**

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in solid samples
Unit: Bq/kg

Field code	S6C		S6S		S10C		S10S		S11B		S11A	
	Lab code	Value	Unc.	MDA	Lab code	Value	Unc.	MDA	Lab code	Value	Unc.	MDA
²³⁵ U	331	10	0.35	343	11	0.35	11	0.35	103	3	0.35	130
²³⁸ U	334	10	0.35	346	11	0.35	112	0.36	104	3	0.36	140
²²⁶ Ra	100	17	48	154	16	40	84.6	15.3	45	69.4	29	56
²¹⁰ Pb	219	34	100	147	25	77	127	84	162	23	67	578
²³² U	15.2	0.5	0.016	15.8	0.5	0.016	5.11	0.17	0.017	4.75	0.16	0.016
²³² Th	45.0	1.6	2.9	48.3	1.6	2.8	25.6	1.5	2.4	31.7	1.6	2.4
²²⁶ Ra	46	21	65	< MDA	85	< MDA	< MDA	82	< MDA	80	105	25
²²⁸ Th	39	17	160	45	13	130	32	13	130	46	14	120
⁴⁰ K	330	107	330	313	87	260	442	99	280	410	160	99
Gross alpha	4840	940	1600	1400	570	1500	2010	620	1400	1790	590	1300
Gross beta	1530	110	180	1160	90	120	856	79	130	747	74	130
										8610	260	310
										15100	1800	2600
										5430	210	320

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
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Date: **12 September 2016**
Report number: **RS2016-2551-01**
Pages: **3**
Your reference: **4900105466**

Analysis Report

Radioactivity analysis of sediment

Compile by: **MJ Raven**

Checked by: **N Seaga**

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Report number: **RS2016-2551-01**

Page 2 of 3

1. SERVICE

Analysis of sediment samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium series.

Number of sample(s) received: 6

Date sample(s) received: 2016-06-10

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-114	Dry, mill and homogenise samples	2016-06-22	E Motlabane	O Mathekga
WIN-138	Gross alpha/beta analysis on solids	2016-07-11	S May	E Nhlapo
WIN-167	Uranium/Thorium by neutron activation analysis	2016-07-05	Z Ntuli	A Sathekge
WIN-101	²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ⁴⁰ K by gamma spectrometry	2016-07-22	R Gaven	A Sathekge
WIN-158	²¹⁰ Pb by low energy gamma spectrometry	2016-08-10	M Rapetsoa	N Seaga

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results reported relate only to the sample portions analysed.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

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Report number: RS2016-2551-01 Page 3 of 3

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in solid samples

Unit: Bq/kg

Field code	S 11 A			S 11 B			S 6			S 10			S 14			ORWD		
	RS2016-2551X001		Value	RS2016-2551X002		Value	RS2016-2551X003		Value	RS2016-2551X004		Value	RS2016-2551X005		Value	RS2016-2551X006		
Lab code	Value	Unc.		MDA	Value		Unc.	MDA		Value	Unc.		MDA	Value		Unc.	MDA	Value
Nuclide																		
²³⁸ U	1380	30	0.52	2360	60	0.54	6940	170	0.50	101	3	0.50	253	6	0.52	606	15	0.53
²³⁴ U	1390	30	0.53	2400	60	0.54	7000	170	0.51	102	3	0.51	255	7	0.53	611	15	0.54
²²⁶ Ra	466	27	54	768	35	56	939	42	73	93.7	12.8	33	217	16	33	954	38	55
²¹⁰ Pb	701	76	210	1150	110	290	1640	150	420	< MDA		160	< MDA		170	1400	110	300
²³⁵ U	63.7	1.6	0.024	110	3	0.025	319	8	0.023	4.64	0.13	0.023	11.7	0.3	0.024	27.9	0.7	0.024
²³² Th	69.0	3.7	14	106	4	18	142	6	27	47.1	2.8	14	37.7	2.4	11	50.3	3.2	15
²²⁸ Ra	57	27	85	90	31	95	127	39	120	39	17	52	< MDA		67	66	25	78
²³² Th	49	14	140	96	20	180	82	19	200	31	10	110	34	5.1	97	52	25	180
⁴⁰ K	250	100	390	380	130	390	280	140	440	< MDA		340	< MDA		310	490	124	360
Gross alpha	4900	1020	2100	9330	1430	2800	12800	1900	4400	1200	520	1300	2390	670	1400	6530	1140	2100
Gross beta	3350	150	180	6090	210	240	14400	300	290	727	73	120	917	83	140	3380	160	210

*Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Water Radioanalysis Results from the South Deep Gold Mine

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Date: **23 September 2011**
Report number: **01**
Pages: **05**
Our reference: **RA-11431**
Your reference: **4500392409**

Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**
Technical signatories: **J Smit, S Seema, E Nhlapho**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-11431** Report number: **01** Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 9

Date samples received: 18 March 2011

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	23/03/2011	O Sambo
030112	Gross alpha/beta-analysis	WIN-167	05/04/2011	JJ van der Walt
090631	Uranium by alpha spectrometry	WIN-145	30/08/2011	A Mathopo
090711	Thorium by alpha spectrometry	WIN-142	04/08/2011	C Zwane
090311	Radium by alpha spectrometry	WIN-145	01/08/2011	N Sono
090821	Polonium-210 by alpha spectrometry	WIN-129	04/07/2011	A Mamaila
090820	Lead-210 by alpha spectrometry	WIN-129	Pending	

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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- 4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: RA-11431 Report number: 01 Page 3 of 5

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 1			Sida 2			Sida 3			Sida 4			Sida 5		
	Lab code	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.
²³⁸ U	RA-11431X001	132	9	1.8	793	20	1.4	1350	30	1.3	1070	20	1.3	7.06	1.71
		170	11	1.8	781	20	1.4	1240	20	1.3	1000	20	1.3	39.1	4.0
²³² Th	RA-11431X001	39.5	7.5	8.6	7.16	7.39	7.0	135	23	15	69.4	12.2	9.5	110	24
		8.41	1.59	0.81	9.82	1.74	0.83	174	7	0.81	7.57	1.55	0.86	2.26	0.80
²¹⁰ Pb	RA-11431X001	2.41	1.21	1.9	1.6	0.91	1.8	7.80	2.49	2.2	1.7	1.00	1.9	12.4	3.0
		6.68	2.11	1.8	33.6	4.2	1.4	59.9	5.4	1.3	49.3	1.0	0.060	0.325	0.079
²²⁷ Th	RA-11431X001	6.94	2.21	3.6	2.90	1.63	2.9	18.3	4.3	2.4	2.5	2.0	6.4	3.1	14
		-2.2	1.7	1.5	0.22	1.7	1.3	13.6	7.4	1.3	-2.0	1.2	1.3	0.38	0.86
²³² Th	RA-11431X001	2.89	1.18	1.3	2.8	1.2	2.9	35.6	5.6	2.4	4.90	1.63	1.5	16	8.6
		7.14	1.84	1.3	8.93	2.09	4.2	10.3	3.2	6.2	2.7	1.4	3.9	23	9.7
²²⁶ Ra	RA-11431X001	0.79	0.79	2.1	0.69	0.69	1.9	6.77	2.14	1.8	0.71	0.71	1.9	1.91	1.10
		-53	210	700	1080	220	680	1770	410	1300	1820	480	1500	-120	120
Gross alpha		340	170	560	370	170	560	1870	200	580	540	180	590	-120	160
Gross beta															

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: RA-11431 Report number: 01 Page 4 of 5

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 8			Sida 10			Sida 11			Sida 12		
	Lab code	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.
²³⁸ U	RA-11431X006	387	13	1.2	540	19	1.8	4780	50	1.4	1550	20
		368	13	1.2	497	18	1.8	4470	50	5.0	1330	20
²³² Th	RA-11431X006	30.6	6.1	9.0	14.3	3.3	7.5	56.8	10.0	8.5	18.2	4.1
		164	7	0.91	1.19	0.60	0.81	213	8	0.86	183	8
²¹⁰ Pb	RA-11431X006											
		5.59	1.87	1.8	0.25	0.25	1.8	7.16	2.28	2.0	4.22	1.90
²²⁷ Th	RA-11431X006	19.2	2.9	1.2	23.8	4.0	1.8	217	11	1.4	65.2	4.7
		18.4	3.5	3.7	3.8	1.7	4.0	3.3	2.4	7.2	5.9	3.2
²²⁶ Ra	RA-11431X006	10.2	7.6	1.4	0.20	0.64	1.3	-2.4	9.7	1.6	-14	9.3
		1.6	1.1	3.7	0.85	0.86	3.2	1.96	0.98	1.3	2.1	1.3
²³² Th	RA-11431X006	15.2	2.8	1.4	4.23	1.34	1.1	5.81	1.80	3.5	4.5	2.0
		2.27	1.31	2.1	< MDA			2.51	1.45	2.3	1.9	1.3
²²⁶ Ra	RA-11431X006	340	540	1800	-320	300	1000	5330	480	910	1990	360
		1540	200	600	210	170	570	1560	230	630	998	184
Gross alpha												
Gross beta												

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: **RA-11431** Report number: **01** Page **5** of **5**

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 1	RA-11431X001	200	45	34	34	64	36
Sida 2	RA-11431X002	230	82	61	62	110	71
Sida 3	RA-11431X003	820	230	170	180	370	200
Sida 4	RA-11431X004	280	97	74	71	120	96
Sida 5	RA-11431X005	490	100	74	69	110	75
Sida 8	RA-11431X006	560	140	100	120	270	110
Sida 10	RA-11431X007	150	53	39	39	68	47
Sida 11	RA-11431X008	1100	440	330	340	650	410
Sida 12	RA-11431X009	500	180	130	150	320	160

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Bi ($\approx^{210}\text{Pb}$) ^{235}U and ^{231}Pa ($\approx^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$) ^{228}Ra up to ^{228}Th ($\approx^{228}\text{Th}$) ^{224}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 5. Dose rate values are reported with 2 significant digits.

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NUCLEAR SERVICES

Contact: **Mr C Malebanye**

Date: **29 November 2011**

Company: **Placer Dome Western Areas Joint Venture**

Report number: **Final**

Address: **P O Box 776
Western Areas
1780**

Pages: **3**
Our reference: **RA-12259**
Your reference: **4500435818**

Analysis Report

Gross Alpha/Beta-activity analysis of water

Signature:

Compiler: **JJ van der Walt**

Technical Signatory: **E Nhlapo**

Directors: Mr Mame Dipoo (Chairperson), Adv Brenda Maduna (Deputy Chairperson), Mr Stefan Senele
 Mr Mphahlele (Lefika), Prof Gideon Geyenssen (Mr Phumile Tshikane), Mr Abdul Mity.
 Company Secretary: Mr Adurey Mubunda



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Job Code: RA-12259	Report: Final	Page 2 of 3
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1. SERVICE

Six liquid samples were received on 12 October 2011 for gross alpha/beta activity analysis.

2. SAMPLE PREPARATION AND ANALYSES

Product	Description	Procedure	Sampling Date	Completed	Assayer
020121	Filtration and acidification of water	RA-WIN-121	12-Oct-2011	13-Oct-2011	J Smit
030112	Gross Alpha/Beta of residual liquids	RA-WIN-161	12-Oct-2011	21-Nov-2011	JJ van der Walt

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 The method for gross alpha/beta activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 The validity of these results have been confirmed by the Technical Signatories.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job Code: RA-12259	Report: Final	Page 3 of 3
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APPENDIX: ANALYTICAL RESULTS

Gross alpha/beta-activity in samples

Activity unit: Bq/L

Sample code	Client code	Gross alpha-activity			Gross beta-activity		
		Value	Unc.	MDA	Value	Unc.	MDA
RA-12259X001	49 L	6.95	0.59	1.1	3.93	0.29	0.55
RA-12259X002	95 A	6.09	0.56	1.2	3.50	0.26	0.53
RA-12259X003	95 L	8.22	0.68	1.1	4.84	0.33	0.56
RA-12259X004	33 L	0.023	0.10	0.35	0.16	0.14	0.46
RA-12259X005	50 L	0.052	0.12	0.39	0.26	0.14	0.46
RA-12259X006	94 L	7.84	0.66	1.1	5.69	0.35	0.56

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **07 October 2011**
Report number: **Final**
Pages: **05**
Our reference: **RA-11123**
Your reference: **4500381044**

Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**

Technical signatories: **J Smit, S Seema, E Nhlapo**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-11123** Report number: **Final** Page **2** of **5**

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received:10

Date samples received:27 January 2011

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	27/01/2011	O Sambo
030112	Gross alpha/beta-analysis	WIN-167	07/02/2011	JJ van der Walt
090631	Uranium by alpha spectrometry	WIN-145	06/07/2011	A Mathopo
090711	Thorium by alpha spectrometry	WIN-142	31/03/2011	C Zwane
090311	Radium by alpha spectrometry	WIN-145	06/07/2011	N Sono
090821	Polonium-210 by alpha spectrometry	WIN-129	18/02/2011	A Mamaila
090820	Lead-210 by alpha spectrometry	WIN-129	06/10/2011	A Mamaila

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.

4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: RA-11123 Report number: Final Page 3 of 5

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	SIDA 1			SIDA 2			SIDA 3			SIDA 4			SIDA 5		
	Lab code	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	Value	Unc.	MDA
²³⁸ U	555	15	1.1	545	14	0.93	3860	40	1.3	290	10	0.99	42.7	7.5	3.6
²³⁴ U	534	15	1.1	518	13	0.93	3520	40	1.3	293	11	0.99	55.4	8.8	3.6
²³⁰ Th	38.0	7.3	24	2.6	2.9	28	84.0	14.5	25	48.9	9.9	37	18	4.6	26
²²⁶ Ra	11.4	1.7	0.72	66.2	4.3	0.76	333	10	0.86	3.34	1.18	1.1	2.52	1.13	1.4
²¹⁰ Pb	3.17	2.14	2.1	2.17	1.65	2.0	41.1	7.3	1.8	1.7	1.4	1.9	4.56	2.45	2.0
²¹⁰ Po	3.17	2.14	2.1	2.17	1.65	2.0	8.28	2.80	2.5	1.7	1.4	1.9	4.56	2.45	2.0
²³⁵ U	25.8	3.2	1.1	25.1	2.9	0.93	172	9	1.3	13.4	0.5	0.046	1.97	0.35	0.17
²²⁷ Th	1.9	1.7	5.8	8.23	2.49	4.8	38.9	5.0	6.2	1.8	2.2	7.8	0.016	1.3	5.6
²²⁶ Ra	-0.84	0.94	4.0	0.89	-4.0	2.4	0.94	9.92	7.92	1.2	0.53	1.0	1.5	9.86	2.48
²³² Th	0.55	0.94	4.0	2.0	1.4	4.8	5.23	1.74	1.6	9.34	2.81	2.3	2.4	1.7	5.6
²²⁸ Th	2.7	1.6	5.0	1.3	0.91	1.8	8.12	2.71	6.9	7.61	2.80	6.2	6.01	2.24	5.5
²²⁶ Ra	< MDA	1.6	0.63	0.63	1.7	2.64	1.32	1.8	0.87	0.87	2.4	< MDA	< MDA	2.9	2.9
Gross alpha	647	167	520	660	230	740	4130	500	1300	250	140	440	120	110	370
Gross beta	130	190	630	170	190	640	2910	260	680	250	190	630	-200	190	620

Notes:

- If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
- The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
- The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
- A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: RA-11123 Report number: Final Page 4 of 5

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	SIDA 6			SIDA 8			SIDA 10			SIDA 11			SIDA 12		
	Lab code	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	Value	Unc.	MDA
²³⁸ U	18.1	2.9	1.3	8670	90	2.2	27.6	4.9	2.4	5580	60	1.3	1320	30	1.3
²³⁴ U	19.9	3.0	1.3	7390	80	5.9	25.4	4.9	2.4	5190	50	1.3	1210	30	1.3
²³⁰ Th	12	3.3	25	41.5	7.7	22	20	4.8	27	49.8	9.4	28	29.8	6.0	22
²²⁶ Ra	0.96	0.68	1.3	188	10	1.3	7.19	1.86	1.3	181	10	1.4	66.7	5.6	1.3
²¹⁰ Pb	15.2	4.0	1.8	58.3	8.2	1.7	7.55	2.86	1.8	1.9	1.5	2.0	1.7	1.4	1.9
²¹⁰ Po	0.89	0.75	2.0	3.84	1.85	2.2	1.7	1.0	2.0	1.9	1.5	2.0	1.7	1.4	1.9
²³⁵ U	0.93	0.66	1.3	399	4	0.10	1.27	0.23	0.11	257	3	0.061	60.6	1.2	0.062
²²⁷ Th	2.7	2.0	6.2	36.5	4.3	3.6	-1.3	1.1	5.8	-0.18	1.7	6.9	2.5	1.5	3.7
²²⁶ Ra	10.3	2.4	1.8	42.4	8.6	1.8	19.7	3.5	1.7	2.45	7.31	1.9	-1.9	4.0	1.7
²²⁸ Th	2.9	1.7	5.3	5.0	2.0	5.3	2.50	1.25	1.7	5.76	1.92	1.7	5.19	1.79	3.7
²²⁸ Th	2.8	1.7	5.2	6.41	2.25	5.9	6.85	2.07	1.7	8.29	2.62	5.9	5.70	1.98	4.7
²²⁶ Ra	< MDA	2.7	3.10	1.79	2.8	1.0	1.0	2.7	< MDA	< MDA	3.0	< MDA	< MDA	2.7	2.7
Gross alpha	-140	130	460	10300	800	1400	210	120	400	8400	680	1100	1340	270	820
Gross beta	-160	190	630	3640	330	750	7.1	190	630	2280	290	750	480	200	640

Notes:

- If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
- The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
- The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
- A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: **RA-11123** Report number: **Final** Page 5 of 5

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
SIDA 1	RA-11123X001	190	65	48	47	83	58
SIDA 2	RA-11123X002	260	76	57	60	130	69
SIDA 3	RA-11123X003	1500	490	370	380	770	440
SIDA 4	RA-11123X004	190	49	37	38	69	42
SIDA 5	RA-11123X005	130	36	25	25	44	21
SIDA 6	RA-11123X006	100	31	22	22	37	19
SIDA 8	RA-11123X007	2000	780	590	580	1000	720
SIDA 10	RA-11123X008	140	35	25	26	51	20
SIDA 11	RA-11123X009	1100	470	360	360	690	450
SIDA 12	RA-11123X010	350	130	97	100	200	120

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($\approx^{238}\text{U}$) ^{235}Ra up to ^{214}Bi ($\approx^{235}\text{Ra}$) ^{210}Pb and ^{210}Bi ($\approx^{210}\text{Pb}$) ^{238}U and ^{234}Pa ($\approx^{238}\text{U}$)
 ^{227}Ac up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{213}Pb ($\approx^{223}\text{Ra}$) ^{228}Ra up to ^{228}Th ($\approx^{228}\text{Th}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$)
 - Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 - Dose rate values are reported with 2 significant digits.

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Date: **15 December 2011**
Report number: **01**
Pages: **05**
Our reference: **RA-11623**
Your reference: **4500410854**

Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**

Technical signatories: **J Smit, S Seema, E Nhlapo**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-11623** Report number: **01** Page **2** of **5**

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 09 June 2011

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	09/06/2011	O Sambo
030112	Gross alpha/beta-analysis	WIN-167	25/07/2011	JJ van der Walt
090631	Uranium by alpha spectrometry	WIN-145	08/11/2011	A Mathopo
090711	Thorium by alpha spectrometry	WIN-142	23/09/2011	C Zwane
090311	Radium by alpha spectrometry	WIN-145	15/11/2011	N Sono
090821	Polonium-210 by alpha spectrometry	WIN-129	30/08/2011	A Mamaila
090820	Lead-210 by alpha spectrometry	WIN-129	Pending	

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Page 3 of 5

Report number: 01

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code Lab code	Sida 1 RA-11623X001			Sida 2 RA-11623X002			Sida 3 RA-11623X003			Sida 4 RA-11623X004			Sida 5 RA-11623X005		
	Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	Value	Unc.	MDA
	²³⁸ U	394	15	1.6	447	17	1.7	522	15	1.2	1400	30	1.4	37.2	4.5
	²³⁵ U	344	15	1.6	383	16	1.7	464	15	1.2	1360	30	1.4	42.5	4.9
	²³⁰ Th	47.7	10.7	4.1	34.4	7.2	2.6	57.9	10.7	2.4	22.9	4.5	1.5	35.7	6.8
	²²⁶ Ra	10.8	1.8	0.79	15.3	2.1	0.77	143	6	0.80	3.52	1.02	0.79	3.43	1.03
	²¹⁰ Pb	6.17	2.19	2.2	9.00	2.52	2.0	4.20	1.89	2.5	7.51	2.53	2.4	0.54	0.54
	²¹⁰ Po	6.17	2.19	2.2	9.00	2.52	2.0	4.20	1.89	2.5	7.51	2.53	2.4	0.54	0.54
	²²⁶ U	18.1	0.7	0.074	20.6	0.8	0.077	24.0	0.7	0.055	64.6	1.2	0.064	1.71	0.21
	²²⁷ Th	7.41	2.84	2.9	-0.50	2.2	8.8	12.6	3.1	4.6	0.86	1.4	5.0	0.087	1.6
	²²⁶ Ra	0.55	1.4	1.1	0.60	1.6	1.0	-0.19	4.7	1.1	-0.22	0.69	1.1	-0.68	0.88
	²²⁸ Th	3.2	3.9	14	3.34	1.49	1.8	3.1	1.7	4.6	3.41	1.26	2.8	10.7	2.3
	²²⁸ Ac	< MDA			7.95	2.65	6.2	9.39	2.58	4.6	2.3	1.1	2.8	3.4	3.5
	²²⁸ Ra	< MDA			1.7	< MDA	1.6	1.2	0.88	1.7	< MDA		1.7	< MDA	1.9
	⁴⁰ K														
	Gross alpha	471	133	410	443	111	330	995	237	710	1910	200	460	91	65
	Gross beta	1280	220	690	1400	220	680	1700	230	710	2210	240	690	58	200

- Notes:
1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
 2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
 3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
 4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: RA-11623

Report number: 01

Page 4 of 5

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code Lab code Nuclide	Sida 6 RA-11623X006			Sida 8 RA-11623X007			Sida 10 RA-11623X008			Sida 11 RA-11623X009			Sida 12 RA-11623X010		
	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	12.9	2.5	1.3	3950	50	1.9	55.0	8.2	3.1	5720	70	2.2	343	15	1.8
²³⁵ U	19.7	3.2	1.3	3500	50	1.9	55.3	8.2	3.1	5170	70	2.2	333	15	1.8
²³⁰ Th	29	7.0	40	44.7	7.9	15	23	5.7	32	13	3.3	20	40.8	7.3	15
²²⁶ Ra	2.01	0.82	0.91	179	8	0.86	533	1.78	1.6	146	6	0.69	17.7	3.1	1.5
²¹⁰ Pb	2.2	1.3	2.4	15.2	3.6	2.3	9.67	2.71	2.1	5.42	2.23	2.6	4.76	1.81	2.0
²¹⁰ Po	2.2	1.3	2.4	15.2	3.6	2.3	9.67	2.71	2.1	5.42	2.23	2.6	4.76	1.81	2.0
²²⁶ U	0.592	0.116	0.062	182	2	0.087	2.67	0.38	0.14	263	3	0.10	15.8	0.7	0.085
²²⁷ Th	2.3	4.0	15	26.8	3.6	6.2	-2.6	2.0	9.9	5.41	1.90	3.8	4.26	1.45	1.1
²²⁶ Ra	-0.046	0.79	1.4	8.11	7.54	1.3	-1.5	1.4	2.5	-0.50	5.9	1.1	-1.4	1.2	1.7
²²⁸ Th	6.28	2.56	2.8	1.96	0.88	1.1	2.46	1.42	2.2	2.04	1.02	1.4	4.00	1.39	2.9
²²⁸ Th	7.3	4.0	12	5.84	1.60	2.9	8.16	2.58	2.2	5.59	1.97	4.7	7.55	2.42	6.6
²²⁶ Ra	0.75	0.75	2.0	2.13	1.23	1.9	< MDA		3.6	< MDA		1.6	< MDA		3.9
⁴⁰ K															
Gross alpha	-16	71	250	5420	470	870	63	72	240	9370	710	700	366	100	300
Gross beta	230	210	680	4840	330	740	470	210	680	5850	400	770	1080	220	680

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: RA-11623

Report number: 01

Page 5 of 5

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 1	RA-11623X001	260	77	56	55	98	61
Sida 2	RA-11623X002	270	86	61	59	110	62
Sida 3	RA-11623X003	470	120	91	100	240	100
Sida 4	RA-11623X004	320	140	100	94	150	120
Sida 5	RA-11623X005	100	20	15	15	25	18
Sida 6	RA-11623X006	150	27	21	21	39	21
Sida 8	RA-11623X007	1200	420	310	310	590	380
Sida 10	RA-11623X008	200	58	39	38	66	33
Sida 11	RA-11623X009	1100	470	360	360	660	450
Sida 12	RA-11623X010	230	67	49	49	92	52

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($\approx^{238}\text{U}$) ^{226}Ra up to ^{210}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Bi ($\approx^{210}\text{Pb}$) ^{235}U and ^{231}Pa ($\approx^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$) ^{228}Ra up to ^{228}Th ($\approx^{228}\text{Th}$) ^{226}Ra up to ^{210}Bi ($\approx^{226}\text{Ra}$)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 5. Dose rate values are reported with 2 significant digits.

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Date: **22 February 2012**

Company: **Placer Dome Western Areas Joint Venture**

Report number: **Final**

Address: **P O Box 776
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Pages: **3**
Our reference: **RA-12563**
Your reference: **4500451400**

Analysis Report

Gross Alpha/Beta-activity analysis of water

Signature:

Compiler: **JJ van der Walt**

Technical Signatory: **E Nhlapo**

Directors: M Mene (Chairperson), Aki Branda Madumbe (Deputy Chairperson), M Sediso (Stipend),
Ms Mphahlele (Lefika), Prof Ockon Greyvenstein, M Phumiso Tshelane, M Abul Mity,
Company Secretary: M Aukrey Mubunda

RSG 200905073006



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Job Code: RA-12563	Report: Final	Page 2 of 3
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1. SERVICE

Two liquid samples were received on 18 January 2012 for gross alpha/beta activity analysis.

2. SAMPLE PREPARATION AND ANALYSES

Product	Description	Procedure	Sampling Date	Completed	Assayer
020121	Filtration and acidification of water	RA-WIN-121	18-Jan-2012	24-Jan-2012	J Smit
030112	Gross Alpha/Beta of residual liquids	RA-WIN-161	18-Jan-2012	10-Feb-2012	JJ van der Walt

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 The method for gross alpha/beta activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 The validity of these results have been confirmed by the Technical Signatories.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job Code: **RA-12563** Report: **Final** Page **3** of **3**

APPENDIX: ANALYTICAL RESULTS

Gross alpha/beta-activity in samples

Activity unit: Bq/L

Sample code	Client code	Gross alpha-activity			Gross beta-activity		
		Value	Unc.	MDA	Value	Unc.	MDA
RA-12563X001	Sida 6	0.010	0.16	0.53	0.097	0.079	0.26
RA-12563X002	Sida 5	-0.0049	0.14	0.49	0.12	0.078	0.25

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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NUCLEAR SERVICES

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Date: **26 March 2012**

Company: **Placer Dome Western Areas Joint Venture**

Report number: **Final**

Address: **P O Box 776
Western Areas
1780**

Pages: **3**

Our reference: **RA-12562**
Your reference: **4500451401**

Analysis Report

Gross Alpha/Beta-activity analysis of water

Signature:

Compiler: **JJ van der Walt**

Technical Signatory: **Deon Kotze**

Directors: Mr Mame Dipa (Chairperson), Adv Brendo Mofene (Deputy Chairperson), Mr Sibusiso Shole, NIG 286965/2008
Ms Mphahleli Lefoka, Prof Gideon Greyvenstein, Mr Phumiso Tshwane, Mr Abdul Muty
Company Secretary: Mr Aakrey Mburda



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Job Code: RA-12562	Report: Final	Page 2 of 3
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1. SERVICE

Nine liquid samples were received on 18 January 2012 for gross alpha/beta activity analysis.

2. SAMPLE PREPARATION AND ANALYSES

Product	Description	Procedure	Sampling Date	Completed	Assayer
020121	Filtration and acidification of water	RA-WIN-121	18-Jan-2012	25-Jan-2012	J Smit
030112	Gross Alpha/Beta of residual liquids	RA-WIN-161	18-Jan-2012	26-Mar-2012	JJ van der Walt

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 The method for gross alpha/beta activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 The validity of these results have been confirmed by the Technical Signatories.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job Code: RA-12562	Report: Final	Page 3 of 3
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APPENDIX: ANALYTICAL RESULTS

Gross alpha/beta-activity in samples

Activity unit: Bq/L

Sample code	Client code	Gross alpha-activity			Gross beta-activity		
		Value	Unc.	MDA	Value	Unc.	MDA
RA-12562X001	Sida 1	-0.038	0.20	0.66	0.951	0.170	0.53
RA-12562X002	Sida 2	0.87	0.29	0.95	1.40	0.18	0.53
RA-12562X003	Sida 3	8.37	0.83	1.9	7.56	0.42	0.62
RA-12562X004	Sida 4	0.22	0.34	1.1	0.941	0.17	0.54
RA-12562X005	Sida 8	0.56	0.74	2.4	3.59	0.25	0.57
RA-12562X006	Sida 10	-0.099	0.16	0.55	0.542	0.164	0.52
RA-12562X007	Sida 11	7.25	0.78	1.9	6.62	0.46	1.1
RA-12562X008	Sida 12	5.06	5.69	2.0	4.09	0.38	1.0
RA-12562X009	Sida 19	12.8	1.1	2.2	8.91	0.59	1.1

Notes:

- If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
- The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
- The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
- A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Date: **29 March 2012**
Report number: **01**
Pages: **04**
Our reference: **RA-12176**
Your reference: **4500436575**

Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**

Technical signatories: **J Smit, S Seema, E Nhlapo**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-12176** Report number: **01** Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 3

Date samples received: 29 September 2011

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	04/10/2011	O Sambo
030112	Gross alpha/beta-analysis	WIN-167	04/01/2012	JJ van der Walt
090631	Uranium by alpha spectrometry	WIN-145	06/03/2012	A Mathopo
090711	Thorium by alpha spectrometry	WIN-142	28/02/2012	C Zwane
090311	Radium by alpha spectrometry	WIN-145	22/02/2012	N Sono
090821	Polonium-210 by alpha spectrometry	WIN-129	28/02/2012	A Mamaila
090820	Lead-210 by alpha spectrometry	WIN-129	Pending	

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: RA-12176 Report number: 01 Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 13			Sida 19			Sida 7 received 14/12/2011		
Lab code	RA-12176X001			RA-12176X002			RA-12176X003		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	12000	200	6.8	27300	300	10	27200	300	8.7
²³⁴ U	10800	200	6.8	23600	300	10	24200	300	8.7
²³⁰ Th	118	22	51	21.2	4.5	16	36.5	6.8	16
²²⁶ Ra	103	5	3.6	144	6	0.78	15.4	2.1	2.6
²¹⁰ Pb	2.49	1.25	2.0	7.15	2.17	1.9	3.23	1.45	2.0
²¹⁰ Po	2.49	1.25	2.0	7.15	2.17	1.9	3.23	1.45	2.0
²³⁵ U	553	8	0.32	1260	10	0.46	1250	10	0.40
²²⁷ Th	12.3	4.9	3.9	6.69	2.01	3.4	-3.5	1.5	7.3
²²³ Ra	8.30	2.75	3.0	0.99	2.7	2.2	20.1	2.6	2.9
²³² Th	17.4	5.4	11	2.33	1.04	1.3	0.46	0.46	1.2
²²⁸ Th	11	4.9	13	3.68	1.30	1.2	3.2	1.4	3.3
²²⁴ Ra	1.8	1.3	2.5	1.9	1.3	2.6	78.2	8.5	2.5
Gross alpha	3130	520	1600	5370	590	1500	9190	840	1700
Gross beta	4640	290	640	6780	380	670	4690	370	710

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: RA-12176 Report number: 01 Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 13	RA-12176X001	2200	920	700	680	1200	900
Sida 19	RA-12176X002	4200	2000	1500	1400	2400	1900
Sida 7 received 14/12/2011	RA-12176X003	4200	2000	1500	1400	2300	1900

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Po (= ²¹⁰Po)
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²³¹Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²³Ra up to ²²³Th (= ²²³Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Report number: **Final**

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Pages: **3**
Our reference: **RA-13071**
Your reference: **4500477286**

Analysis Report

Gross Alpha/Beta-activity analysis of water

Signature: 

Compiler: **N Yawa**

Technical Signatory: **E Nhlapo**

Directors: Mr Meme Dipoo (Chairperson), Ad Benda Mdumane (Deputy Chairperson), Mr Sibusiso Shole
Ms Makhosonke Lufaka, Prof Odion Grayvenstein, Mr Phumiso Tsholane, Mr Abdul Mmy,
Company Secretary: Mr Aubrey Mibunda

REG. 2005/072906



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Job Code: **RA-13071** Report: **Final** Page **2** of **3**

1. SERVICE

One liquid sample was received on 28 March 2012 for gross alpha/beta activity analysis.

2. SAMPLE PREPARATION AND ANALYSES

Product	Description	Procedure	Sampling Date	Completed	Assayer
020121	Filtration and acidification of water	RA-WIN-121	28-Mar-2012	04-Apr-2012	J Smit
030112	Gross Alpha/Beta of residual liquids	RA-WIN-161	28-Mar-2012	20-Jun-2012	N Yawa

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 The method for gross alpha/beta activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 The validity of these results have been confirmed by the Technical Signatories.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job Code: RA-13071	Report: Final	Page 3 of 3
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APPENDIX: ANALYTICAL RESULTS

Gross alpha/beta-activity in samples

Activity unit: Bq/L

Sample code	Client code	Gross alpha-activity			Gross beta-activity		
		Value	Unc.	MDA	Value	Unc.	MDA
RA-13071X001	SIDA 5	0.479	0.089	0.25	0.43	0.18	0.58
RA-13071X002	SIDA 6	0.26	0.09	0.28	0.35	0.18	0.58

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Address: **PO Box 776**
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Date: **26 July 2012**
Report number: **Final**
Pages: **05**
Our reference: **RA-12381**
Your reference: **4500432675**

Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**

Technical signatories: **J Smit, S Seema, E Nhlapo**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-12381** Report number: **Final** Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 9

Date samples received: 25 November 2011

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	04/10/2011	O Sambo
030112	Gross alpha/beta-analysis	WIN-167	19/12/2011	JJ van der Walt
090631	Uranium by alpha spectrometry	WIN-145	25/04/2012	A Mathopo
090711	Thorium by alpha spectrometry	WIN-142	08/05/2012	C Zwane
090311	Radium by alpha spectrometry	WIN-145	12/04/2012	N Sono
090821	Polonium-210 by alpha spectrometry	WIN-129	08/03/2012	A Mamalia
090820	Lead-210 by alpha spectrometry	WIN-129	18/07/2012	C Zwane

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.

4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: **RA-12381**

Report number: **Final**

Page 3 of 5

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code Lab code	SIDA 1 RA-12381X001			SIDA 2 RA-12381X002			SIDA 3 RA-12381X003			SIDA 4 RA-12381X004			SIDA 5 RA-12381X005		
	Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.
	²³⁸ U	136	7	0.88	1280	20	0.85	2710	30	0.84	2060	30	0.88	9.53	1.94
	²³⁴ U	151	7	0.88	1170	20	0.85	2480	30	0.84	1900	30	0.88	60.7	4.9
	²³⁴ Th	16.0	3.5	14	18.6	4.2	16	27.6	5.5	15	26.2	5.2	20	17.1	3.7
	²²⁶ Ra	5.26	1.64	3.2	8.38	1.71	2.4	136	7	3.5	3.18	1.12	2.7	2.76	0.87
	²¹⁰ Pb	0.55	0.87	2.6	38.5	9.0	3.5	12.9	3.9	1.6	3.2	2.4	4.1	1.7	1.3
	²¹⁰ Po	0.55	0.87	2.6	-17	5.3	0.92	12.9	3.9	1.6	-1.4	1.3	0.30	1.7	1.3
	²²⁸ U	6.28	0.31	0.041	58.8	0.9	0.039	139	7	0.84	94.7	1.2	0.041	0.439	0.090
	²²⁸ Th	10.4	2.5	5.4	12.3	2.9	6.0	22.4	3.4	3.5	14.2	2.4	1.1	14.3	2.5
	²²⁸ Ra	2.1	2.0	6.5	-0.32	1.6	4.8	17.2	5.5	3.5	1.1	0.97	1.5	-0.081	0.76
	²³² Th	0.42	0.42	1.1	1.00	0.70	1.3	4.71	1.49	1.3	0.40	1.1	4.3	1.3	0.95
	²²⁸ Th	4.97	1.55	3.0	3.46	1.31	1.3	8.89	2.04	1.3	5.56	1.48	1.1	2.1	1.1
	²²⁸ Ra	13.8	4.0	8.5	1.4	0.95	1.8	4.75	1.79	1.8	0.61	0.61	1.6	1.2	0.82
	Gross alpha	-17	210	720	1210	260	800	3540	520	1500	2350	340	960	-200	190
	Gross beta	-3.4	280	960	1590	310	970	4140	380	1000	2970	330	1000	-280	290

Notes:

- If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
- The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
- The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
- A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 6			Sida 8			Sida 10			Sida 11		
	Lab code	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.
²³⁸ U	RA-12381X006	50.6	4.2	0.95	172	8	0.99	16.2	2.6	1.1	8600	90
²³⁴ U		76.7	5.2	0.95	156	8	0.99	22.8	3.1	1.1	7660	80
²³⁰ Th		24.1	5.5	21	14.1	3.2	13	79.2	13.6	28	20.8	4.5
²²⁶ Ra		0.27	0.89	3.5	161	7	2.7	1.5	1.1	3.5	135	11
²¹⁰ Pb		15.2	5.2	1.8	2.12	1.51	1.7	11.5	5.1	4.2	2.27	1.79
²¹⁰ Po		-1.6	4.1	1.4	2.12	1.51	1.7	-4.8	3.0	0.34	2.27	1.79
²³⁵ U		2.46	0.93	0.95	7.91	0.36	0.046	0.747	0.118	0.051	396	4
²²⁷ Th		18.3	3.8	1.8	28.1	3.7	5.2	21.2	3.6	1.5	23.3	3.6
²²⁶ Ra		-0.94	0.69	4.0	9.11	5.31	3.0	-0.65	0.73	3.4	6.4	5.6
²²⁸ Th		2.58	1.29	1.8	< MDA		1.1	2.2	1.7	5.9	1.92	0.96
²²⁸ Ra		23.1	4.2	6.9	7.88	1.85	2.9	7.02	1.95	1.5	8.50	2.00
Gross alpha		< MDA		4.1	11.4	2.6	1.6	0.53	0.91	3.9	21.5	7.2
Gross beta		-180	220	760	-210	540	1800	-210	190	650	11200	900
		-210	290	970	1360	330	1000	77	290	950	10700	600

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: **RA-12381**

Report number: **Final**

Page 5 of 5

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
SIDA 1	RA-12381X001	190	41	31	30	54	33
Sida 2	RA-12381X002	420	150	110	110	190	130
Sida 3	RA-12381X003	930	320	240	240	450	280
Sida 4	RA-12381X004	510	180	140	130	220	170
Sida 5	RA-12381X005	170	28	22	20	33	27
Sida 6	RA-12381X006	390	83	61	66	130	55
Sida 8	RA-12381X007	530	110	84	96	230	93
Sida 10	RA-12381X008	340	58	46	45	77	53
Sida 11	RA-12381X009	1700	690	520	520	920	670

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb)
²³⁵U and ²³¹Pa (= ²³⁵U) ²²⁷Ac up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 5. Dose rate values are reported with 2 significant digits.

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Contact: **Ms C Legoete** Date: **27 August 2012**
Company: **Placer Dome Western Aria Joint Venture** Report number: **01**
Address: **PO Box 776** Pages: **05**
Western Area Our reference: **RA-12784**
1780 Your reference: **4500477289**

Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**

Technical signatories: **J Smit, S Seema, E Nhlapo**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-12784** Report number: **01** Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 21 June 2012

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	02/07/2012	O Sambo
030112	Gross alpha/beta-analysis	WIN-167	08/08/2012	S Yawa
090631	Uranium by alpha spectrometry	WIN-145		T Moketse
090711	Thorium by alpha spectrometry	WIN-142		A Mamaila
090311	Radium by alpha spectrometry	WIN-145		A Mathopo
090821	Polonium-210 by alpha spectrometry	WIN-129	08/08/2012	C Zwane
090820	Lead-210 by alpha spectrometry	WIN-129	Pending	

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: RA-12784 Report number: 01 Page 3 of 5

APPENDIX 1: ANALYTICAL RESULTS Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code Lab code	SIDA 1 RA-12784X001			SIDA 2 RA-12784X002			SIDA 3 RA-12784X003			SIDA 4 RA-12784X004			SIDA 8 RA-12784X005		
	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	155	10	5.8	799	23	1.9	5470	60	5.0	869	24	1.8	399	13	4.2
²³⁴ U	185	11	1.7	709	22	1.9	4940	60	5.0	800	24	1.8	361	13	1.2
²³⁰ Th															
²²⁶ Ra															
²¹⁰ Pb															
²¹⁰ Po	2.36	1.19	1.9	0.13	0.13	1.4	28.3	4.2	1.6	11.6	2.7	1.7	27.9	4.3	1.7
²³⁵ U	7.15	0.46	0.27	39.6	5.4	6.4	263	13	1.8	40.0	1.1	0.085	18.4	0.6	0.20
²²⁷ Th															
²²⁶ Ra															
²²⁵ Th															
²²⁷ Th															
²²⁶ Ra															
Gross alpha	43	98	330	963	192	570	7990	670	1100	881	194	590	180	350	1200
Gross beta	200	190	630	1090	200	640	7750	430	730	1090	200	640	1900	230	670

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Activity concentrations of nuclides in filtered samples

Job reference: RA-12784 Report number: 01 Page 4 of 5

Unit: mBq/L

Field code Lab code	SIDA 10 RA-12784X006			SIDA 11 RA-12784X007			SIDA 12 RA-12784X008			SIDA 19 RA-12784X009		
	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	33.6	8.1	13	6520	70	3.9	8190	80	3.4	5990	60	10
²³⁴ U	26.8	7.5	13	6060	60	8.8	7410	70	1.2	5510	60	11
²³⁰ Th												
²²⁶ Ra												
²¹⁰ Pb												
²¹⁰ Po	0.69	0.49	1.5	2.73	1.12	1.4	27.6	4.3	1.8	2.08	1.04	1.7
²³⁵ U	1.55	0.37	0.60	300	3	0.18	377	4	0.15	276	3	0.46
²²⁷ Th												
²²⁶ Ra												
²²⁵ Th												
²²⁷ Th												
²²⁶ Ra												
Gross alpha	-200	86	300	13900	1100	1200	10500	800	1200	9790	780	1000
Gross beta	10	190	620	9270	560	810	11400	600	760	8830	500	760

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: **RA-12784** Report number: **01** Page 5 of 5

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
SIDA 1	RA-12784X001						
SIDA 2	RA-12784X002						
SIDA 3	RA-12784X003						
SIDA 4	RA-12784X004						
SIDA 8	RA-12784X005						
SIDA 10	RA-12784X006						
SIDA 11	RA-12784X007						
SIDA 12	RA-12784X008						
SIDA 19	RA-12784X009						

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Bi ($\approx^{210}\text{Pb}$) ^{235}U and ^{231}Pa ($\approx^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$) ^{223}Ra up to ^{223}Th ($\approx^{223}\text{Th}$) ^{224}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 - Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 - Dose rate values are reported with 2 significant digits.

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Contact: **Ms C Legoete** Date: **27 August 2012**
Company: **Placer Dome Western Area Joint Venture** Report number: **01**
Address: **PO Box 776** Pages: **04**
Western Area Our reference: **RA-13141**
1780 Your reference: **450086552**

Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**

Technical signatories: **J Smit, S Seema, E Nhlapo**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job reference: **RA-13141** Report number: **01** Page **2** of **4**

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 12 June 2012

2. SAMPLE PREPARATION AND ANALYSIS

Product	Description	Procedure	Completed	Assayer
020121	Filtration of suspended solids	WIN-121	25/06/2012	O Sambo
030112	Gross alpha/beta-analysis	WIN-167	07/08/2012	S Yawa
090631	Uranium by alpha spectrometry	WIN-145	21/08/2012	T Moketse
090711	Thorium by alpha spectrometry	WIN-142	Pending	
090311	Radium by alpha spectrometry	WIN-145	23/08/2012	A Mathopo
090821	Polonium-210 by alpha spectrometry	WIN-129	08/08/2012	C Zwane
090820	Lead-210 by alpha spectrometry	WIN-129	Pending	

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 This report is a compilation of results obtained from different test reports individually signed by the SANAS Technical Signatories for the respective methods. The compiler is the Technical Expert for all the methods. The individual test reports are available upon request.
- 4.3 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: **RA-13141** Report number: **01** Page **3** of **4**

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	SIDA 5			SIDA 6		
Lab code	RA-13141X001			RA-13141X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	23.4	4.3	2.2	49.0	6.2	2.1
²³⁴ U	69.2	7.5	2.2	92.6	8.7	2.1
²³⁰ Th						
²²⁶ Ra	2.99	1.13	1.2	3.45	1.22	1.2
²¹⁰ Pb	0.20	0.20	1.6	0.17	0.17	1.6
²¹⁰ Po	0.20	0.20	1.6	0.17	0.17	1.6
²³⁵ U	1.08	0.20	0.10	2.26	0.29	0.099
²²⁷ Th						
²²³ Ra	0.60	1.0	1.6	0.49	1.1	1.6
²³² Th						
²²⁸ Th						
²²⁴ Ra	< MDA		2.4	2.70	1.56	2.4
Gross alpha	-68	150	500	-77	170	560
Gross beta	-55	160	540	30	170	550

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: **RA-13141** Report number: **01** Page **4** of **4**

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
SIDA 5	RA-13141X001						
SIDA 6	RA-13141X002						

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Po ($\approx^{210}\text{Pb}$)
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{231}\text{Pa}$) ^{227}Ra and ^{211}Pb ($\approx^{227}\text{Ra}$)
 ^{223}Ra up to ^{223}Th ($\approx^{223}\text{Ra}$) ^{223}Th up to ^{212}Bi ($\approx^{223}\text{Th}$)
 - Dose rate values are reported with 2 significant digits.

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Contact: **Ms C Legoete**
Company: **Placer Dome Western Areas Joint Venture**
Address: **P O Box 776 Western Areas 1780**

Date: **04 December 2012**
Report number: **RA-13376-01**
Pages: **4**
Your reference: **4900074778**

Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job number: **RA-13376-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 31 July 2012

Purchase order received: 30 August 2012

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	06/08/2012	O Sambo	J Smit
WIN-167	Gross alpha/beta-analysis	18/09/2012	S Yawa	S Nhlapo
WIN-145	Uranium by alpha spectrometry	28/09/2012	T Moketse	S Seema
WIN-142	Thorium by alpha spectrometry	08/10/2012	A Mamaila	S Seema
WIN-145	Radium by alpha spectrometry	10/10/2012	A Mathopo	S Seema
WIN-129	Polonium-210 by alpha spectrometry	13/09/2012	C Zwane	S Seema
WIN-129	Lead-210 by alpha spectrometry		C Zwane	S Seema

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: **RA-13376-01**

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 5			Sida 6		
Lab code	RA-13376X001			RA-13376X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	75.3	7.1	1.8	70.0	7.5	2.2
²³⁴ U	128	9	1.8	151	11	2.2
²³⁰ Th	58.2	10.4	37	53.5	9.7	36
²²⁶ Ra	1.1	0.69	2.1	3.88	1.18	2.6
²¹⁰ Pb	3.04	1.52	2.3	4.08	1.23	1.1
²¹⁰ Po	3.04	1.52	2.3	4.08	1.23	1.1
²³⁵ U	3.47	0.33	0.083	3.23	0.34	0.099
²²⁷ Th	13.7	3.7	7.3	18.9	3.4	4.0
²²³ Ra	1.4	1.2	4.4	0.86	1.6	4.7
²³² Th	7.20	2.00	1.5	2.73	1.22	1.5
²²⁸ Th	7.01	2.09	4.0	2.1	1.3	3.9
²²⁴ Ra	3.7	2.2	6.9	0.74	0.74	2.0
Gross alpha	622	103	290	359	108	340
Gross beta	717	121	370	462	119	380

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("**< MDA**") will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("**< MDA**") is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: **RA-13376-01**

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
Sida 5	RA-13376X001	270	53	40	38	65	44
Sida 6	RA-13376X002	290	54	42	38	59	50

- Notes: 1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Po ($\approx^{210}\text{Pb}$)
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$)
 ^{228}Ra up to ^{228}Th ($\approx^{228}\text{Th}$) ^{224}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
4. Dose rate values are reported with 2 significant digits.

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Contact: **Ms C Legoete**
Company: **Placer Dome Western Areas J/V**
Address: **P O Box 776**
Western Areas
1780

Date: **19 December 2012**
Report number: **RA-13644-01**
Pages: **5**
Your reference: **4900076552**

Interim Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Report number: RA-13644-01

Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 01/10/2012

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	04/10/2012	O Sambo	J Smit
WIN-167	Gross alpha/beta-analysis	07/11/2012	S Yawa	E Nhlapo
WIN-145	Uranium by alpha spectrometry	30/10/2012	T Moketse	S Seema
WIN-142	Thorium by alpha spectrometry	05/11/2012	N Sono	S Seema
WIN-145	Radium by alpha spectrometry	06/11/2012	A Mathopo	S Seema
WIN-129	Polonium-210 by alpha spectrometry	23/10/2012	C Zwane	S Seema
WIN-129	Lead-210 by alpha spectrometry	Pending	Pending	S Seema

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Page 3 of 5

Report number: RA-13644-01

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Sida 1		Sida 2			Sida 3			Sida 4			Sida 8					
Field code		RA-13644X001			RA-13644X002			RA-13644X003			RA-13644X004			RA-13644X005		
Lab code	Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
	²³⁵ U	71.0	7.4	2.1	1780	40	3.1	11700	100	2.4	911	30	2.7	273	14	1.8
	²³⁴ U	131	10	2.1	1670	40	3.1	10200	100	2.4	864	30	2.7	275	14	1.8
	²³² Th	128	22	40	38.2	7.6	24	881	135	29	31.8	6.7	26	84.0	14.8	28
	²²⁶ Ra	4.12	1.30	1.1	16.5	2.4	0.91	117	7	1.0	12.3	2.4	1.3	160	8	1.1
	²¹⁰ Pb															
	²¹⁰ Po	8.09	2.26	1.8	0.93	0.66	1.8	6.22	1.81	1.5	2.1	1.2	2.3	4.20	1.59	1.8
	²³⁵ U	3.27	0.34	0.097	82.1	2.1	0.14	539	5	0.11	42.0	1.4	0.12	12.6	0.6	0.084
	²²⁷ Th	2.1	3.9	14	8.54	2.66	5.6	31.3	5.3	7.0	5.0	2.6	7.1	16.5	4.0	8.6
	²³² Ra	2.60	1.70	1.8	0.20	2.3	1.4	30.0	7.5	1.6	-2.4	2.1	2.0	8.61	8.21	1.7
	²³² Th	25.5	5.3	7.5	3.00	1.34	1.6	45.0	5.9	5.5	7.86	2.45	4.8	5.73	2.03	1.9
	²²⁸ Th	7.1	3.4	9.4	7.16	2.39	5.5	20.9	3.9	2.0	11.1	2.7	1.8	3.56	1.59	1.9
	²²⁶ Ra	1.9	1.3	2.5	<MDA		2.1	6.87	2.43	2.3	1.1	1.1	2.9	0.92	0.92	2.5
	Gross alpha	980	155	450	2230	210	460	12400	1000	1100	1440	200	570	1070	320	1000
	Gross beta	1010	140	440	1700	170	460	13100	700	590	1410	150	450	1610	170	470

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-13644-01 Page 4 of 5

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 10			Sida 11			Sida 19			Sida 12			S11 A		
	Lab code	Value	Unc.	MDA	Lab code	Value	Unc.	MDA	Lab code	Value	Unc.	MDA	Lab code	Value	Unc.
	RA-13644X006				RA-13644X007				RA-13644X008				RA-13644X009		
²³⁸ U		13.8	4.4	3.7	6230	60	1.8	4360	60	1.9	3200	50	2.1	643	21
²³⁴ U		43.6	7.8	3.7	5590	60	1.8	4130	60	1.9	2870	50	2.1	610	21
²³⁰ Th		81.1	14.2	26	82.4	14.4	25	92.1	15.7	23	143	24	29	255	41
²²⁶ Ra		2.94	0.98	0.89	307	11	1.0	300	10	0.92	109	7	4.1	52.6	4.0
²¹⁰ Pb															
²¹⁰ Po		2.2	1.3	2.3	3.41	1.40	1.7	1.4	0.98	2.4	1.4	0.79	1.6	1.64	0.82
²³⁵ U		0.637	0.201	0.17	287	3	0.082	201	3	0.088	156	11	2.1	29.6	1.0
²²⁷ Th		1.3	2.6	9.3	16.2	3.8	8.1	10.4	3.3	8.8	3.6	2.3	6.9	8.20	3.05
²²³ Ra		-0.46	0.87	1.4	-7.0	10	1.6	-26	9.4	1.5	-1.7	6.5	6.6	-1.8	4.2
²²⁷ Th		7.24	2.37	4.8	4.50	1.70	1.7	5.28	1.76	1.6	6.71	2.47	5.5	17.5	3.7
²²³ Ra		9.81	2.70	4.8	5.75	1.92	1.7	4.67	1.65	1.6	5.9	2.8	8.0	3.2	2.5
²²³ Th															
²²³ Ra		< MDA			< MDA										
Gross alpha		300	110	370	8730	680	790	4960	420	710	3420	310	640	958	141
Gross beta		230	130	430	4540	320	560	3970	260	500	2760	210	480	200	130

*Results indicated in bold in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation to this laboratory

- Notes:
1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
 2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
 3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
 4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-13644-01

Page 5 of 5

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
Sida 1	RA-13644X001	310	68	50	46	75	56
Sida 2	RA-13644X002	450	160	120	120	210	150
Sida 3	RA-13644X003	3100	1000	800	770	1300	1000
Sida 4	RA-13644X004	300	99	74	75	140	86
Sida 8	RA-13644X005	480	110	84	95	220	97
Sida 10	RA-13644X006	200	37	28	30	57	30
Sida 11	RA-13644X007	1500	560	430	440	860	540
Sida 19	RA-13644X008	1200	420	320	340	690	400
Sida 12	RA-13644X009	770	280	220	220	410	280
S11 A	RA-13644X010	490	110	87	88	170	110

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Pb (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) ²²⁶U and ²²⁶Pa (= ²²⁶U)
²²⁷Ac up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra) ²²⁶Ra up to ²²⁶Th (= ²²⁶Th) ²²⁶Ra up to ²¹²Bi (= ²²⁶Ra)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 5. Dose rate values are reported with 2 significant digits.

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Contact: **Ms C Legoete** Date: **11 February 2013**
Company: **Placer Dome Western Aria Joint Venture** Report number: **RA-13141-02**
Address: **PO Box 776** Pages: **04**
Western Area Your reference: **4500486552**
1780



Final Analysis Report

Radioactivity analysis of water

Compiler: **D Kotze**

Checked: **J Smit**

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Job reference: **RA-13141-02**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 21 June 2012

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	25/06/2012	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	07/08/2012	S Yawa	E Nhlapo
WIN-145	Uranium by alpha spectrometry	21/08/2012	T Moketse	S Seema
WIN-142	Thorium by alpha spectrometry	13/09/2012	A Mamaila	S Seema
WIN-145	Radium by alpha spectrometry	23/08/2012	A Mathopo	S Seema
WIN-129	Polonium-210 by alpha spectrometry	08/08/2012	C Zwane	S Seema
WIN-129	Lead-210 by alpha spectrometry	24/01/2013	C Zwane	S Seema

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Lead-210 is determined by analysing its decay product (daughter nuclide) polonium-210. Two measurements are performed: one directly after sampling (or sample receipt) and the other approximately 6 months later. Lead-210 is estimated from the difference in the results obtained taking into account the amount of polonium-210 formed from the decay of lead-210 but also the amount of polonium decayed. If the difference is not significant, it is indicative that the activities of the nuclides are close to equilibrium. In such cases, lead- and polonium-210 results will be equal to each other.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job reference: RA-13141-02

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	SIDA 5			SIDA 6		
	RA-13141X001			RA-13141X002		
Lab code	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	23.4	4.3	2.2	49.0	6.2	2.1
²³⁴ U	69.2	7.5	2.2	92.6	8.7	2.1
²³⁰ Th	24.4	5.8	2.0	36.0	7.6	2.0
²²⁶ Ra	2.99	1.13	1.2	3.45	1.22	1.2
²¹⁰ Pb	5.15	2.17	1.5	2.93	1.78	2.3
²¹⁰ Po	-0.51	0.40	1.7	-0.22	0.34	1.5
²²⁸ U	1.08	0.20	0.10	2.26	0.29	0.099
²²⁷ Th	0.39	2.9	1.1	18.5	4.4	7.0
²²³ Ra	0.60	1.0	1.6	0.49	1.1	1.6
²³² Th	2.3	1.7	5.6	44.0	5.9	5.6
²²⁸ Th	3.8	2.0	5.5	42.2	5.7	5.6
²²⁴ Ra	< MDA		2.4	2.70	1.56	2.4
Gross alpha	-68	150	500	-77	170	560
Gross beta	-55	160	540	30	170	550

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job reference: RA-13141-02

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: μSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
SIDA 5	RA-13141X001	120	25	19	19	33	21
SIDA 6	RA-13141X002	550	110	80	91	180	69

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Pb (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb)
²³²U and ²³²Th (= ²³²U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²¹²Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **27 February 2013**
Report number: **RA-13645-01**
Pages: **04**
Your reference: **4900076531**

Interim Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

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Job number: **RA-13645-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 01-October-2012

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	02/10/2012	O Sambo	J Smit
WIN-167	Gross alpha/beta-analysis	22/10/2012	S Yawa	S Nhlapo
WIN-145	Uranium by alpha spectrometry	06/11/2012	T Moketse	S Seema
WIN-142	Thorium by alpha spectrometry	05/11/2012	A Mamaila	S Seema
WIN-145	Radium by alpha spectrometry	10/01/2013	A Mathopo	S Seema
WIN-129	Polonium-210 by alpha spectrometry	31/10/2012	C Zwane	S Seema
WIN-129	Lead-210 by alpha spectrometry	Pending	C Zwane	S Seema

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-13645-01

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 5			Sida 6		
Lab code	RA-13645X001			RA-13645X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	18.5	3.9	2.2	95.1	9.3	2.5
²³⁴ U	90.2	8.6	2.2	186	13	2.5
²³⁰ Th	235	38	29	115	19	27
²²⁶ Ra	1.69	0.98	1.5	2.21	0.90	1.00
²¹⁰ Pb						
²¹⁰ Po	6.80	2.28	2.2	3.61	1.81	2.7
²³⁵ U	0.853	0.178	0.10	4.38	0.43	0.11
²²⁷ Th	6.31	2.63	2.0	7.2	3.7	9.1
²²³ Ra	1.5	1.2	2.0	0.26	0.74	1.3
²³² Th	8.24	2.48	2.0	6.93	2.19	1.9
²²⁸ Th	8.87	2.77	5.4	17.8	3.7	6.3
²²⁴ Ra	< MDA		3.3	< MDA		2.1
Gross alpha	83	89	300	-38	100	350
Gross beta	41	78	260	99	79	260

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: RA-13645-01

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 5	RA-13645X001	380	74	56	53	90	65
Sida 6	RA-13645X002	310	69	51	53	100	50

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Po (= ²¹⁰Po)
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **01 March 2013**
Report number: **RA-13375-02**
Pages: **5**
Your reference: **4900074776**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Report number: **RA-13375-02**

Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 31 July 2012

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	03/08/2012	O Sambo	J Smit
WIN-167	Gross alpha/beta-analysis	11/09/2012	S Yawa	E Nhlapo
WIN-145	Uranium by alpha spectrometry	20/09/2012	T Moketse	S Seema
WIN-142	Thorium by alpha spectrometry	30/10/2012	A Mamaila	S Seema
WIN-145	Radium by alpha spectrometry	15/11/2012	A Mathopo	S Seema
WIN-129	Polonium-210 by alpha spectrometry	14/09/2012	C Zwane	S Seema
WIN-129	Lead-210 by alpha spectrometry	22/02/2013	C Zwane	S Seema

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reported results relate only to the sample portions tested.
- 3.3 Results for lead-210 for all samples and thorium results for samples X006 and X007 are still outstanding
- 3.4 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.
- 3.5 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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- 4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.
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 - Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
 - The individual test reports are available upon request
- 4.3 The compiler is the Technical Expert for all the methods.
- 4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

APPENDIX 1: ANALYTICAL RESULTS
Activity concentrations of nuclides in filtered samples
Unit: mBq/L

Field code	Sida 1			Sida 2			Sida 3			Sida 4			Sida 8		
	Lab code	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	Value	Unc.	MDA
²³⁸ U		78.7	12.6	5.5	1450	30	1.6	1510	30	2.2	1530	30	1.8	87.0	8.0
²³⁴ U		101	14	5.5	1420	30	1.6	1330	30	2.2	1450	30	1.8	94.8	8.5
²³² Th		52	10	60	61.3	11.1	42	140	23	51	45	9.1	52	83.5	14.7
²²⁸ Ra		3.69	1.02	0.77	6.47	1.46	2.6	103	6	0.94	3.46	1.04	0.85	165	7
²¹⁰ Pb		37.4	6.6	1.2	4.62	2.25	1.6	43.7	9.2	2.3	10.3	3.4	1.5	11.4	3.9
²¹⁰ Po		-2.3	2.1	2.1	4.62	2.25	1.6	5.56	3.94	2.0	10.3	3.4	1.5	11.4	3.9
²³⁵ U		4.0	2.9	5.5	71.6	6.5	1.6	69.6	1.6	0.10	70.5	1.5	0.083	4.00	0.37
²²⁷ Th		7.6	4.3	12	8.10	2.88	4.7	17.7	4.2	2.1	11.2	4.2	1.1	9.3	3.8
²²³ Ra		0.064	1.2	1.4	-2.0	1.8	4.5	5.98	7.07	1.7	-0.35	1.2	1.5	-16	8.0
²²³ Th		8.12	2.71	2.4	2.55	1.28	1.7	9.91	2.95	5.6	3.9	2.1	5.7	3.59	1.61
²²⁸ Th		13.3	3.7	6.6	10.7	2.7	4.6	15.8	3.4	2.0	2.3	2.3	8.2	17.9	3.6
²²⁸ Ra		0.73	0.73	2.0	< MDA		2.4	2.67	1.54	2.4	< MDA		2.2	< MDA	2.2
Gross alpha		100	140	470	1960	200	480	1840	270	770	1700	210	570	630	310
Gross beta		99	80	260	1130	120	290	2060	130	270	1120	110	270	1490	120

*Results indicated in **bold** in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation to this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Activity concentrations of nuclides in filtered samples
Unit: mBq/L

Field code	Sida 10			Sida 11			Sida 12			Sida 19			Sida 21		
	Lab code	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	Value	Unc.	MDA
²³⁸ U		42.4	6.5	2.7	8730	100	3.1	5100	60	1.9	7980	80	2.2	9.49	2.63
²³⁴ U		47.6	7.1	2.7	7500	90	3.1	4490	60	1.9	7270	80	2.2	25.1	4.3
²³² Th		63.5	11.7	46	97.3	17.4	60	84.4	14.7	44	92.1	15.6	38	88.4	15.1
²²⁸ Ra		0.61	0.43	0.83	226	9	1.0	84.9	4.8	0.72	223	9	0.89	10.5	1.9
²¹⁰ Pb		7.92	3.11	1.8	12.9	4.5	2.2	11.3	4.1	2.1	20.4	5.2	1.4	45.7	7.4
²¹⁰ Po		7.92	3.11	1.8	12.9	4.5	2.2	11.3	4.1	2.1	1.8	2.3	1.9	3.70	3.16
²³⁵ U		1.95	0.30	0.13	402	5	0.14	235	3	0.086	368	4	0.10	0.437	0.121
²²⁷ Th		15.6	4.7	8.4	16.5	6.2	14	13.2	4.0	7.1	25.3	4.5	4.2	22.4	4.3
²²³ Ra		0.41	0.64	1.5	-3.3	11	1.9	-7.6	5.3	1.3	-15	9.6	1.6	-2.0	2.0
²²⁷ Th		3.5	2.3	7.5	5.40	2.21	2.4	2.6	1.9	6.1	5.19	1.73	1.6	6.55	1.97
²²⁸ Th		9.5	3.5	9.6	14.0	4.5	12	8.33	2.48	4.7	11.8	2.6	1.5	4.1	1.7
²²⁸ Ra		< MDA		2.1	0.99	0.99	2.7	1.4	0.97	1.9	< MDA		2.3	< MDA	2.4
Gross alpha		66	130	430	6300	500	760	4320	380	710	5900	480	740	84	110
Gross beta		190	81	260	6380	340	380	4330	240	330	7340	360	370	572	87

*Results indicated in **bold** in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation to this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-13375-02

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APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
Sida 1	RA-13375-02X001	260	77	56	59	110	48
Sida 2	RA-13375-02X002	460	160	120	110	200	140
Sida 3	RA-13375-02X003	820	250	190	190	370	210
Sida 4	RA-13375-02X004	460	170	120	120	190	150
Sida 8	RA-13375-02X005	490	130	91	110	260	86
Sida 10	RA-13375-02X006	300	62	46	41	65	48
Sida 11	RA-13375-02X007	1900	750	570	560	1000	700
Sida 12	RA-13375-02X008	1200	450	340	330	580	420
Sida 19	RA-13375-02X009	1800	700	530	530	990	670
Sida 21	RA-13375-02X010	410	95	72	68	110	75

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{226}Ra ($=^{226}\text{U}$) ^{226}Ra up to ^{214}Bi ($=^{226}\text{Ra}$) ^{210}Pb and ^{210}Bi ($=^{210}\text{Pb}$) ^{235}U and ^{231}Pa ($=^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($=^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($=^{223}\text{Ra}$) ^{223}Ra up to ^{223}Th ($=^{223}\text{Th}$) ^{224}Ra up to ^{212}Bi ($=^{224}\text{Ra}$)
 - Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 - Dose rate values are reported with 2 significant digits.

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Contact: **Ms C Legoete**
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Address: **PO Box 776**
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Date: **25 June 2013**
Report number: **RA-13709-01**
Pages: **04**
Your reference: **4900076834**

Final Analysis Report

Radioactivity analysis of process water

Compiled by:

D Koze

Checked by:

J Smit

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job number: RA-13709-01

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 17 October 2012

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	23/10/2012	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	13/12/2012	M S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	19/12/2012	T Mokatse	S Seema
WIN-142	Thorium by alpha spectrometry	14/11/2012	A Rasutha	S Seema
WIN-145	Radium by alpha spectrometry	05/12/2012	A Mokgalane	S Seema
WIN-129	Polonium-210 by alpha spectrometry	06/11/2012	C Zwane	S Seema
WIN-129	Lead-210 by alpha spectrometry	31/05/2012	C Zwane	S Seema

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

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- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-13709-01

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 5			Sida 6		
Lab code	RA-13709X001			RA-13709X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	62.8	6.6	1.9	139	10	2.1
²³⁴ U	86.4	7.9	1.9	183	12	2.1
²³⁰ Th	38.0	7.8	37	121	23	88
²²⁶ Ra	1.85	0.75	0.83	1.26	0.56	0.68
²¹⁰ Pb	0.77	0.96	4.8	0.77	3.6	5.0
²¹⁰ Po	0.77	0.96	4.8	2.78	1.24	1.2
²³⁵ U	2.89	0.30	0.087	6.41	0.48	0.096
²²⁷ Th	7.09	3.23	5.5	13	7.0	17
²²³ Ra	-0.39	0.36	1.1	-0.27	0.27	0.88
²³² Th	10.8	2.8	2.0	6.84	3.42	4.6
²²⁸ Th	15.7	3.3	1.9	21.8	6.6	13
²²⁴ Ra	0.66	0.66	1.8	0.54	0.54	1.5
Gross alpha	55	230	750	150	350	1200
Gross beta	7.4	83	270	289	92	280

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: **RA-13709-01**

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 5	RA-13709X001	240	52	38	41	80	35
Sida 6	RA-13709X002	370	79	59	62	120	59

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Po ($\approx^{210}\text{Po}$)
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$)
 ^{228}Ra up to ^{212}Th ($\approx^{228}\text{Th}$) ^{224}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 - Dose rate values are reported with 2 significant digits.

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Date: **28 August 2013**
Report number: **RA-14064-02**
Pages: **04**
Your reference: **4900083495**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job number: RA-14064-02

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 04 March 2013

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	12/03/2013	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	15/03/2013	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	22/05/2013	T Mokatse	S Seema
WIN-142	Thorium by alpha spectrometry	02/04/2013	N Sova	S Seema
WIN-124	Radium by alpha spectrometry	02/05/2013	A Mokgalane	S Seema
WIN-129	Polonium-210 by alpha spectrometry	27/03/2013	C Zwane	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	20/08/2013	C Zwane	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-14064-02

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	SIDA 5			SIDA 6		
Lab code	RA-14064X001			RA-14064X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	35.7	5.6	2.4	54.8	9.0	4.0
²³⁴ U	61.8	7.5	2.4	116	13	4.0
²³⁰ Th	33.8	6.8	19	26.8	6.0	1.8
²²⁶ Ra	1.45	0.65	0.78	1.8	1.5	5.0
²¹⁰ Pb	9.54	3.33	1.7	2.96	1.92	1.8
²¹⁰ Po	15.3	3.0	1.5	2.96	1.92	1.8
²³⁵ U	1.64	0.26	0.11	2.52	0.41	0.18
²²⁷ Th	-0.21	2.2	8.8	4.0	2.1	5.8
²²³ Ra	-2.0	1.2	5.5	1.1	1.2	4.2
²³² Th	1.1	1.1	4.1	4.30	1.52	1.5
²²⁸ Th	1.1	1.1	4.1	6.95	2.07	3.9
²²⁴ Ra	24.2	3.8	1.6	20.9	3.9	2.0
Gross alpha	19	69	230	-43	67	230
Gross beta	-150	440	1500	-280	440	1500

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: **RA-14064-02**

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
SIDA 5	RA-14064X001	200	65	43	36	52	36
SIDA 6	RA-14064X002	150	39	27	27	50	25

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Po ($\approx^{210}\text{Po}$)
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$)
 ^{226}Ra up to ^{226}Th ($\approx^{226}\text{Th}$) ^{224}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 - Dose rate values are reported with 2 significant digits.

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Date: **28August 2013**
Report number: **RA-14049-02**
Pages: **05**
Your reference: **4900083496**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

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Report number: **RA-14049-02**

Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 05 March 2013

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	13/03/2013	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	03/05/2013	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	25/04/2013	T Mokaise	S Seema
WIN-142	Thorium by alpha spectrometry	21/05/2013	NSovo	S Seema
WIN-124	Radium by alpha spectrometry	02/05/2013	A Mokgalane	S Seema
WIN-129	Polonium-210 by alpha spectrometry	10/04/2013	C Zwane	S Seema
WIN-129	Lead-210 by alpha spectrometry	20/08/2013	C Zwane	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

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- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

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Report number: **RA-14049-02**

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Lab code	S11A		SIDA 3		SIDA 4		SIDA 2		SIDA 8	
		Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.
		1170	30	2.2	3850	50	2.1	750	36	4.6	30
		1070	30	2.2	3290	50	2.1	700	35	4.6	29
		111	22	88	281	44	29	53.3	10.6	42	18
		79.4	5.5	1.0	107	6	2.6	3.26	1.15	2.8	1.71
		3.0	2.4	4.4	46.4	7.7	0.031	21.0	5.7	2.4	2.59
		3.0	2.4	4.4	0.72	0.95	3.5	2.32	1.12	1.4	2.59
		53.9	1.4	0.10	177	3	0.097	34.5	1.6	0.21	43.3
		8.9	7.3	20	63.6	7.2	5.7	19.0	6.4	6.6	9.13
		4.8	4.5	5.2	12.1	4.7	5.3	0.47	1.3	4.6	2.1
		11.3	4.6	5.1	10.4	2.8	5.7	2.7	2.4	8.3	9.80
		9.2	4.9	14	15.4	3.2	5.5	16.4	4.1	8.0	8.82
		33.7	5.3	5.8	24.8	4.0	5.5	16.1	3.4	5.8	14.9
		1500	140	280	3530	310	540	616	132	300	1220
		1050	180	560	4740	290	600	770	180	570	854
											177
											560
											210
											590

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Unit: mBq/L

Unit: mBq/L

Notes:

1. If a measured value (**Value** column) was reported, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) value will be indicated.
2. The reported uncertainty (**Unc** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated at a confidence level of 95%.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (<MDA) will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor $k = 1$). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (<MDA) is in the Value column.
3. The minimum detectable activity concentration (**MDA** column) is calculated at a confidence level of 95%.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

Page 5 of 5

Unit: $\mu\text{Sv/a}$

Notes: 1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide: LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.

2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.

3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($=^{238}\text{U}$) ^{226}Ra up to ^{214}Pb ($=^{226}\text{Ra}$) ^{215}Po and ^{215}Bi ($=^{215}\text{Po}$) ^{235}U and ^{231}Pa ($=^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($=^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($=^{223}\text{Ra}$) ^{223}Ra up to ^{223}Th ($=^{223}\text{Th}$) ^{224}Ra up to ^{212}Bi ($=^{224}\text{Ra}$)

4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.

5. Dose rate values are reported with 2 significant digits.

Notes: 1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide: LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.

2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.

3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($=^{238}\text{U}$) ^{226}Ra up to ^{214}Pb ($=^{226}\text{Ra}$) ^{215}Po and ^{215}Bi ($=^{215}\text{Po}$) ^{235}U and ^{231}Pa ($=^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($=^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($=^{223}\text{Ra}$) ^{223}Ra up to ^{223}Th ($=^{223}\text{Th}$) ^{224}Ra up to ^{212}Bi ($=^{224}\text{Ra}$)

4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.

5. Dose rate values are reported with 2 significant digits.

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Date: **24 February 2014**
Report number: **RA-14558-02**
Pages: **04**
Your reference: **4900087829**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job number: **RA-14558-02**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 05 July 2013

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	10/07/2013	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	19/08/2013	M S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	22/08/2013	T Mokatse	A Rasutha
WIN-142	Thorium by alpha spectrometry	13/08/2013	N Sovo	A Rasutha
WIN-124	Radium by alpha spectrometry	20/08/2013	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	06/08/2013	C Zwane	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	18/02/2014	T Kota	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Lead-210 is determined by analysing its decay product (daughter nuclide) polonium-210. Two measurements are performed: one directly after sampling (or sample receipt) and the other approximately 6 months later. Lead-210 is estimated from the difference in the results obtained taking into account the amount of polonium-210 formed from the decay of lead-210 but also the amount of polonium decayed. If the difference is not significant, it is indicative that the activities of the nuclides are close to equilibrium. In such cases, lead- and polonium-210 results will be equal to each other.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

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- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-14558-02

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 5			Sida 6		
Lab code	RA-14558X001			RA-14558X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	14.4	4.8	4.3	56.1	9.9	4.7
²³⁴ U	90.6	12.1	4.3	86.8	12.5	4.7
²³⁰ Th	71.6	15.9	72	28.7	5.7	18
²²⁶ Ra	3.06	1.02	0.92	0.157	0.070	0.085
²¹⁰ Pb	8.00	3.83	4.7	2.4	2.4	5.1
²¹⁰ Po	8.00	3.83	4.7	2.4	2.4	5.1
²³⁵ U	0.663	0.221	0.20	2.58	0.46	0.22
²²⁷ Th	13	6.3	18	5.95	2.04	4.5
²²³ Ra	0.034	0.73	1.2	0.038	0.12	0.19
²³² Th	1.9	3.3	14	0.48	0.84	3.6
²²⁸ Th	-1.9	5.0	23	7.20	2.30	5.8
²²⁴ Ra	0.72	0.72	1.9	< MDA		0.33
Gross alpha	257	51	130	180	65	200
Gross beta	532	122	380	420	121	390

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: RA-14558-02

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
Sida 5	RA-14558X001	290	67	48	47	83	46
Sida 6	RA-14558X002	160	35	26	26	46	25

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Po (= ²¹⁰Pb)
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²³¹Th) ²²⁷Ra and ²¹¹Pb (= ²²⁷Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **24 February 2014**
Report number: **RA-14557-02**
Pages: **5**
Your reference: **4900087828**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

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Report number: **RA-14557-02**

Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 05 July 2013

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	11/07/2013	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	20/08/2013	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	13/09/2013	T Mokatse	O Moya
WIN-142	Thorium by alpha spectrometry	03/09/2013	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	13/09/2013	A Rasutha	O Moya
WIN-129	Polonium-210 by alpha spectrometry	06/08/2013	C Zwane	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	18/02/2014	L Khumalo	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Lead-210 is determined by analysing its decay product (daughter nuclide) polonium-210. Two measurements are performed: one directly after sampling (or sample receipt) and the other approximately 6 months later. Lead-210 is estimated from the difference in the results obtained taking into account the amount of polonium-210 formed from the decay of lead-210 but also the amount of polonium decayed. If the difference is not significant, it is indicative that the activities of the nuclides are close to equilibrium. In such cases, lead- and polonium-210 results will be equal to each other.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

APPENDIX 1: ANALYTICAL RESULTS
Activity concentrations of nuclides in filtered samples
Unit: mBq/L

Field code	Sida 1			Sida 2			Sida 3			Sida 4			Sida 8		
	RA-14557X001			RA-14557X002			RA-14557X003			RA-14557X004			RA-14557X005		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	135	14	4.1	1610	50	4.5	1090	30	2.0	1690	40	3.1	165	12	2.4
²³⁴ U	191	17	4.1	1400	50	4.5	969	28	2.0	1500	40	3.1	179	13	2.4
²³⁵ Th	262	49	110	71.0	12.8	28	17	3.9	20	16	3.9	20	41	11	59
²²⁶ Ra	5.80	1.33	0.83	12.2	2.0	0.85	192	8	0.89	5.46	1.36	0.92	139	7	0.95
²¹⁰ Pb	7.5	4.4	13	16	7.3	18	8.9	5.0	13	1.6	5.6	29	7.5	6.0	21
²¹⁰ Po	1.03	0.70	0.32	6.92	1.62	0.12	0.779	0.692	0.44	0.13	0.33	0.59	1.35	0.75	0.21
²³⁴ U	6.21	0.66	0.19	74.3	2.4	0.21	50.3	1.3	0.093	77.6	2.0	0.14	7.60	0.55	0.11
²³² Th	15	9.0	27	17.1	4.3	7.7	10.3	2.9	7.3	3.6	2.3	6.8	29.2	8.5	21
²²⁶ Ra	0.54	1.1	1.1	0.36	1.5	1.1	4.55	6.02	1.2	0.50	1.1	1.2	-0.26	6.9	1.5
²³² Th	43.2	11.2	7.8	12.9	3.0	1.9	2.06	1.03	1.4	4.13	1.46	1.4	1.5	1.5	4.1
²³⁴ Th	17	8.1	21	7.73	2.33	1.9	3.07	1.25	1.4	11.3	2.5	3.8	6.04	3.02	4.1
²²⁶ Ra	< MDA	1.7	< MDA	< MDA	1.8	< MDA	< MDA	< MDA	1.9	< MDA	< MDA	1.9	0.79	0.79	2.1
Gross alpha	67	95	320	1710	170	370	1570	230	630	1760	180	410	68	140	490
Gross beta	170	110	350	1550	140	370	1810	150	380	1820	150	370	829	123	370

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

- Notes:
- If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
 - The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
 - The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
 - A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Activity concentrations of nuclides in filtered samples
Unit: mBq/L

Field code	Sida 9			Sida 10			Sida 11			Sida 12			Sida 7		
	RA-14557X006			RA-14557X007			RA-14557X008			RA-14557X009			RA-14557X010		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	7290	80	2.1	54.2	7.7	2.9	11400	100	2.8	890	36	4.0	568	18	1.6
²³⁴ U	6620	70	2.1	89.7	10.0	2.9	9970	100	2.8	850	37	4.0	545	19	1.6
²³⁵ Th	20	4.6	22	73.2	14.7	50	58.4	11.4	34	50.0	9.3	24	39.1	7.8	22
²²⁶ Ra	370	11	0.96	5.49	1.47	1.1	352	11	0.93	44.3	3.7	0.83	16.1	2.2	0.84
²¹⁰ Pb	18.1	5.8	12	17.0	5.4	11	16	9.4	30	10	5.5	17	13	6.1	17
²¹⁰ Po	0.317	0.652	0.27	1.20	0.77	0.17	-0.86	0.48	0.42	0.0821	0.4624	0.076	0.792	0.698	0.030
²³⁴ U	336	3	0.098	2.50	0.35	0.14	525	5	0.13	41.0	1.7	0.19	26.1	0.9	0.075
²³² Th	10.3	3.1	7.9	29.2	6.5	9.5	14.0	4.7	13	22.8	4.5	4.5	10.7	3.1	4.3
²²⁶ Ra	-1.4	11	1.5	-2.3	1.0	1.7	-16	11	1.5	-3.0	3.5	1.3	4.83	2.56	1.3
²³⁴ Th	8.41	2.17	1.5	2.6	1.8	3.5	5.3	2.5	6.5	7.33	2.12	1.7	21.9	3.7	1.7
²²⁶ Th	6.12	2.30	6.0	11.6	4.3	9.5	7.1	3.1	8.2	8.90	2.45	4.4	4.0	1.9	5.3
²²⁶ Ra	1.6	1.1	2.2	< MDA	< MDA	2.4	3.10	1.55	2.1	0.69	0.69	1.9	< MDA	< MDA	1.9
Gross alpha	8880	680	710	-79	81	290	8700	660	660	806	123	340	813	109	290
Gross beta	6930	400	470	290	110	350	7580	420	480	612	116	360	541	114	350

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

- Notes:
- If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
 - The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
 - The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
 - A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-14557-02

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APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 1	RA-14557X001	500	87	70	69	120	88
Sida 2	RA-14557X002	580	180	140	130	220	160
Sida 3	RA-14557X003	490	150	120	130	300	140
Sida 4	RA-14557X004	400	160	120	120	210	140
Sida 8	RA-14557X005	520	110	83	93	210	94
Sida 9	RA-14557X006	1600	650	490	510	1000	610
Sida 10	RA-14557X007	460	86	67	66	110	73
Sida 11	RA-14557X008	2200	930	700	710	1300	890
Sida 12	RA-14557X009	510	130	100	100	190	120
Sida 7	RA-14557X010	290	80	61	60	110	75

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($=^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($=^{226}\text{Ra}$) ^{210}Pb and ^{210}Bi ($=^{210}\text{Pb}$) ^{235}U and ^{231}Pa ($=^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($=^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($=^{223}\text{Ra}$) ^{225}Ra up to ^{223}Th ($=^{225}\text{Ra}$) ^{224}Ra up to ^{212}Bi ($=^{224}\text{Ra}$)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 5. Dose rate values are reported with 2 significant digits.

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Date: **02 April 2014**
Report number: **RA-15229-01**
Pages: **04**
Your reference: **4900092347**

Interim Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **J Smit**

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Job number: RA-15229-01

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 22 November 2013

Job Card received: 19 December 2013

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	06/01/2014	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	14/02/2014	S May	S Nhlapo
WIN-145	Uranium by alpha spectrometry	28/03/2014	T Mokatse	O Moya
WIN-142	Thorium by alpha spectrometry	03/03/2014	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	20/03/2014	A Mathopo	O Moya
WIN-129	Polonium-210 by alpha spectrometry	06/03/2014	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry		Pending	

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-15229-01

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	90 L			105 L		
	RA-15229X001			RA-15229X002		
Lab code	Value	Unc.	MDA	Value	Unc.	MDA
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	10100	100	5.4	9600	150	6.4
²³⁴ U	8280	130	5.4	7870	140	6.4
²³² Th	92.6	16.4	30	51.9	9.7	25
²²⁶ Ra	263	13	1.7	80.3	4.8	0.78
²¹⁰ Pb						
²¹⁰ Po	7.43	2.16	1.8	34.7	7.2	3.8
²³⁵ U	463	7	0.25	442	7	0.29
²²⁷ Th	15.9	5.4	12	39.7	5.9	9.8
²²³ Ra	-33	11	2.6	13.4	4.2	4.3
²³¹ Th	9.73	2.81	2.2	3.90	1.59	1.8
²²⁹ Th	18.3	3.8	2.2	12.1	2.8	1.7
²²⁴ Ra	< MDA		3.7	3.6	2.3	7.2
Gross alpha	9640	720	670	7060	540	610
Gross beta	8270	430	480	5930	320	450

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: RA-15229-01

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
90 L	RA-15229X001	-2100	830	630	630	1200	780
105 L	RA-15229X002	2200	860	640	610	1000	770

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Po ($\approx^{210}\text{Po}$)
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$)
 ^{228}Ra up to ^{228}Th ($\approx^{228}\text{Th}$) ^{228}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 - Dose rate values are reported with 2 significant digits.

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Date: **30 May 2014**
Report number: **RA-15476-01**
Pages: **5**
Your reference: **4900094185**

Interim Analysis Report

Radioactivity analysis of water

Compiled by: **I Louw** *[Signature]*

Checked by: **J Smit** *[Signature]*

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Job number: **RA-15476-01** Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 21 February 2014

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	07/03/2014	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	19/03/2014	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	09/05/2014	T Mokatse	D Kotze
WIN-142	Thorium by alpha spectrometry	28/03/2014	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	09/05/2014	T Kota	D Kotze
WIN-129	Polonium-210 by alpha spectrometry	10/04/2014	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry		Pending	

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.

3.4 Lead-210 is determined by analysing its decay product (daughter nuclide) polonium-210. Two measurements are performed: one directly after sampling (or sample receipt) and the other approximately 6 months later. Lead-210 is estimated from the difference in the results obtained taking into account the amount of polonium-210 formed from the decay of lead-210 but also the amount of polonium decayed. If the difference is not significant, it is indicative that the activities of the nuclides are close to equilibrium. In such cases, lead- and polonium-210 results will be equal to each other.

3.5 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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- The individual test reports are available upon request

Job number: **RA-15476-01** Page 3 of 5

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4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-15476-01

Page 4 of 5

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	SIDA-1			SIDA-2		
	RA-15476X001			RA-15476X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	195	15	3.0	1120	30	2.9
²³⁴ U	244	17	3.0	1010	30	2.9
²³⁰ Th	94.9	17.1	42	87.4	15.5	36
²²⁶ Ra	1.00	1.3	4.7	4.80	1.36	3.2
²¹⁰ Pb						
²¹⁰ Po	2.87	1.29	1.8	2.38	1.20	1.9
²³⁰ U	8.98	0.67	0.14	51.6	1.6	0.13
²²⁷ Th	11.6	3.5	2.5	5.3	3.0	7.4
²²⁷ Ra	-1.3	0.93	5.1	0.54	1.1	3.0
²³² Th	24.3	5.1	8.6	21.0	4.0	2.1
²²⁸ Th	6.2	3.0	8.5	8.42	2.79	5.8
²²⁶ Ra	0.70	0.70	1.9	2.23	1.12	1.5
Gross alpha	120	87	290	1020	120	300
Gross beta	-31	110	380	390	120	380

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: RA-15476-01

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APPENDIX 2: Dose rate calculations

Unit: μSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
SIDA-1	RA-15476X001	300	60	46	44	72	57
SIDA-2	RA-15476X002	370	120	89	88	150	110

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Po (= ²¹⁰Pb)
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²³¹Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **14 July 2014**
Report number: **RA-15228-01**
Pages: **6**
Your reference: **4900092348**

Analysis Report

Radioactivity analysis of water

Compiled by: **I Louw**

Checked by: **J Smit**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale" which is available on request.

Report number: **RA-15228-01**

Page 2 of 6

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 22 November 2013

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	08/01/2014	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	17/02/2014	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	08/05/2014	T Mokatse	D Kolze
WIN-142	Thorium by alpha spectrometry	10/06/2014	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	13/05/2014	T Kota	I Louw
WIN-129	Polonium-210 by alpha spectrometry	23/04/2014	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	12/06/2014	T Kota	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Lead-210 is determined by analysing its decay product (daughter nuclide) polonium-210. Two measurements are performed: one directly after sampling (or sample receipt) and the other approximately 6 months later. Lead-210 is estimated from the difference in the results obtained taking into account the amount of polonium-210 formed from the decay of lead-210 but also the amount of polonium decayed. If the difference is not significant, it is indicative that the activities of the nuclides are close to equilibrium. In such cases, lead- and polonium-210 results will be equal to each other.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for

Report number: RA-15228-01

Page 3 of 6

- those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request.
 - The compiler is the Technical Expert for all the methods.
 - The compiled report is checked by a person other than the compiler for accuracy of data transcription.
 - The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: RA-15228-01

Page 4 of 6

APPENDIX 1: ANALYTICAL RESULTS
Activity concentrations of nuclides in filtered samples
Unit: mBq/L

Field code	Side 1			Side 2			Side 3			Side 5			Side 8		
Lab code	RA-15228X001			RA-15228X002			RA-15228X003			RA-15228X004			RA-15228X005		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	102	13	4.6	992	32	2.7	1840	50	3.7	25.2	5.8	3.6	5760	90	4.1
²³⁴ U	172	17	4.6	919	31	2.7	1690	50	3.7	83.8	10.6	3.6	4950	90	4.1
²³² Th	47.8	9.7	3.1	69.5	12.7	2.6	57.5	12.0	4.2	74.1	13.4	2.6	398	56	3.8
²²⁶ Ra	5.89	1.28	2.8	7.44	1.47	2.4	257	11	6.4	1.3	0.79	2.4	9.12	1.92	4.0
²¹⁰ Pb	5.65	3.57	5.3	4.4	2.8	4.4	51.1	10.5	8.1	4.78	2.57	2.0	5.87	3.12	2.2
²¹⁰ Po	5.65	3.57	5.3	4.4	2.8	4.4	-4.7	7.3	21	4.78	2.57	2.0	5.87	3.12	2.2
²³⁵ U	4.70	0.61	0.21	45.7	1.5	0.13	64.8	2.3	0.17	1.15	0.27	0.17	265	4	0.19
²²⁷ Th	24.6	5.5	6.5	10.1	3.9	2.0	40.6	9.1	21	18.8	5.5	1.3	60.5	9.6	7.9
²²⁶ Ra	-0.52	1.0	3.5	-1.0	1.1	3.2	11.8	8.5	5.3	-2.6	1.1	5.6	-1.3	1.4	4.6
²²⁷ Th	15.8	3.7	2.4	22.2	4.2	5.4	4.7	2.9	8.7	33.3	5.0	2.0	38.9	6.6	2.9
²²⁷ Th	13.7	3.8	8.0	6.7	3.2	8.7	12.8	4.5	11	14.5	3.2	2.0	23.0	5.1	7.7
²²⁶ Ra	1.3	0.99	3.2	1.1	0.76	1.5	4.74	2.12	2.6	1.64	0.95	1.5	3.82	1.56	1.7
Gross alpha	450	270	880	1570	140	270	3000	330	720	100	71	240	6500	570	780
Gross beta	1280	150	410	1220	130	370	3550	220	400	130	110	360	7920	410	430

*Results indicated in bold in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation for this laboratory

Notes:

- If a measured value (Value column) was reported, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
- The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
- The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
- A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

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Report number: RA-15228-01

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code Lab code	Sida 10			Sida 11			Sida 12			S 30			50L		
	RA-15228X005			RA-15228X007			RA-15228X008			RA-15228X009			154-15228X010		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	105	15	5.8	175	21	6.9	227	15	2.6	6610	80	2.4	878	27	2.3
²³⁴ U	167	19	5.8	251	26	6.9	221	15	2.6	5770	70	2.4	833	27	2.3
²³² Th	197	33	37	26.0	5.6	22	126	24	55	100	18	35	80.2	14.0	22
²²⁶ Ra	167	7	2.9	47.9	3.6	2.9	8.66	2.03	4.1	275	9	3.7	60.3	4.6	4.6
²¹⁰ Pb	16.9	6.3	6.4	6.02	3.15	2.3	1.8	1.6	2.4	9.43	4.05	2.3	2.49	1.78	2.0
²¹⁰ Po	16.9	6.3	6.4	6.02	3.15	2.3	1.8	1.6	2.4	9.43	4.05	2.3	2.49	1.78	2.0
²³⁴ U	4.84	0.66	0.27	3.03	0.97	0.32	10.5	0.7	0.12	304	4	0.11	40.4	1.3	0.11
²³² Th	35.2	7.6	15	5.0	2.2	5.7	26.3	9.7	11	43.2	8.2	11	27.1	5.5	8.8
²²⁸ Ra	-7.3	4.9	4.6	-0.82	2.7	2.9	-2.6	1.8	7.2	-13	6.1	5.2	-5.2	3.2	4.6
²³² Th	25.9	5.2	2.8	3.1	1.6	4.5	23.2	6.0	4.2	26.9	5.4	7.3	13.8	2.9	1.7
²³⁴ Th	16.3	4.3	7.5	4.9	2.1	5.7	27.0	7.0	14	16.4	4.8	12	14.0	3.0	4.5
²²⁶ Ra	7.92	2.26	4.2	0.56	0.97	4.1	0.79	1.4	5.8	0.54	0.94	4.0	2.42	1.21	1.9
Gross alpha	61	71	240	74	85	290	322	78	230	9920	770	680	1330	120	260
Gross beta	350	110	360	300	110	370	210	110	360	6400	330	480	663	120	370

*Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-15228-01

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APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 1	RA-15228X001	440	88	66	64	110	69
Sida 2	RA-15228X002	370	110	83	80	140	100
Sida 3	RA-15228X003	1300	370	270	280	560	300
Sida 5	RA-15228X004	410	77	58	58	100	61
Sida 8	RA-15228X005	1900	570	440	420	700	560
Sida 10	RA-15228X006	920	200	150	150	320	160
Sida 11	RA-15228X007	190	59	42	44	92	44
Sida 12	RA-15228X008	630	120	89	93	170	96
S 30	RA-15228X009	1900	650	490	500	950	610
50L	RA-15228X010	640	150	120	120	240	140

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) ²³⁵U and ²³⁵Pa (= ²³⁵U)
²³²Th up to ²²⁸Ac (= ²³²Th) ²²⁸Ra and ²¹²Pb (= ²²⁸Ra) ²²⁶Ra up to ²²⁸Th (= ²²⁶Ra) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 5. Dose rate values are reported with 2 significant digits.

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Date: **07 November 2014**
Report number: **RA-15475-01**
Pages: **4**
Your reference: **4900094182**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **I Louw**

Checked by: **J Smit**

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Report number: **RA-15475**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 6

Date samples received: 21 February 2014

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	13/03/2014	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	11/04/2014	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	15/07/2014	T Mokatse	A Rasutha
WIN-142	Thorium by alpha spectrometry	30/05/2014	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	10/07/2014	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	24/04/2017	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	19/08/2014	T Kotze	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results relate only to the sample portion tested.

3.3 Lead-210 is determined by analysing its decay product (daughter nuclide) polonium-210. Two measurements are performed: one directly after sampling (or sample receipt) and the other approximately 6 months later. Lead-210 is estimated from the difference in the results obtained taking into account the amount of polonium-210 formed from the decay of lead-210 but also the amount of polonium decayed. If the difference is not significant, it is indicative that the activities of the nuclides are close to equilibrium. In such cases, lead- and polonium-210 results will be equal to each other.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request.

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: RA-15475
Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code Lab code	SIDA-3 RA-15475X001			SIDA-8 RA-15475X002			SIDA-10 RA-15475X003			SIDA-11 RA-15475X004			SIDA-12 RA-15475X005			SIDA-13 RA-15475X006		
	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	3660	60	2.5	3400	50	1.9	51.6	7.3	2.8	3810	50	1.8	1100	40	3.5	3860	60	2.6
²³⁵ U	3480	60	2.5	3110	50	1.9	82.2	9.3	2.8	3700	50	1.8	986	36	3.5	3380	60	2.6
²³² Th	42.5	8.3	24	179	29	20	32.4	7.3	32	12	8.6	100	29.8	6.6	27	20	6.9	65
²²⁶ Ra	217	9	0.93	151	8	1.2	2.88	1.02	0.98	321	11	1.1	15.0	2.5	1.1	423	13	1.1
²¹⁰ Pb	16.4	5.8	2.7	35.0	8.3	2.5	6.42	3.15	2.1	5.11	3.32	2.9	4.53	2.46	1.8	30.1	8.2	0.83
²¹⁰ Po	16.4	5.8	2.7	0.94	2.1	1.9	6.42	3.15	2.1	5.11	3.32	2.9	4.53	2.46	1.8	7.28	3.85	3.1
²³⁴ U	182	3	0.12	157	2	0.089	2.37	0.34	0.13	161	10	1.8	50.6	1.7	0.16	178	3	0.12
²²⁷ Th	35.4	5.1	4.9	45.8	6.0	11	13.0	5.0	13	39	18	54	20.1	4.8	11	19	9.9	29
²²⁷ Ra	14	8.0	1.5	23.5	8.7	1.9	-0.34	0.92	1.5	-38	10	1.7	0.47	2.4	1.7	-120	19	2.5
²²⁸ Th	2.01	1.16	1.8	17.0	3.4	6.1	3.57	1.78	2.4	15	7.8	22	7.76	2.69	5.7	25.8	7.8	17
²²⁸ Ac	9.22	2.80	6.1	11.7	2.8	5.2	14.1	3.7	6.5	12	7.1	21	3.1	1.9	5.6	18.2	5.7	4.9
²²⁸ Ra	2.30	1.33	2.1	4.94	2.21	2.7	< MDA		2.2	1.8	1.2	2.4	< MDA		2.5	4.65	2.69	4.2
Gross alpha	3700	340	620	3330	350	780	388	98	300	4230	350	570	1490	140	320	4130	350	570
Gross beta	4250	240	400	4870	260	390	883	119	350	3530	220	410	893	126	360	3000	210	410

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

*Results indicated in bold in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation to this laboratory

Report number: RA-15475

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APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
SIDA-3	RA-15475X001	1300	440	330	330	640	400
SIDA-8	RA-15475X002	1400	410	320	320	590	390
SIDA-10	RA-15475X003	300	68	49	49	88	45
SIDA-11	RA-15475X004	1300	430	320	340	710	400
SIDA-12	RA-15475X005	440	130	97	92	160	120
SIDA-13	RA-15475X006	1400	470	350	380	830	410

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Bi ($\approx^{210}\text{Pb}$)
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{227}\text{Th}$) ^{227}Ra and ^{211}Pb ($\approx^{227}\text{Ra}$)
 ^{223}Ra up to ^{223}Th ($\approx^{223}\text{Th}$) ^{224}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 4. Dose rate values are reported with 2 significant digits.

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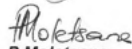
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Date: **30 January 2015**
Report number: **RA-15935-02**
Pages: **4**
Your reference: **4900095630**

Final Analysis Report

Radioactivity analysis of water

Compiled by: 
Checked by: 
P Moletsane

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Job number: **RA-15935-02**

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1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 2014-05-13

Purchase order received: 2014-06-04

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	2014-06-09	O Sambo	J Smit
WIN-167	Gross alpha/beta-analysis	2014-06-18	MS May	S Nhlapo
WIN-145	Uranium by alpha spectrometry	2014-07-31	T Mokatse	A Rasutha
WIN-142	Thorium by alpha spectrometry	2014-08-06	N Sono	A Rasutha
WIN-145	Radium by alpha spectrometry	2014-08-04	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2014-07-10	T Kato	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2015-01-26	T Kato	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Reference date for polonium-210 activity is the date and time of the extraction of this nuclide for alpha spectrometric measurement. The activity is not expressed on date of sampling because the contribution of polonium-210 formed from the decay of lead-210 is not known. In the final report in which lead-210 is determined, this contribution will be taken into account and polonium-210 activity will be reported on date of sampling. Note that the polonium-210 results in the final report may therefore differ from the results in this interim report.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-15935-02

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	Sida 12			Sida 13		
Lab code	RA-15935X001			RA-15935X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	625	23	14	2970	60	15
²³⁴ U	505	20	9.4	2840	60	18
²³⁰ Th	14	3.9	30	33.8	7.1	34
²²⁶ Ra	15.3	2.1	0.75	266	9	0.78
²¹⁰ Pb	35.4	7.2	2.0	7.00	3.26	2.1
²¹⁰ Po	-3.1	1.4	2.3	7.00	3.26	2.1
²³⁵ U	30.0	5.1	7.3	137	3	0.67
²²⁷ Th	5.8	2.6	6.0	14.8	3.7	5.4
²²³ Ra	0.66	0.98	0.84	-130	13	2.0
²³² Th	3.20	1.43	1.7	8.17	2.46	2.0
²²⁸ Th	15.9	3.4	5.9	16.3	3.8	6.8
²²⁴ Ra	< MDA		2.3	1.4	1.4	3.7
Gross alpha	976	106	250	3120	250	390
Gross beta	332	96	300	1360	140	330

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: RA-15935-02

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APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 - 17 a	> 17 a
Sida 12	RA-15935X001	360	120	88	92	170	82
Sida 13	RA-15935X002	1000	350	260	280	590	310

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ²³⁰Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Po (= ²¹⁰Pb)
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Ra) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **03 February 2015**
Report number: **RA-15477-02**
Pages: **4**
Your reference: **4900095506**

Final Analysis Report

Radioactivity analysis of Groundwater

Compiled by: **D Kotze**

Checked by: **P Moletsane**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job number: **RA-15477-02**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 21 February 2014

P/O received: 21 May 2014

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	23/05/2014	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	30/05/2014	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	21/07/2014	T Mokatse	A Rasutha
WIN-142	Thorium by alpha spectrometry	10/07/2014	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	10/07/2014	A Mathopo	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	10/07/2014	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2015/01/20	T Kota	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 Lead-210 is determined by analysing its decay product (daughter nuclide) polonium-210. Two measurements are performed: one directly after sampling (or sample receipt) and the other approximately 6 months later. Lead-210 is estimated from the difference in the results obtained taking into account the amount of polonium-210 formed from the decay of lead-210 but also the amount of polonium decayed. If the difference is not significant, it is indicative that the activities of the nuclides are close to equilibrium. In such cases, lead- and polonium-210 results will be equal to each other.

3.4 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: RA-15477-02

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	SIDA 5			110 AC SW		
	RA-15477X001			RA-15477X002		
Lab code	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	22.7	5.5	8.8	11500	100	3.6
²³⁴ U	46.7	7.7	8.8	10100	100	3.6
²³⁰ Th	44.8	8.7	26	41.3	8.2	27
²²⁶ Ra	1.63	0.81	1.1	454	14	1.2
²¹⁰ Pb	13.7	5.1	2.7	43.9	8.9	2.6
²¹⁰ Po	-7.4	3.9	4.3	-14	7.7	1.7
²³⁵ U	1.04	0.25	0.40	528	6	0.17
²²⁷ Th	1.8	2.6	9.3	35.9	5.8	12
²²³ Ra	00.41	0.43	1.5	8.00	10.78	1.6
²³¹ Th	8.74	2.42	1.8	4.77	1.80	1.8
²²⁸ Th	9.36	2.50	1.8	6.09	2.03	1.8
²²⁴ Ra	<MDA		2.3	2.82	1.63	2.5
Gross alpha	150	79	260	7770	590	590
Gross beta	394	105	330	5260	320	440

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation to this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: RA-15477-02

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
SIDA 5	RA-15477X001	190	47	34	35	66	31
110 AC SW	RA-15477X002	2600	1000	770	780	1500	960

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Pb (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Po (= ²¹⁰Pb)
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **24 February 2015**
Report number: **RA-15934-02**
Pages: **5**
Your reference: **4900095695**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **I Louw**

Checked by: **P Moletsane**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Report number: **RA-15934-02**

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1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 30 May 2014

Purchase order received: 11 June 2014

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	25-06-2014	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	08-09-2014	S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	12-09-2014	T Mokatse	A Rasutha
WIN-142	Thorium by alpha spectrometry	06-10-2014	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	11-09-2014	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	25-07-2014	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	16-02-2015	T Kota	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reported results relate only to the sample portions tested.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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Report number: RA-15934-02

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code Lab code	Sida 1 RA-15934X001			Sida 2 RA-15934X002			Sida 3 RA-15934X003			Sida 4 RA-15934X004			Sida 5 RA-15934X005		
	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	50.7	8.6	3.9	1370	40	2.7	346	18	2.6	2000	40	2.3	18.1	4.1	2.6
²³⁵ U	71.6	10.4	3.9	1250	40	2.7	335	18	2.6	1800	40	2.3	53.4	7.2	2.6
²³² Th	41.0	8.4	24	45	11	47	60	15	74	22	6.7	47	40	14	80
²²⁶ Ra	3.34	1.06	0.91	4.60	1.33	1.0	178	7	0.83	10.3	2.0	1.0	4.88	1.30	0.94
²¹⁰ Pb	21.9	6.0	2.1	20.1	6.4	2.9	6.4	4.8	8.3	-8.2	6.9	16	18	13	40
²¹⁰ Po	3.11	2.37	2.4	4.00	2.50	2.2	6.4	4.8	8.3	34.3	6.6	1.3	3.90	2.92	0.64
²²⁸ U	2.34	0.39	0.18	63.1	1.7	0.12	15.9	0.8	0.12	92.0	1.9	0.11	0.833	0.191	0.12
²²⁸ Th	33.2	5.7	6.0	1.1	5.9	14	9.2	8.9	23	3.7	5.5	14	7.4	12	37
²²⁶ Ra	6.76	2.09	1.6	-1.2	1.4	1.9	-8.0	8.6	1.5	0.93	2.4	1.8	-0.21	1.5	1.7
²²⁸ Th	4.1	2.1	6.0	9.27	3.79	4.2	9.8	6.0	18	4.6	3.4	11	7.95	4.59	7.2
²²⁶ Th	7.91	2.50	2.1	24.2	6.4	11	21.6	8.0	18	15.1	5.7	14	23	11	31
²²⁶ Ra	< MDA			< MDA			< MDA			< MDA			< MDA		
Gross alpha	200	88	280	1520	150	320	569	181	560	2140	190	360	-87	73	260
Gross beta	454	111	350	1860	140	360	1640	140	370	2750	170	370	130	110	350

*Results indicated in **bold** in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation for this laboratory. Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Activity concentrations of nuclides in filtered samples

Report number: RA-15934-02

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Unit: mBq/L

Field code		Sida 6			Sida 7			Sida 8			Sida 10			Sida 11		
Lab code		RA-15934X006			RA-15934X007			RA-15934X008			RA-15934X009			RA-15934X010		
Nuclide		Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U		7710	150	7.9	47.6	8.7	4.3	253	14	2.1	34.0	5.2	2.2	2090	40	1.8
²³⁵ U		7400	150	7.9	350	24	4.3	225	14	2.1	36.5	5.6	2.2	1900	40	1.8
²³² Th		41	9.9	44	27	8.0	53	44	11	48	31	10	72	23	6.4	40
²²⁶ Ra		273	10	0.94	18.9	2.5	0.87	185	8	0.89	3.67	1.06	0.83	206	9	1.00
²¹⁰ Pb		7.36	4.02	5.9	18.4	5.6	9.8	9.3	6.1	19	27.0	7.0	12	18	8.0	21
²¹⁰ Po		7.36	4.02	5.9	4.54	2.46	1.3	0.95	1.5	1.3	0.58	1.9	1.3	2.82	2.60	1.4
²²⁸ U		355	7	0.37	2.19	0.40	0.20	11.9	0.7	0.099	1.56	0.24	0.10	96.3	1.7	0.083
²²⁸ Th		-9.2	7.0	24	0.65	6.3	21	6.2	7.9	19	11	12	41	12	7.6	23
²²⁶ Ra		-10	11	1.7	2.65	3.10	1.6	-9.2	9.1	1.6	-0.97	1.1	1.5	0.44	10	1.8
²²⁸ Th		10	4.8	14	3.5	2.5	4.8	3.2	3.2	12	11.9	5.3	6.4	5.3	3.2	9.7
²²⁶ Th		27.1	7.1	15	13.9	4.9	4.7	34.5	7.4	4.2	12	6.1	17	9.0	3.8	9.4
²²⁶ Ra		0.92	0.92	2.5	< MDA		2.3	0.87	0.87	2.4	0.81	0.81	2.2	2.93	1.69	2.6
Gross alpha		8060	610	580	15	120	420	300	190	610	-28	75	260	2280	210	420
Gross beta		8700	450	470	110	110	360	1790	150	370	300	110	350	2620	170	370

*Results indicated in **bold** in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation for this laboratory. Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated at a confidence level of 95%.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RA-15934-01

Page 5 of 5

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group					
Field code	Lab code	< 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12- 17 a	> 17 a
Sida 1	RA-15934X001	470	91	70	66	110	75
Sida 2	RA-15934X002	520	180	130	130	240	140
Sida 3	RA-15934X003	540	140	100	120	290	100
Sida 4	RA-15934X004	690	270	190	170	280	200
Sida 5	RA-15934X005	380	83	62	63	110	58
Sida 6	RA-15934X006	1800	710	530	550	1000	650
Sida 7	RA-15934X007	320	84	61	64	120	58
Sida 8	RA-15934X008	580	140	110	130	330	98
Dida 10	RA-15934X009	350	73	56	56	97	57
Sida 11	RA-15934X010	700	240	180	190	410	220

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($=^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($=^{226}\text{Ra}$) ^{210}Pb and ^{210}Bi ($=^{210}\text{Pb}$) ^{235}U and ^{231}Pa ($=^{235}\text{U}$)
 ^{227}Ac up to ^{227}Th ($=^{227}\text{Th}$) ^{223}Ra and ^{215}Pb ($=^{223}\text{Ra}$) ^{223}Ra up to ^{215}Th ($=^{223}\text{Th}$) ^{226}Ra up to ^{214}Bi ($=^{226}\text{Ra}$)
 4. Activity concentrations of potassium-40 were not included in the calculations as this nuclide was not analysed for.
 5. Dose rate values are reported with 2 significant digits.

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Date: **15 April 2016**
Report number: **RS2015-3591-02**
Pages: **4**
Order no.: **4900102215**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **P Moletsane**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Job number: **RS2015-3591-02**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 2015-10-28

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	2015-11-02	L Seshoka	O Mathekga
WIN-167	Gross alpha/beta-analysis	2015-11-13	Q Daniels	E Nhlapo
WIN-145	Uranium by alpha spectrometry	2016-01-12	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2015-12-14	N Sono	A Rasutha
WIN-145	Radium by alpha spectrometry	2016-02-19	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2015-12-11	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2016-04-08	T Kota	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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- The individual test reports are available upon request

4.3 The compiler is the Technical Expert for all the methods.

4.4 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Job number: **RS2015-3591-02**

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	Sida 5			Sida 7		
Lab Code	RS2015-3591X001			RS2015-3591X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	12.4	2.5	1.4	25.6	3.6	1.4
²³⁴ U	40.4	4.6	1.4	333	13	1.4
²³⁰ Th	24.4	5.4	11	11.9	3.2	11
²²⁶ Ra	0.46	1.5	6.0	22.4	3.7	1.6
²¹⁰ Pb	4.84	2.95	2.7	2.23	1.58	1.8
²¹⁰ Po	4.84	2.95	2.7	2.23	1.58	1.8
²³⁵ U	0.573	0.117	0.065	1.18	0.17	0.064
²²⁷ Th	37.7	5.1	4.3	0.40	2.8	11
²²³ Ra	0.37	1.3	5.6	3.19	2.06	1.8
²³² Th	10.2	2.7	4.3	1.1	0.80	1.5
²²⁸ Th	5.77	2.19	5.3	2.8	1.7	5.2
²²⁴ Ra	3.86	1.93	2.6	4.0	2.8	5.4
Gross alpha	336	69	200	395	104	310
Gross beta	429	105	330	470	109	340

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: **RS2015-3591-02**

Page **4** of **4**

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
Sida 5	RS2015-3591X001	71	60	56	73	78
Sida 7	RS2015-3591X002	35	28	30	50	35

- Notes:
- Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 - Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 - The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to $^{234\text{m}}\text{Pa}$ ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$) ^{210}Pb and ^{210}Po ($\approx^{210}\text{Po}$)
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$)
 ^{228}Ra up to ^{228}Th ($\approx^{228}\text{Th}$) ^{228}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 - Dose rate values are reported with 2 significant digits.

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Date: **27 May 2016**
Report number: **RS2015-3507-02**
Pages: **05**
Order no.: **4900102222**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **D Kotze**

Checked by: **P Moletsane**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Report: **RS2015-3507-02**

Page 2 of 5

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 10

Date samples received: 2015-10-23

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2015-11-04	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2015-12-23	Q Daniels	E Nhlapo
WIN-145	Uranium by alpha spectrometry	2016-01-12	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2016-03-14	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	2016-03-04	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2015-12-11	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2016-05-18	T Kota	A Rasutha

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results relate only to the sample portion tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

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4.5 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

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Report: **RS2015-3507-02**

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples
Unit: mBq/L

Field Code Lab Code Nuclide	Sida 1			Sida 2			Sida 3			Sida 4			Sida 8		
	RS2015-3507X001	Value	Unc.	RS2015-3507X002	Value	Unc.	RS2015-3507X003	Value	Unc.	RS2015-3507X004	Value	Unc.	RS2015-3507X005	Value	Unc.
²³⁸ U	73.0	5.9	1.3	323	13	1.4	859	32	3.2	993	32	2.7	349	13	1.3
²³⁴ U	111	7	1.3	310	13	1.4	743	30	3.2	982	32	2.7	359	14	1.3
²³⁸ Th	30.6	6.0	8.9	38.4	7.6	12	42.8	8.1	9.7	49.6	9.6	14	23.4	5.0	9.3
²²⁶ Ra	12.9	2.2	0.97	6.04	1.42	0.91	207	11	6.6	3.15	1.04	2.4	40.5	4.0	3.5
²¹⁰ Pb	14.3	5.1	2.5	4.66	2.72	2.2	5.38	3.15	2.6	17.1	5.9	2.5	16.2	5.6	2.5
²¹⁰ Po	14.3	5.1	2.5	4.66	2.72	2.2	5.38	3.15	2.6	1.4	2.5	2.2	16.2	5.6	2.5
²³⁵ U	3.36	0.27	0.060	14.9	0.6	0.066	39.6	1.5	0.15	45.7	1.5	0.13	16.1	0.6	0.061
²²⁷ Th	7.2	2.6	7.2	9.9	3.8	11	5.1	2.7	7.5	2.2	2.8	7.9	6.2	2.9	6.8
²²³ Ra	0.46	0.96	1.1	0.91	0.80	1.0	2.51	4.67	2.1	10.5	1.8	2.1	3.0	1.2	1.4
²²⁴ Th	7.10	1.83	1.3	2.6	1.5	4.5	9.35	2.27	1.5	15.4	3.4	2.0	2.62	1.17	1.4
²²⁸ Th	1.4	1.0	3.3	13.3	3.0	4.5	6.51	1.88	1.5	13.0	3.7	8.7	13.6	2.8	4.5
²²⁴ Ra	< MDA		3.3	< MDA		3.1	5.47	3.16	4.9	2.53	1.46	2.3	< MDA		3.3
Gross alpha	170	120	390	250	98	310	912	199	590	891	140	380	360	170	560
Gross beta	502	115	360	524	113	350	2040	160	370	1300	130	360	1730	150	370

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

- Notes:
- If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
 - The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
 - The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
 - A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code Lab Code Nuclide	Sida 10		Sida 11		Sida 12		Sida 13		Sida 37	
	Value	MDA	Value	MDA	Value	MDA	Value	MDA	Value	MDA
²³⁸ U	21.5	3.4	3320	50	182	10	5280	100	5.5	27.4
²³⁴ U	27.1	3.9	3060	50	185	10	4720	100	5.5	61.8
²³⁵ Th	83.0	14.5	13	69.2	12.7	15	40.6	10.1	32	22.9
²²⁶ Ra	4.68	1.53	3.0	131	7	2.6	1.30	7	4.5	1.2
²¹⁰ Pb	6.24	3.49	5.1	15	8.4	24	7.48	3.81	4.9	7.2
²¹⁰ Po	6.24	3.49	5.1	15	2.6	1.7	7.48	3.81	4.9	7.2
²³⁵ U	0.990	0.158	0.069	153	2	0.10	8.06	2.08	1.5	243
²²⁷ Th	1.5	3.3	12	24.6	5.6	7.2	28.4	7.1	11	7.6
²²³ Ra	-0.39	0.45	1.4	14.9	3.7	1.2	1.4	1.2	1.4	6.44
²²⁸ Th	10.8	2.8	4.7	34.3	5.2	2.1	26.4	5.4	9.1	17.7
²²⁸ Th	8.17	2.43	4.6	13.6	3.2	2.0	18.0	4.1	2.6	-4.8
²²⁴ Ra	1.4	1.4	3.7	5.9	3.1	8.3	2.5	1.8	3.4	4.60
Gross alpha	-30	74	260	3090	260	440	320	84	250	6150
Gross beta	454	110	350	3410	200	380	428	110	350	5520

*Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

- Notes:
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 2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
 3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
 4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
Sida 1	RS2015-3507X001	62	45	41	55	40
Sida 2	RS2015-3507X002	67	52	55	84	92
Sida 3	RS2015-3507X003	120	96	110	180	130
Sida 4	RS2015-3507X004	98	82	82	99	140
Sida 8	RS2015-3507X005	90	70	69	90	110
Sida 10	RS2015-3507X006	41	33	32	38	62
Sida 11	RS2015-3507X007	270	230	230	300	320
Sida 12	RS2015-3507X008	90	76	74	89	140
Sida 13	RS2015-3507X009	360	300	300	370	390
Sida 37	RS2015-3507X010	46	38	39	49	74

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator licensing guide LG-1032. Consumption rates for the different age groups in this guide and dose rate conversion factors published in IAEA Safety Series 115 were used. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra) ²¹⁰Pb and ²¹⁰Po (= ²¹⁰Po)
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2016-07-15**
Report number: **RS2016-0500-01**
Pages: **4**
Order no.: **4900103663**

Interim Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **P Moletsane**

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① Directors Dr KR Kemm (Chairperson), Dr NT Magau, Dr XH Mkhwanazi, Dr AS Tsela, Mr MPK Tshivase, Mr N Ngcobo, Mr ZC Ngidi, Ms P Bosman, Ms RP Mosia, Mr GP Tshelane (CEO)

② Company Secretary First Corporate Secretaries (Pty) Ltd

REG. 2000/003735/06



Job number: **RS2016-0500-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 3

Date samples received: 09 February 2016

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2016-02-10	L Soshake	O Mathekga
WIN-161	Gross alpha/beta-analysis	2016-02-10	Q Daniels	E Nhlapo
WIN-145	Uranium by alpha spectrometry	2016-03-31	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2016-04-15	N Sono	A Rasutha
WIN-124	Radium by alpha spectrometry	2016-04-06	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2016-04-11	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	Pending		

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

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Job number: RS2016-0500-01

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	Main Gate			SD 39			95L Station		
Lab Code	RS2016-0500X001			RS2016-0500X002			RS2016-0500X003		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	26.2	3.5	1.2	26.2	4.5	2.1	4.61	1.88	2.1
²³⁴ U	60.8	5.3	1.2	68.2	7.3	2.1	14.4	3.3	2.1
²³⁰ Th	11.7	2.7	7.9	76.3	16.1	37	4.88	4.97	3.7
²²⁶ Ra	1.09	0.63	0.98	2.39	0.97	1.1	2.5	2.8	10
²¹⁰ Pb									
²¹⁰ Po	4.18	1.88	2.5	4.26	2.14	3.2	4.12	1.85	2.5
²³⁵ U	1.21	0.16	0.057	1.21	0.21	0.096	0.212	0.087	0.096
²²⁷ Th	10.9	2.6	5.9	24	9.0	25	1.0	0.61	1.5
²²³ Ra	1.3	0.86	1.3	0.71	0.91	1.4	7.2	3.4	10
²³² Th	1.75	0.78	0.95	39.4	8.4	12	2.16	0.60	0.45
²²⁸ Th	2.4	1.2	3.7	11	5.4	15	1.5	0.59	1.5
²²⁴ Ra	< MDA		2.1	0.83	0.63	2.3	1.6	1.6	4.5
Gross alpha	-1.8	67	230	4.8	120	400	7.0	34	120
Gross beta	403	121	390	534	126	400	270	120	380

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Job number: RS2016-0500-01

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
Main Gate	RS2016-0500X001	32	25	23	30	29
SD 39	RS2016-0500X002	53	43	43	60	68
95L Station	RS2016-0500X003	15	11	10	12	11

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra)
²¹⁰Pb up to ²¹⁰Po (= ²¹⁰Pb) if only ²¹⁰Po was measured else ²¹⁰Pb and ²¹⁰Pb (= ²¹⁰Pb) if ²¹⁰Pb was measured
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2017-11-17**
Report number: **RS2017-1294-01**
Pages: **4**
Order no.: **4900109258**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **N Sono**

This report is for Pb-210 results. Refer to RS2017-1096-01 for other nuclides results.

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Directors Dr KR Kemm (Chairman), Dr NT Magau, Dr GJ Davids, Mr MPK Tshivhase, Mr ENN Ngcobo, Mr ZC Ngidi, Ms P Bosman, Ms RP Mosia, Mr SM Sekgota, Mr GP Tshelane (CEO)

Company Secretary First Corporate Secretaries (Pty) Ltd

REG. 2000/003735/06



Report Number: **RS2017-1294-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 3

Date samples received: 2017-03-15

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2017-03-29	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2017-04-06	Q Daniels	E Nhlapo
WIN-124	Radium by alpha spectrometry	2017-07-26	A Mokgalane	C Zwane
WIN-145	Uranium by alpha spectrometry	2017-05-23	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2017-05-24	N Sono	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2017-06-27	T Kota	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2017-11-17	T Kota	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reported results relate only to the sample portions tested.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.
 - Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
 - Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- 4.3 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.4 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report Number: **RS2017-1294-01**

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	50L Drinking			95L Drinking			94L Drinking		
Lab Code	RS2017-1096X001			RS2017-1096X002			RS2017-1096X003		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	32.2	4.3	1.6	59.9	5.3	1.3	94.4	6.5	1.2
²³⁴ U	73.2	6.5	1.6	193	10	1.3	146	8	1.2
²³⁰ Th	42.6	10.7	31	41.0	9.6	25	26.8	6.5	18
²²⁶ Ra	4.13	1.26	2.8	5.08	1.20	0.76	7.26	1.59	0.94
²¹⁰ Pb	3.12	2.10	2.1	5.40	2.75	2.0	5.42	2.73	2.0
²¹⁰ Po	3.12	2.10	2.1	5.40	2.75	2.0	5.42	2.73	2.0
²³⁵ U	1.48	0.20	0.072	2.76	0.25	0.059	4.34	0.30	0.056
²²⁷ Th	10	5.8	11	21.2	7.2	18	4.8	4.6	12
²²³ Ra	-0.077	1.1	4.3	-1.9	1.4	1.6	-1.2	2.1	1.9
²³² Th	9.0	4.8	14	1.2	2.1	9.1	7.07	2.50	2.4
²²⁸ Th	16.3	4.9	4.0	8.4	4.3	13	11.2	4.0	10
²²⁴ Ra	-0.97	2.1	10	1.8	1.3	2.4	< MDA		3.0
Gross alpha	432	62	150	197	50	150	120	47	150
Gross beta	130	130	410	-130	120	410	100	130	410

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report Number: **RS2017-1294-01**

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
50L Drinking	RS2017-1096X001	50	39	43	70	88
95L Drinking	RS2017-1096X002	63	51	49	68	71
94L Drinking	RS2017-1096X003	52	40	42	65	72

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra)
²¹⁰Pb up to ²¹⁰Po (= ²¹⁰Pb) if only ²¹⁰Po was measured else ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) if ²¹⁰Pb was measured
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²³¹Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Ra) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2018-02-14**
Report number: **RS2017-4297-01**
Pages: **4**
Order no.: **4900111751**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **N Sono**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Directors Dr KR Kemm (Chairman), Dr NT Magau, Dr GJ Davids, Mr MPK Tshivase, Mr ENN Ngcobo, Mr ZC Ngidi, Ms P Bosman, Ms RP Mosia, Mr SM Sekgota, Mr GP Tshelane (CEO)

Company Secretary First Corporate Secretaries (Pty) Ltd

REG. 2009/003735/06



Report number: **RS2017-4297-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 3

Date samples received: 2017-09-05

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2017-09-11	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2017-10-10	Q Daniels	E Nhlapo
WIN-124	Radium by alpha spectrometry	2017-12-14	A Mokgalane	C Zwane
WIN-145	Uranium by alpha spectrometry	2018-01-18	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2018-01-22	N Sono	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2018-01-30	T Kota	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Reported results relate only to the sample portions tested.
- 3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

- 4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.
- 4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.
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 - Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.
- 4.3 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.4 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: **RS2017-4297-01**

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	50D Level			95D Level			93D Level		
	RS2017-4297X001			RS2017-4297X002			RS2017-4297X003		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	58.7	9.1	3.8	30.1	4.3	1.6	15.0	3.4	2.0
²³⁴ U	63.0	9.6	3.8	114	8	1.6	26.4	4.5	2.0
²³⁰ Th	37.7	8.0	17	42.0	8.8	18	31.5	7.2	19
²²⁶ Ra	3.51	1.24	1.2	3.50	1.24	1.2	6.49	1.57	1.0
²¹⁰ Po	5.86	2.23	2.4	18.3	4.6	3.0	4.9	2.8	9.4
²³⁵ U	2.70	0.42	0.17	1.39	0.20	0.075	0.692	0.155	0.094
²²⁷ Th	5.1	4.0	12	4.4	4.5	13	7.1	5.2	16
²²³ Ra	0.087	1.2	1.9	-0.93	1.00	1.9	-0.45	1.5	1.6
²³² Th	34.8	5.5	6.1	22.1	4.3	2.3	23.2	4.5	2.4
²²⁸ Th	7.4	2.9	7.6	18.4	4.4	9.0	14.1	3.9	8.2
²²⁴ Ra	< MDA		2.7	0.98	0.98	2.7	< MDA		2.3
Gross alpha	106	31	88	71	29	87	75	30	92
Gross beta	180	130	440	140	130	440	170	130	440

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (**Value** column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (**MDA** column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the **Value** column.
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: **RS2017-4297-01**

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APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
50D Level	RS2017-4297X001	43	34	32	44	43
95D Level	RS2017-4297X002	100	74	74	110	120
93D Level	RS2017-4297X003	52	41	44	69	83

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra)
²¹⁰Pb up to ²¹⁰Po (= ²¹⁰Pb) if only ²¹⁰Po was measured else ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) if ²¹⁰Pb was measured
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2018-08-22**
Report number: **RS2018-1045-01**
Pages: **4**
Order no.: **4900114102**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **A Mokgalane**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

① **Directors** Dr KR Kemm (Chairman), Dr NT Magau, Dr GJ Davids, Mr MPK Tshivase, Mr ENN Ngcobo, Mr ZC Ngidi, Ms P Bosman, Ms RP Mosia, Mr SM Sekgota, Mr GP Tshelane (CEO)

② **Company Secretary** First Corporate Secretaries (Pty) Ltd

REG. 2000/000735/06



Report number: **RS2018-1045-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 2

Date samples received: 2018-03-08

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2018-03-15	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2018-04-13	Q Daniels	E Nhlapo
WIN-124	Radium by alpha spectrometry	2018-07-25	A Mokgalane	C Zwane
WIN-145	Uranium by alpha spectrometry	2018-05-14	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2018-07-18	N Sono	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2018-08-02	N Yawa	A Rasutha

**Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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4.4 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: **RS2018-1045-01**

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	Sida 22			Sida 23		
	RS2018-1045X001			RS2018-1045X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	35.6	5.4	2.2	34.4	4.8	1.8
²³⁴ U	64.8	7.3	2.2	63.8	6.6	1.8
²³⁰ Th	12.8	3.0	7.1	9.23	9.42	7.0
²²⁶ Ra	5.64	2.13	2.2	8.84	3.34	3.4
²¹⁰ Po	6.8	7.0	26	14	6.1	17
²³⁵ U	1.84	0.25	0.10	1.58	0.22	0.084
²²⁷ Th	3.6	2.3	7.6	5.6	2.1	5.7
²²³ Ra	0.37	1.0	2.4	7.43	4.07	4.6
²³² Th	3.36	1.12	1.0	< MDA		0.99
²²⁸ Th	2.3	1.3	3.9	9.09	1.82	0.99
²²⁴ Ra	< MDA		7.1	29.1	8.8	7.2
Gross alpha	539	138	390	130	120	390
Gross beta	781	123	370	642	120	370

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: **RS2018-1045-01**

Page 4 of 4

APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
Sida 22	RS2018-1045X001	53	38	34	43	33
Sida 23	RS2018-1045X002	55	39	40	59	58

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra)
²¹⁰Pb up to ²¹⁰Po (= ²¹⁰Pb) if only ²¹⁰Po was measured else ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) if ²¹⁰Pb was measured
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²²⁷Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2018-09-12**
Report number: **RS2017-5260-01**
Pages: **4**
Order no.: **4900112806**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **A Mokgalane**

This report is for Pb-210 results. Refer to RS2017-5259-01 for other nuclides results.

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

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Company Secretary First Corporate Secretaries (Pty) Ltd

REG. 2000/003735/06



Report number: **RS2017-5260-01**

Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: **mBq/L**

Field Code	SIDA 5			SIDA 7		
Lab Code	RS2017-5259X001			RS2017-5259X002		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	78.2	7.3	1.9	74.3	6.8	1.7
²³⁴ U	595	20	1.9	523	18	1.7
²³⁰ Th	24.8	5.6	20	27.0	6.0	21
²²⁶ Ra	149	7	0.81	171	7	0.79
²¹⁰ Pb	35.1	9.5	0.74	11.3	4.7	2.5
²¹⁰ Po	-24	12	6.6	11.3	4.7	2.5
²³⁵ U	3.60	0.34	0.086	3.42	0.31	0.078
²²⁷ Th	11.4	4.8	10	31.3	5.2	7.9
²²³ Ra	-18	4.3	1.1	-24	4.4	1.1
²²³ Th	8.88	2.46	1.9	9.64	2.67	2.0
²²⁸ Th	37.1	5.4	8.7	6.6	2.6	6.7
²²⁴ Ra	9.33	2.41	1.7	1.2	0.86	1.6
Gross alpha	891	117	240	508	90	220
Gross beta	1070	140	400	270	120	400

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
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3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
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Date: **2018-12-14**
Report number: **RS2018-1044-01**
Pages: **4**
Order no.: **4900115443**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **A Mokgalane**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Directors Dr KR Kemm (Chairman), Dr NT Maseu, Dr GJ Davids, Mr MPK Tshihase, Mr ENN Ngoboo, Mr ZC Ngidi, Ms P Bosman, Ms RP Mosia, Mr SM Sekgota, Mr GP Tshelane (CEO)

Company Secretary First Corporate Secretaries (Pty) Ltd

REG. 2009/003735/06



Report number: **RS2018-1044-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for selected radionuclides in the uranium and thorium decay series.
Number of samples received: 10
Date samples received: 2018-03-08
PO received: 2018-04-18

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2018-07-23	L Seshoka	O Mathekga
WIN-124	Radium by alpha spectrometry	2018-11-06	A Mokgalane	A Rasutha
WIN-145	Uranium by alpha spectrometry	2018-12-14	N Mokwana	A Rasutha
WIN-142	Thorium by alpha spectrometry	2018-11-27	K Shokane	A Rasutha

**Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

- 3.1 Results are attached as an appendix to this report.
- 3.2 Results relate only to the sample portion tested.

4. QUALITY ASSURANCE

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- 4.3 The compiled report is checked by a person other than the compiler for accuracy of data transcription.
- 4.4 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code Lab Code	SIDA 5		SIDA 6		SIDA 8		SIDA 10		SIDA 11	
	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.
²³⁸ U	93.0	7.4	1.6	54.2	5.7	1.6	880	23	1.6	1120
²³⁴ U	766	21	1.6	394	15	1.6	893	24	1.6	1130
²³² Th	20	5.1	25	96.8	17.5	30	91.0	16.3	28	77.2
²²⁶ Ra	221	11	1.5	2.80	1.14	1.3	288	12	1.4	44.6
²³⁵ U	4.28	0.34	0.073	2.50	0.26	0.074	40.5	1.1	0.074	51.4
²²⁷ Th	0.64	1.4	5.1	19.2	4.9	11	20.3	4.6	9.4	12
²²³ Ra	-10	7.7	2.0	-0.18	0.78	1.7	-12	8.5	1.9	-0.34
²²⁷ Th	11.9	3.2	6.4	16.9	4.1	7.8	18.2	4.4	9.4	33.7
²²⁸ Th	5.6	3.2	10	6.0	4.3	14	5.5	2.4	5.8	6.33
²²⁶ Ra	49.7	7.5	3.1	2.93	1.69	2.6	2.1	1.5	2.9	0.95

*Results indicated in bold in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code Lab Code	SIDA 12		SIDA 17		SIDA 18		SIDA 19		SIDA 21	
	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.	Value	Unc.
²³⁸ U	1040	20	1.6	17.7	3.2	1.5	41.5	5.0	1.7	30.9
²³⁴ U	971	24	1.6	65.3	6.1	1.5	94.6	7.7	1.7	264
²³² Th	18	4.3	20	91.9	17.2	40	6.7	7.2	26	37.9
²²⁶ Ra	36.6	4.8	1.7	25.5	3.4	1.2	16.6	2.9	1.4	59.3
²³⁵ U	47.9	1.1	0.073	0.814	0.146	0.071	1.91	0.23	0.076	1.42
²²⁷ Th	15.4	3.9	9.8	45.4	8.5	19	-2.2	1.7	5.3	12.2
²²³ Ra	2.65	3.79	2.3	4.83	3.70	1.9	2.2	3.1	2.2	-6.6
²²⁷ Th	1.1	0.80	1.5	70.8	9.1	8.2	4.4	2.3	6.7	39.8
²²⁸ Th	4.4	2.1	6.3	1.4	6.0	22	9.4	3.7	11	4.5
²²⁶ Ra	5.29	2.65	3.6	6.15	2.51	2.8	9.33	3.30	3.2	2.0

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Notes:

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Date: **2018-12-14**
Report number: **RS2018-1046-01**
Pages: **4**
Order no.: **4900115444**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Rasutha**

Checked by: **A Mokgalane**

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Directors Dr KR Kani (Chairman), Dr NT Magau, Dr GJ Davids, Mr MPK Tshihase, Mr ENN Ngcobo, Mr ZC Ngidi, Ms P Bosman, Ms RP Mosia, Mr SM Sekgota, Mr GP Tshelane (CEO)

Company Secretary First Corporate Secretaries (Pty) Ltd

REG. 2000/003735/08



Report number: **RS2018-1046-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 6

Date samples received: 2018-03-08

PO received: 2018-07-20

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2018-07-23	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2018-10-26	Q Daniels	E Nhlapo
WIN-124	Radium by alpha spectrometry	2018-12-05	A Mokgalane	C Zwane
WIN-145	Uranium by alpha spectrometry	2018-11-29	C Zwane	A Rasutha
WIN-142	Thorium by alpha spectrometry	2018-11-29	K Shokane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2018-12-04	N Yawa	A Rasutha

**Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results relate only to the sample portion tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples
Unit: mBq/L

Field Code Lab Code	Sida 1			Sida 2			Sida 4			Sida 1			Sida 2			Sida 4		
	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	77.3	7.6	2.0	623	28	3.4	1460	30	1.7	166	10	1.7	1320	30	2.1	650	22	1.9
²³⁵ U	133	10	2.0	630	29	3.4	1480	30	1.7	235	12	1.7	1220	30	2.1	681	23	1.9
²³² Th	22.7	4.9	1.6	35.5	7.1	1.7	19.5	4.7	1.9	19.7	5.0	1.9	14	3.4	1.6	12	3.3	1.6
²²⁶ Ra	0.83	0.59	1.1	11.2	2.4	1.4	10.4	2.6	1.8	8.04	2.84	2.7	20.8	4.8	3.0	11.6	3.5	2.9
²¹⁰ Po	9.61	3.39	8.8	4.6	3.4	12	13.8	5.7	6.4	7.65	3.16	3.6	22.1	7.5	6.8	8.37	3.00	3.0
²²⁷ U	3.56	0.35	0.093	28.7	1.3	0.16	67.3	1.4	0.080	7.66	0.47	0.079	60.6	1.5	0.096	29.9	1.0	0.090
²²⁷ Th	4.9	5.2	18	13.1	2.8	4.1	7.5	3.0	8.1	13.0	3.3	7.3	16.1	4.4	12	19.4	3.8	7.0
²²³ Ra	1.64	0.87	1.3	2.86	1.63	1.6	1.6	2.2	2.4	-1.4	1.2	3.4	-1.2	2.6	3.6	4.76	3.12	3.5
²²⁷ Th	3.21	1.31	1.4	0.57	1.2	5.1	0.017	1.2	5.7	2.4	2.1	7.3	1.6	1.2	3.8	-0.014	1.1	5.0
²²⁸ Th	6.37	1.84	1.4	1.2	2.2	8.3	3.8	3.1	11	1.8	1.4	4.5	6.17	2.05	4.8	2.0	2.6	9.2
²²⁶ Ra	< MDA	3.5	3.3	2.3	4.5	8.14	3.32	3.7	< MDA	6.2	4.9	3.5	6.7	11.9	5.3	6.5		
Gross alpha	160	44	110	871	80	110	1860	130	140	192	45	110	1360	100	120	797	100	190
Gross beta	180	78	250	766	89	230	996	99	250	290	75	230	1080	100	220	1550	120	240

*Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
Sida 1	RS2018-1046X001	58	44	41	56	57
Sida 2	RS2018-1046X002	89	71	69	97	83
Sida 4	RS2018-1046X003	160	120	120	170	140
Sida 1	RS2018-1046X004	59	46	43	58	49
Sida 2	RS2018-1046X005	190	140	140	190	150
Sida 4	RS2018-1046X006	100	84	80	110	94

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²²⁸U up to ^{234m}Pa (= ²²⁸U) ²²⁶Ra up to ²¹⁴Pb (= ²²⁶Ra)
²¹⁰Pb up to ²¹⁰Po (= ²¹⁰Pb) if only ²¹⁰Po was measured else ²¹⁰Pb and ²¹⁰Pb (= ²¹⁰Pb) if ²¹⁰Pb was measured
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²³¹Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Th) ²²⁶Ra up to ²¹²Bi (= ²²⁶Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2020-05-21**
Report number: **RS2019-1419-01**
Pages: **4**
Order no.: **4900117251**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Mokgalane**

Checked by: **A Rasutha**

This report is for Pb-210 results. Refer to RS2019-1418-01 for results of other nuclides.

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Directors Ms A Chowan, Dr G J Davids, Mr M J Maboa, Dr N T Magau, Ms S K N Masengo, Ms L Noge-Thungamirai, Mr L J Shayi, Mr D R Nicholls (Chairman), Mr A B Myoli (Acting CEO)

REG. 2000/003735/06



Report number: **RS2019-1419-01**

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1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 3

Date samples received: 2019-04-02

PO date received: 2019-10-16

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2019-10-18	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2019-12-04	T Mkwana	E Nhiapo
WIN-124	Radium by alpha spectrometry	2020-02-03	T Mokatse	C Zwane
WIN-145	Uranium by alpha spectrometry	2020-02-04	N Mokwana	A Rasutha
WIN-142	Thorium by alpha spectrometry	2020-02-10	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2020-02-03	N Sono	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2020-05-15	N Sono	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

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Report number: **RS2019-1419-01**

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APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	SIDA 1			SIDA 2			SIDA 4		
Lab Code	RS2019-1418X001			RS2019-1418X002			RS2019-1418X003		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	149	11	2.4	912	28	2.3	26.7	4.4	2.0
²³⁴ U	171	13	2.4	824	27	2.3	210	12	2.0
²³⁰ Th	44.0	8.3	19	64.2	12.1	28	21.3	4.4	13
²²⁶ Ra	2.95	1.04	1.00	6.11	1.69	1.3	15.6	3.5	2.1
²¹⁰ Pb	27.3	7.5	10	27.3	8.8	18	7.59	4.21	6.4
²¹⁰ Po	-56	20	19	-52	23	38	7.59	4.21	6.4
²³⁵ U	6.84	0.53	0.11	42.0	1.3	0.10	1.23	0.20	0.090
²²⁷ Th	9.81	2.57	4.1	5.6	2.8	7.4	1.5	1.8	6.2
²²³ Ra	-1.1	0.70	1.5	-1.3	1.4	2.0	0.43	3.3	3.2
²³² Th	7.56	2.10	1.6	5.86	2.21	2.3	3.56	1.19	1.1
²²⁸ Th	5.9	2.3	5.9	11.7	3.1	2.3	1.1	1.8	6.4
²²⁴ Ra	< MDA			2.2	2.1	1.5	2.8	1.7	1.7
Gross alpha	574	66	110	923	85	110	327	55	120
Gross beta	516	123	390	735	127	390	43	120	390

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
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3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: **RS2019-1419-01**

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APPENDIX 2: Dose rate calculations

Unit: μ Sv/a

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
SIDA 1	RS2019-1418X001	76	59	55	73	58
SIDA 2	RS2019-1418X002	150	120	110	160	140
SIDA 4	RS2019-1418X003	45	34	33	50	38

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra)
²¹⁰Pb up to ²¹⁰Po (= ²¹⁰Pb) if only ²¹⁰Po was measured else ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) if ²¹⁰Pb was measured
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²³¹Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Ra) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2020-05-21**
Report number: **RS2019-1419-01**
Pages: **4**
Order no.: **4900117251**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Mokgalane**

Checked by: **A Rasutha**

This report is for Pb-210 results. Refer to RS2019-1418-01 for results of other nuclides.

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Directors Ms A Chowan, Dr G J Davids, Mr M J Maboa, Dr N T Magau, Ms S K N Masengo, Ms L Noge-Thungamirai, Mr L J Shayi, Mr D R Nicholls (Chairman), Mr A B Myoli (Acting GCEO)

REG. 2000/003735/06



Report number: **RS2019-1419-01**

Page 2 of 4

1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 3

Date samples received: 2019-04-02

PO date received: 2019-10-16

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2019-10-18	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2019-12-04	T Mkwana	E Nhiapo
WIN-124	Radium by alpha spectrometry	2020-02-03	T Mokatse	C Zwane
WIN-145	Uranium by alpha spectrometry	2020-02-04	N Mokwana	A Rasutha
WIN-142	Thorium by alpha spectrometry	2020-02-10	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2020-02-03	N Sono	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2020-05-15	N Sono	A Rasutha

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Reported results relate only to the sample portions tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

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Page 3 of 4

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code	SIDA 1			SIDA 2			SIDA 4		
Lab Code	RS2019-1418X001			RS2019-1418X002			RS2019-1418X003		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
²³⁸ U	149	11	2.4	912	28	2.3	26.7	4.4	2.0
²³⁴ U	171	13	2.4	824	27	2.3	210	12	2.0
²³⁰ Th	44.0	8.3	19	64.2	12.1	28	21.3	4.4	13
²²⁶ Ra	2.95	1.04	1.00	6.11	1.69	1.3	15.6	3.5	2.1
²¹⁰ Pb	27.3	7.5	10	27.3	8.8	18	7.59	4.21	6.4
²¹⁰ Po	-56	20	19	-52	23	38	7.59	4.21	6.4
²³⁵ U	6.84	0.53	0.11	42.0	1.3	0.10	1.23	0.20	0.090
²²⁷ Th	9.81	2.57	4.1	5.6	2.8	7.4	1.5	1.8	6.2
²²³ Ra	-1.1	0.70	1.5	-1.3	1.4	2.0	0.43	3.3	3.2
²³² Th	7.56	2.10	1.6	5.86	2.21	2.3	3.56	1.19	1.1
²²⁸ Th	5.9	2.3	5.9	11.7	3.1	2.3	1.1	1.8	6.4
²²⁴ Ra	< MDA			2.2	2.1	1.5	2.8	1.7	1.7
Gross alpha	574	66	110	923	85	110	327	55	120
Gross beta	516	123	390	735	127	390	43	120	390

*Results indicated in **bold** in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA ("< MDA") will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

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APPENDIX 2: Dose rate calculations

Unit: µSv/a

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
SIDA 1	RS2019-1418X001	76	59	55	73	58
SIDA 2	RS2019-1418X002	150	120	110	160	140
SIDA 4	RS2019-1418X003	45	34	33	50	38

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
²³⁸U up to ^{234m}Pa (= ²³⁸U) ²²⁶Ra up to ²¹⁴Bi (= ²²⁶Ra)
²¹⁰Pb up to ²¹⁰Po (= ²¹⁰Pb) if only ²¹⁰Pb was measured else ²¹⁰Pb and ²¹⁰Bi (= ²¹⁰Pb) if ²¹⁰Pb was measured
²³⁵U and ²³¹Th (= ²³⁵U) ²³¹Pa up to ²²⁷Th (= ²³¹Th) ²²³Ra and ²¹¹Pb (= ²²³Ra)
²²⁸Ra up to ²²⁸Th (= ²²⁸Ra) ²²⁴Ra up to ²¹²Bi (= ²²⁴Ra)
 4. Dose rate values are reported with 2 significant digits.

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Date: **2020-06-04**
Report number: **RS2019-1421-01**
Pages: **5**
Order no.: **4900117249**

Final Analysis Report

Radioactivity analysis of water

Compiled by: **A Mokgalane**

Checked by: **A Rasutha**

Note that this report is for Pb-210 results. Refer to RS2019-1420-01 for results of other nuclides.

The views and opinions of authors expressed in this report do not necessarily state or reflect those of Necsa. The liability of Necsa is limited to the "General Conditions of Sale", which is available on request.

Directors Ms A Chowan, Dr G J Davids, Mr M J Mabos, Dr N T Magau, Ms S K N Masango, Ms L Noge-Thungamirai, Mr L J Shayi, Mr D R Nicholls (Chairman), Mr A B Myoli (Acting CEO)

REG. 2000/003735/06



Report number: **RS2019-1421-01**

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1. SERVICE

Analysis of water samples for gross alpha/beta-activity and for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 9

Date samples received: 2019-04-02

PO date received: 2019-10-16

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Technical Signatory
WIN-121	Filtration of suspended solids	2019-10-18	L Seshoka	O Mathekga
WIN-161	Gross alpha/beta-analysis	2019-12-03	T Mkwana	E Nhlapo
WIN-124	Radium by alpha spectrometry	2020-02-03	T Mokatse	C Zwane
WIN-145	Uranium by alpha spectrometry	2020-02-24	N Mokwana	A Rasutha
WIN-142	Thorium by alpha spectrometry	2020-02-18	A Mokgalane	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2020-02-03	N Sono	A Rasutha
WIN-129	Lead-210 by alpha spectrometry	2020-05-22	N Sono	A Rasutha

**Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation for this laboratory.*

3. RESULTS

3.1 Results are attached as an appendix to this report.

3.2 Results relate only to the sample portion tested.

3.3 The method for gross alpha/beta-activity is intended to merely be a screening technique and gives only a first order estimate of total activities. Errors associated with unavoidable differences between particle energies of the calibration standards and samples, are not accounted for in the reported uncertainty which is mainly based on counting statistics. The reported uncertainty may therefore be an underestimation of the true uncertainty.

4. QUALITY ASSURANCE

4.1 RadioAnalysis is a SANAS accredited laboratory (Testing Laboratory T0111) based on ISO/IEC Standard 17025. All analytical methods are documented in the RadioAnalysis Quality System.

4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredited methods.

- Test reports containing results obtained from methods included in the SANAS Schedule of Accreditation, are verified and signed by SANAS Technical Signatories for those methods.
- Test reports containing results obtained from methods not included in the SANAS Schedule of Accreditation, are verified and signed by qualified competent analysts for those methods. Results reported for non-accredited methods are indicated in bold.

4.3 The compiled report is checked by a person other than the compiler for accuracy of data transcription.

4.4 The RadioAnalysis Laboratory keeps the original signed hard copy of this report on record for three years.

Report number: RS2019-1421-01

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code Lab Code Nuclide	SIDA 16		SIDA 17		SIDA 23		SIDA 15					
	RS2019-1420X006 Value	Unc. MDA	RS2019-1420X007 Value	MDA	RS2019-1420X008 Value	MDA	RS2019-1420X009 Value	MDA				
²³⁵ U	10.1	2.1	1.2	7.54	1.61	0.93	285	12	1.3	18.8	2.7	1.1
²³⁸ U	27.0	3.5	1.2	16.8	2.4	0.93	262	11	1.3	21.5	3.0	1.1
²³⁴ Th	78.0	17.0	7.4	9.1	9.2	12	64.9	12.8	4.2	26.7	4.9	1.1
²²⁶ Ra	26.8	2.8	0.78	10.3	1.6	0.67	23.2	4.7	2.6	2.19	0.77	0.74
²¹⁰ Pb	9.49	4.31	8.5	7.13	3.78	2.9	33.5	8.4	11	5.56	2.83	2.0
²¹⁰ Po	-17	12	16	-14	10	0.24	-73	22	20	5.56	2.83	2.0
²³⁵ U	0.463	0.099	0.057	0.347	0.074	0.043	13.1	0.5	0.058	0.866	0.126	0.050
²³² Th	10	8.2	26	4.0	1.9	5.0	5.2	5.3	16	9.01	1.85	0.76
²²⁶ Ra	-4.2	1.8	1.1	-0.94	1.1	0.92	-1.8	3.3	3.6	-0.30	0.52	1.0
²³⁴ Th	22.1	6.9	14	0.58	0.58	2.1	10.4	3.3	2.8	1.7	0.80	2.1
²³⁸ Th	32.9	7.8	5.0	19.2	2.4	0.78	8.08	3.19	7.4	3.84	1.16	2.6
²²⁶ Ra	4.82	1.70	1.6	0.51	0.51	1.4	10.1	4.5	5.5	0.57	0.57	1.5
Gross alpha	189	43	110	97	34	100	384	77	180	107	34	96
Gross beta	-6.5	120	390	-99	110	390	320	130	410	-49	110	380

*Results indicated in **bold** in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA*) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA*) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

Report number: RS2019-1421-01

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field Code Lab Code Nuclide	SIDA 3			SIDA 8			SIDA 10			SIDA 11			SIDA 12		
	RS2019-1420X001	Value	MDA	RS2019-1420X002	Value	MDA	RS2019-1420X003	Value	Unc.	RS2019-1420X004	Value	Unc.	RS2019-1420X005	Value	MDA
²³⁸ U	2140	30	1.3	344	16	2.0	33.6	3.3	0.90	1070	20	0.96	215	9	1.0
²³⁴ U	1820	30	1.3	316	16	2.0	27.7	3.1	0.90	930	19	0.96	206	9	1.0
²³⁴ Th	36.6	6.6	15	29.3	6.0	22	61	14	63	27.3	5.0	12	115	24	97
²²⁶ Ra	150	7	0.95	108	7	1.3	2.92	1.19	1.3	19.6	2.7	1.0	32.1	3.3	0.92
²¹⁰ Pb	14.8	5.6	2.3	27.3	7.8	9.9	10.3	4.1	2.2	12.9	5.5	6.9	5.88	3.38	5.2
²¹⁰ Po	-21	17	0.80	-50	22	17	10.3	4.1	2.2	12.9	5.5	6.9	5.88	3.38	5.2
²³⁵ U	98.7	1.5	0.062	15.8	0.7	0.092	1.55	0.15	0.041	49.3	0.9	0.044	9.91	0.42	0.047
²³² Th	4.85	1.77	1.0	12.2	4.2	10	12	7.7	25	5.58	1.31	0.82	48.4	11.5	6.5
²²⁶ Ra	2.38	3.33	1.1	-6.4	5.4	1.8	-0.80	0.86	1.8	0.98	2.2	1.4	-0.61	2.5	1.3
²³⁴ Th	4.15	1.36	2.8	23.1	3.7	5.0	15.6	4.9	4.2	3.34	1.01	0.82	33.8	10.2	22
²³⁸ Th	5.17	1.57	3.4	12.6	2.9	5.7	13.9	5.1	11	0.904	0.522	0.82	50.4	12.5	26
²²⁶ Ra	1.1	1.1	2.9	3.08	1.78	2.8	< MDA			2.8	0.80	2.2	2.12	1.22	1.9
Gross alpha	2740	210	200	611	77	140	73	31	95	1530	110	99	463	56	97
Gross beta	1510	150	410	654	128	400	85	120	380	678	129	390	53	120	380

*Results indicated in **bold** in this report were obtained from methods that are not included in the SAMAS Schedule of Accreditation for this laboratory

Notes:

1. If a measured value (Value column) was recorded, it is reported regardless if the value is less than the minimum detectable activity concentration (MDA column) or even if the value is negative. In the case where a value could not be obtained, a less than MDA (< MDA*) will be indicated.
2. The reported uncertainty (Unc. column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported of a less than MDA (< MDA*) is indicated in the Value column.
3. The minimum detectable activity concentration (MDA column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value and its associated uncertainty are reported with 2 significant digits regardless of their respective magnitudes. A MDA value is always reported with 2 significant digits.

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APPENDIX 2: Dose rate calculations

Unit: $\mu\text{Sv/a}$

Sample ID		Age group				
Field code	Lab code	1 Year	5 Years	10 Years	15 Years	Adult
SIDA 3	RS2019-1420X001	200	160	180	300	180
SIDA 8	RS2019-1420X002	130	100	110	200	130
SIDA 10	RS2019-1420X003	72	55	55	80	92
SIDA 11	RS2019-1420X004	120	95	91	130	92
SIDA 12	RS2019-1420X005	180	150	160	260	310
SIDA 16	RS2019-1420X006	100	81	92	150	180
SIDA 17	RS2019-1420X007	41	32	40	72	90
SIDA 23	RS2019-1420X008	100	81	81	120	94
SIDA 15	RS2019-1420X009	37	29	27	36	37

- Notes:
1. Dose rates were calculated according to guidelines in National Nuclear Regulator regulatory guide RG-002. Activity concentrations used in the calculations were determined according to the conditions set out in points 2 and 3 below.
 2. Where the activity concentration is less than the minimum detectable activity concentration (MDA), half of the MDA value was used in the calculation.
 3. The following radioactive equilibria were assumed for the purpose of the calculations:
 ^{238}U up to ^{234}Pa ($\approx^{238}\text{U}$) ^{226}Ra up to ^{214}Bi ($\approx^{226}\text{Ra}$)
 ^{210}Pb up to ^{210}Po ($\approx^{210}\text{Po}$) if only ^{210}Po was measured else ^{210}Pb and ^{210}Bi ($\approx^{210}\text{Pb}$) if ^{210}Pb was measured
 ^{235}U and ^{231}Th ($\approx^{235}\text{U}$) ^{231}Pa up to ^{227}Th ($\approx^{227}\text{Th}$) ^{223}Ra and ^{211}Pb ($\approx^{223}\text{Ra}$)
 ^{226}Ra up to ^{226}Th ($\approx^{226}\text{Th}$) ^{224}Ra up to ^{212}Bi ($\approx^{224}\text{Ra}$)
 4. Dose rate values are reported with 2 significant digits.

Appendix B: Environmental Radon Monitoring Results

Table B 1 Environmental radon concentrations measured at the South Deep Gold Mine in 2014.

Location	Description	January		March		April		June		July		August		September		October		November		December	
		RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results
		Bq.h.m ⁻³																			
R 1	Orion Peach Farm	811239	25000	211058	21000	410192	11200	510496	23000	611444	22000	511527		710171	39866.67	711847	19000	910218	58000	911604	61000
R 1	Orion Peach Farm	811267	22000	211099	14066.67	410166	16933.33	510435	38000	611360	26000	511534	19800	710158	29000	744861		712663	33000	911717	34133.33
R 2	New tailing dam next to the road SD 10	811266	23000	211057	168000	410101	11200	510578	20393.1	611394	25533.33	511561	31266.67	710113	18000	711616	22000	910157	51000	911665	28000
R 2	New tailing dam next to the road SD 10	811208	23000	211130	22666.67	410092	16933.33	510514	28400	611457	22666.67	511523	86000	710351	28400	711687	24000	910033	37000	911540	31000
R 2	New tailing dam next to the road SD 10	811247	21000	211118	16933.33	410117	31266.67	510464	28400	611385	25533.33	511537	37000	710103	25000	711744	31000	910220	63000	911645	37000
R 3	Perskes Modderfontein Veggie Farm	811129	17511.11	211162	11200	410133	44000	510404	22666.67	611412	11200	511520	31000	710101	36000	711703	19000	712750	#N/A	911600	33000
R 3	Perskes Modderfontein Veggie Farm	811241	20000	211105	34000	410073	22666.67	510532	19000	611434	11200	610029	21000	710052	29000	711863	25000	712725	32000	911509	42000
R 4	Thusanong House No. 24	811201	19800	211083	8333.333	410077	14066.67	510463	26000	611365	25533.33	610099	19800	710230	20000	711774	13966.67	712648	31000	911671	27000
R 4	Thusanong House No. 24	811234	20000	211080	19800	410146	42733.33	510495	42733.33	611391	13000	511547	28400	710266	25533.33	711627	23000	712662	46000	911750	46000
R 5	Corner of old tailing	811262	8333.333	211153		410067	25533.33	510511	22666.67	611335	23000	511513	19800	710198	37000	711832	22000	712690	62000	911656	50000
R 5	Corner of old tailing	811228	19000	211116	16933.33	410153	16933.33	510407	25000	611381	34133.33	511592	16933.33	612021	22666.67	711777	11200	712766	30000	911552	30000
R 5	Corner of old tailing	811258	26000	211171	22000	410173	19800	510448	16933.33	611325	22666.67	511540	14066.67	710019	39866.67	711610	37000	712727	42000	911573	27000
R 6	Old tailings dam road	811248	22000	211066	16933.33	410069	11200	510573	22666.67	611344	19800	511518	30000	710180	17000	711782	17500	910101	34000	911539	32000
R 6	Old tailings dam road	811134	20000	211089	108000	410097	22000	510560	19800	611398	22666.67	511554	28400	710166	14066.67	711801	20000	712813	39000	911513	44000
R 6	Old tailings dam road	811245	19000	211117	5466.667	410065	14066.67	510572	28400	611429	16933.33	610069	19000	611990	19000	711874	13000	712699	32000	911617	22000
R 7	New Slimes Dam	811153	20000	211068	14066.67	410059	19800	510409	19000	611399	25533.33	511566	25533.33	710257	19800	711658	20000	910198	44000	911482	33000
R 7	New Slimes Dam	811218	39600	211146	92000	410123	19800	510471	29000	611479	124000	610090	33000	710247	24000	711802	26700	910093	37000	911662	21000
R 7	New Slimes Dam	811252	20000	211149	28400	410126	34133.33			611478	35000	511530	18000	710298	24000	711796	19800	910025	40000	911555	28000
R 8	Elvis Farm House	811223	34000	211050	25533.33	410075	8333.333	510423	28400	611303	23000	511593	16933.33	710015	24000	711868	11200	712737	36000	911810	23000
R 8	Elvis Farm House	811159		211109	11200	410162	22666.67	510556	19000	611408	14066.67	61004		710350	42000	711820	15500	910183	32000	911654	34000
R 10	Kalbasfontein Tuckshop	811213		211073	37000	410186	21000	510581	25533.33	611370	13500	511542	28400	710152	45000	711779	18000	910021	33000	911702	37000
R 10	Kalbasfontein Tuckshop	811235		211183	19000	410178	19800	510516	24000	611316	28400	511585	27000	710273	35000	711764	14066.67	712787	59000	911669	41000
R 11	Elandfontein	811249	25000	211174	19800	410119		510542	31266.67	611377	16933.33	511528	25533.33	710171	39866.67	711756	21266.67	910099	36000	911570	41000
R 11	Elandfontein	811225	18000	211156		410113		510491	18000	611464	25533.33	511536	25533.33	710158	29000	711557	58000	910002	54000	911842	57000
R 12	Hillshaven Primary School	811212		211128	25533.33	410062	14066.67	510513	42733.33	611435	63000	511582	42733.33	710218	33533.33	711753	19800	712793	22000	911856	22000

Location	Description	January		March		April		June		July		August		September		October		November		December	
		RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results
		Bq.h.m ⁻³																			
R 12	Hillshaven Primary School	811251		211185	8333.333	410112	25533.33	510436	14066.67	611459	25533.33	511560	71400	710229	27000	711684	14000	712740	39000	911591	20000
R 13	Ezulwini Junction	811269	16933.33	211049	28400	410188	25533.33	510571	30000	611359	14066.67	511516	20500	710032	18000	711693		712803	#N/A	911761	23000
R 13	Ezulwini Junction	811246	26000	211133	16933.33	410142	28400	510484	21000	611425	14066.67	511529	25533.33	710085	16500	711800		712762	#N/A	911822	19000
R 14	Leeuspruit S11B	811243	19800	211164	19800	410180	28400	510473	41000	611482	39866.67	511589	20000	710153	59000	711622	26000	712682	55000	911485	42733.33
R 14	Leeuspruit S11B	811139	123000	211091	11200	410179		510549	24000	611334	51333.33	610034	31266.67	710199	21500	711619	25133.33	910182	52000	911502	23000
R 15	Hillshaven Flats	811219	21000	21139		410048		510489	22666.67	611309		511557		710202	8333.333	711594		712645	#N/A	911529	24000
R 15	Hillshaven Flats	811238	24000	211088	28400	410070		510543		611355		511550		710122	16933.33	711871		712689	#N/A	911572	29000
R 16	Waterpan Farm			211112	39000	410125		510575		611306		511565	30000	710172	22000	711697		712649	#N/A	911525	22000
R 16	Waterpan Farm			211168	28000	410127	33000	510428		611379		610077	30000	612004	42733.33	711730		712807	#N/A	911512	26000
R 17	Sewage			211129	11200	410052	16933.33	510592	16933.33	611383	16933.33	511595	22666.67	710040	36000	711857	22666.67	910006	23000	911578	19800
R 17	Sewage			211131	28400	410145	19000	510488	25533.33	611329	22666.67	511539	34133.33	710016	15500	711763	16933.33	910164	34000	911876	26000
R 17	Sewage									611527		511545	42733.33	710042	32000	711650	21000	910080	38000	911846	39000

Table B 2 Environmental radon concentrations measured at the South Deep Gold Mine in 2015.

Location	Description	January		February		March		April		May		June		July		August		September		October		November		December	
		RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results	RGM No.	Results
R 1	Orion Peach Farm	910828	23000	210055		210761	27500	211602	41000	510280	27000	510852	39000	610069	22000			611418	45000	710116	52000	710972	22000	810173	
		910794	35000	210083	22666.67	211054	21000	211601	39000	510349	19000	510094	29500	610031	26000			611505	33000	710188	37000	710849	14200	810362	
R 2	New tailing dam next to the road SD 10	911005	12000	912403	14000	210885	27000	211392	49000	510364	23000	511072	40000	610118	32000	611022		611369	33000	710213	18425	710858	28400	810431	29000
		910871	39866.67	912356	140667	211001	17000	211571	43000	510766	33000	510935	46000	610956		610753		611607	42000	710150	19650	710855	21000	810424	18900
		910915	15000	210021	16933.33	211103	16933.33	211452	26000	510419	29000	511023	57000	610094	29000	610737		611472	33000	710400	19600	710875	28400		
R 3	Perseus Modderfontein Veggie Farm	911083	49000	210019		210800	21000	211458	29000	510272	43000	510968	63000	610986		610931	21000	611332	19700	710189	25000	710263		810128	18250
		911029		210131	14000	210898	18000	211346	22000	510332	31000	510094	60000	610153	26000	611009	31000	611057	23000	710008	27000	710031	35000	810124	19650
R 4	Thursand House No. 24	910876	13000	210078	26000	210992	24000	211297	20000	510026	31000	510886	26000	610039	23000	610897	19750	611398	78000	710507	40000	79994	28000	810425	78000
		910997	16900	912322	19000	211004	24000	211314	33000	510130	30000	510857	71000	610939		610868	29500	611609	38000	710276	28000	710300		810395	32000
R 5	Corner of old tallings	911145	25000	912378	13800	210807	23000	211491	28000	510072	45000	510878	37000	610953		611014	23000	611363	48000	710053		710805	19844.44	810277	26000
		910911	19000	210020	14066.67	210888	18000	211614	27000	510307	26000	510743	40000	610953		610710	22000	611436	39666.67	710044		710876	19000	810272	
		911064	22000	210170		210757	22000	211185	29000	510231	20000	510980	45000	610046	29000	610978	22000	611511	32000	710056		710009		810163	
R 6	Old tallings dam road	910878	15000	210139		210924	20000	211605	30000	510036	31000	510819	46000	610145	28000	611048	20250	611591		710077	42000	710033	24000	810084	21000
		910999		912327	13000	210926	22000	211378	27000	510150	31000	510759	51000	610991		611066	20000	611243		710109	61000	799960	22000	810475	18950
		911137	12000	210018	17000	211091	20000	211451	39000	510120	30000	510860	76000	610980		610847	33000	611546		710139	35000	710829	24000	810232	22666.6

Location	Description	January		February		March		April		May		June		July		August		September		October		November		December	
		RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results
		kg m^{-3}																							
		911045	47000	210034	140666.67	211070	20000	211301	20000	510123	23000	510771	55000	511835	30000	610957	19500	611552	25500	710163	19650	710971	22000	810271	31000
		911139	34133.33	210245	250000	210889	18000	211530	39866.67	510259	23000	510822	37000	610986	20916.67	610986	20916.67	710168	25000	710798	16976.67	810483	34000		

Table B 3 Environmental radon concentrations measured at the South Deep Gold Mine in 2016.

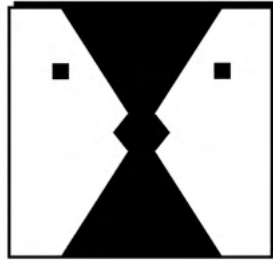
Location	Description	January		February		March		April		May		June	
		RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results
		Bq.h.m ⁻³											
R 1	Orion Peach Farm	910372		210489		310272	20000	311540	29000	49959	31000	410750	32000
		910282		210382		310072	24000	311531	25000	49987	38000	411012	35233.33
		910408	22700	210477	32000	310047	28000	311541	37000	49924	43000	410735	31000
R 2	New tailing dam next to the road SD 10	910363	23000	210436	24000	310215	53000	311591	30000	410065	23000	410649	20000
		910334	27000	210402	28000	39995	26500	311518	17266.67	49955	22000	410810	22000
		910485	28000	210424	28400	310227	26433.33	311597	25000	410056	22000	411036	19000
R 3	Perskes Modderfontein Veggie Farm	910250		210485	19800	310142	33000	311580	27000	410083	27000	410972	27000
		910261	31000	210434		39885	23000	311581	28000	311669	29000	410704	22000
		910197		210440	42000	310119		311552	26000	49989	38000	410831	29000
R 4	Thusanong House No.24	910428	26000	210437	54000	310089	30000	311568	19000	410175	20000	410709	14436.67
		910490	22338.75	210388	20000	39930	32000	311526	22000	410188	17300	410910	20000
		910443	31200	210519	20000	310121	61000	311543	19000	410040	17650	410786	31000
R 5	Corner of old tailings	910441	37000	210523	17250	310221	18950	311559	18000	49984	17650	410711	33000
		910366		210383	30000	310204		311593	22000	410075	26000	410980	24000
		910464	26000	210545	28000	310018	28000	311576	23000	410094	18000	410868	27000
R 6	Old tailings dam road	910219		210528	25533.33	39911	40000	311590	26000	311721	31000	410840	37000
		910515	27000	210560		310000	32000	311594	32000	410029	24000	410871	24500
		910343	23000	210365	28000	310214	25000	311523	20000	311697	29000	410815	21000
R 7	New Slimes dam	910505	23000	210457	17250	39986		311513	16340	410013	20000	410997	18500
		910288	31000	210573	22000	310145		311561	17000	410183	28000	410684	25000
		910392	36000	210426	17273.33	310172		311545	16340	410035	25000	410762	22000
R 8	Elvis Farm House	910458	26000	210371	31000	39899	44500	311525	20377.78	410208	17650	410693	23000
		910397	23000	210368	18650	310063	18600	311588	19000	410122	24000	410729	17000
		910378	20650	210524	34000	310100	34000	311544	36000	410126	35000	411013	30000
R 9	Elvis plot	910368	30500	210487	19466.67	39900	18926.67	311534	35000	311723	47000	410770	30000
		910223	22000	210420	29500	310192	23000	311566	29000	410201	16600	410957	30000
		910381	26000	210380	18300	39917	17200	311583	23000	311698	29000	410795	20000
R 10	Kalbasfontein Tuckshop	910421	24000	210427	21000	39900	18926.67	311585	22000	410085	29000	410691	38000
		910190	23000	210384	38000	310192	23000	311549	31000	311705	27000	410819	29000
		910201	20650	210367	17950	39917	17200	311542	27000	49998	30000	410790	19000

Location	Description	January		February		March		April		May		June	
		RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results
		Bq.h.m ⁻³											
R 11	Elandfontein			210572	18300	310014	28000	311587	19000	410145	25000	410821	33000
				210550	25000			311586	22000	410156	20000	410716	24000
				210387		310213	30000	311599	28000	49961	27000	410853	26000
R 12	Hillshaven Primary School	910354		210495		39897	27000	311565	22000	410084	16950	410685	19000
		910213	24000	210493		310253	20000	311579	19000	410215	23000	410806	26000
		910444	36000	210563	18591.67			311596	19000	410207	17650	410761	26000
R 13	Ezulwini Junction	910340	28400	210490		310013	50000	311527	25000	410216	17650	410899	16000
		910251		210417		39950	48466.67	311530	16340	410127	19000	410655	16000
		910506		210370	17250	310205	17550	311567	15680	410023	21500	410866	16000
R 14	Leeuspruit S11B	910380		210404	53000	310259		311575	40000	410182	26000	410874	
		910313		210570	32000	39979		311517	44000	410172	42000	410860	
		910202		210372		310076		311558	37000	410090	33000	410934	
R 15	Hillshaven Flats	910402		210492	28000	310120	20000	311521	16670	49981	22000	410782	26000
		910271	37000	210507		310073	22666.67	311589	16340	410124	18000	410753	21633.33
		910418	25000	210413	18300	39888	58000	311582		410064	16950	410669	14600
R 16	Waterpan Farm	910477	23000	210389	26000	310099		311600	19800	410025	28000	410720	24000
		910395		210472		310038	23000	311546	22500	410008	22000	410765	31000
		910309	28400	210533		310104	47000	311577	27000	410071	26000	410926	24000
R 17	Sewage	910335		210423		310092	25533.33	311515	21000	311670	35000	410778	19000
		910491	27000	210375	22500	210003		311598	16340	311726	28000	410933	18000
		910367	19576.67	210403	16550	310202	27000	311548	22700	49930	16950	410710	30333.33
R 18	Smith Farm	910399		210576	22666.67	310068				410033	17650	410680	16000
		910291	26500	210460	20000	39992				410163	16250	410672	25000
		910472	25000	210458		310188				410005	17300	410928	36000
R 19	Doornpoort 2	910287	35000	210419	18300	310216	41000	311537	25000	410168	203600	410719	20000
		910231	29000	210391	18650	310244	37000	311532	16681	410036	27000	410989	25000
		910511	29000	210499	16200	310212	19300	311536	15680	410002	16950	411008	24177.78
R 20	Doornpoort 1	910206	29000	210422	18300	310206	44000	311538	21000	49937	17650	410732	15825
		910344	24000	210400	19266.67	310090	24000	311524	16340	410198	22000	410856	28000
		910299	23000	210415	20000	39944	36000	311555	18000	49963	22500	410917	26000

Location	Description	January		February		March		April		May		June	
		RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results	RGM No:	Results
		Bq.h.m ⁻³											
R 21	TWIN SHAFT	910194	26000	210544	19800	310060	35000	311569	20000	410106	21000	410837	14950
		910504	21000	210558	28000	39924	34000	311550	25000	410246	24000	410748	15300
		910205		210546	28000	310160	18250	311573	15086	49956	24000	410712	22000
R 22	WASTE ROCK	910469	29000	210516	18650	310022	32000	311520	16670	410010	26000	410737	16000
		910350	37000	210439	28000	310051	39000	311562	21000	410157	20000	410830	15300
		910337	27500	210451	21500	310042	37000	311557	21000	49962	16600	410798	23133.33

Human interactions with the environment: South Deep Operations

Social Research Study



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Executive Summary

The South Deep Operations are located in a rural area near the town of Westonaria close to the N12 and the R28. The closest residential areas are Glenharvie and Hillshaven, as well as Thusanang, an informal settlement. The mine is surrounded by farms and is in an area where a number of other gold mining companies are operating. The first study exploring human behaviour in relation to the different pathways of exposure in the communities surrounding the mining activities of Gold Fields' South Deep Operations as conducted towards the end of 2016. From the available information it appears that very little has changed in the area, except for large-scale retrenchments that took place at South Deep towards the end of 2018. A downward trend in employment in the gold mining industry over the past decade and retrenchments at gold mining companies during this time resulted in greater unemployment in the area which in turn led to increased levels of poverty in the area. As such the community groups in the area can be considered as more vulnerable than when the 2016 study was conducted.

Table 1 give a summary of the results of the report.

Table 1: Summary of characteristics of different groups under investigation.

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
<i>Location</i>	Hillshaven Glenharvie	Thusanang	Areas around mine	Thusanang
<i>Population distribution</i>	Hillshaven and Glenharvie – not known, but it appears that the majority of residents belong to the Black population group.	All from Black population group.	The majority of the commercial farmers belong to the White population group, while the all the emerging farmers belong to the Black population group.	All from Black population group.
<i>Family structure</i>	Not known for all the areas, but most likely family groups in Hillshaven and Glenharvie.	Mix between families and adults that live alone, or with a family member, friend or partner.	Mixed. The farmers mostly live on the farm with their families. Most of the farm workers that live on the farm, live alone. On some farms there may be farm workers living with their families.	As per the area where they live.
<i>Community activities</i>	Most likely similar to previous report: Hillshaven – people do not spend a lot of time outside. Children play outside or practise sport for about an hour. Teenagers tend to wander in the street. Many people socialise at a tavern or close to the filling station. Not many people observed outside. Glenharvie – not known. Most likely similar to Hillshaven.	People spend time outside gardening, drinking, socialising, gambling, occasionally hunting. Small children play in the streets.	People spend the whole day outside, busy with farming activities.	Most of the day outside.
<i>Access to water</i>	Access to piped water inside dwelling.	Access to a tap outside the yard in the street. Water that is pumped from Hillshaven is kept in tanks.	Boreholes and rainwater tanks.	As per area where they live.
<i>Energy sources</i>	Electricity. Alternative energy sources for lighting (mostly due to financial constraints) are	Energy for lighting – paraffin, candles and solar panels. Generators to run equipment such as TV's.	Electricity. Wood sometimes used for cooking and heating.	As per the area where they live.

	paraffin and candles. Alternative sources for cooking are paraffin and gas, while wood is an alternative source of energy for heating.	Energy for cooking – paraffin, wood, gas, corn cobs, solar devices. Energy for heating – wood.		
<i>Refuse removal</i>	Refuse removed by municipality or private company.	Refuse removed by municipality or burnt by residents.	Varies. Some remove to landfill, others burn or bury.	As per the area where they live.
<i>Sanitation</i>	Flush toilets connected to sewerage system.	Pit toilets without ventilation, flush toilets connected to septic tanks or no toilet facilities.	Flush toilets connected to septic tanks or French drains.	As per the area where they live.
<i>Dwellings</i>	Hillshaven – brick structures with mostly tiled roofs Glenharvie – brick structures with mostly zinc roofs (except in newly built area)	Zinc structures.	Brick structures with tiled or zinc roofs.	As per the area where they live.
<i>Source of food</i>	Mostly shops, in areas with high poverty people tend to grow their own food. Most likely similar to previous report. Previously some residents got milk from dairy farm in area	Spaza shop Own vegetable garden / food garden in community Roots and small game from field	Shops in town Meat mostly from farm Vegetables from shop in town, own vegetable garden, farmer in area Farm workers source roots and plants as well as small game from field	As per area where they live
<i>Food production</i>	Most likely similar to previous report: Low incidence of food gardens in Hillshaven and Glenharvie, but there is a high incidence of fruit trees. Root vegetables: turnips, beetroot, carrots, onions, potatoes. Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, maize, pumpkin, tomatoes Fruit trees: peach, apricot, lemon, fig, prickly pear, grape, mulberry, loquat,	Most likely similar to previous report: High incidence of food gardens. Root vegetables: turnips, beetroot, carrots, onions, potatoes, sweet potatoes Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, beans, maize, pumpkin, tomatoes, peppers, chillies Fruit trees: peach, loquat, fig	Most likely similar to previous report: Commercially farmers grow maize, beans, soya and sunflower. One farmer grows spinach, cabbage and watermelon commercially. Another farm has an orchard that they intend to use commercially (not known whether this has materialised). Feed for livestock grown include sorghum, oats, sugargraze and babala.	As per area where they live.

	plum, apple, mango, avocado		Vegetables for own use: Root vegetables: turnips, beetroot, carrots, onions, shallots, kale chou moullier, potatoes, sweet potatoes Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, beans, pumpkin, tomatoes, chillies Fruit trees: peach	
<i>Categories of food</i>	Most likely similar to previous report: Most food are store bought. A dairy farm from the area delivered milk to Hillshaven. Some people in Hillshaven nought vegetables from people in the community with food gardens. In Glenharvie hawkers sold vegetables and live chickens.	Most likely similar to previous report: Many residents made their own steamed or baked bread. Vegetables were sourced from their gardens when available and there were a vegetable truck that visited the community. Vegetables like onions, spinach, tomatoes and potatoes were consumed daily. Chicken were consumed about once a week and were sourced from a farm in the area. Other vegetables consumed once a week or more, but not daily, included beans, pumpkin and sweet potato. When a vegetable was in season, more would be consumed at the time, but not necessarily during the rest of the year, such as maize. Some harvested medicinal plants such as roots, aloes and African potatoes. Some hunted and would consume	Most likely similar to previous report: Eating habits vary. Some farmers consumed red meat, milk, eggs, spinach, cabbage, tomatoes, onions, beans, carrots, pumpkin, sweet potatoes and potatoes more than once a week to daily. Other farmers could not afford to eat meat daily, and their food consisted of cabbage, spinach, onions, mealie pap and eggs with chicken more than once a week. Some baked their own bread once or twice a week.	As per the area where they live.

		animals such as rabbits and small antelopes.		
<i>Food preparation</i>	Variety of methods used.	Variety of methods used.	Variety of methods used.	As per the area where they live.
<i>Volume of food</i>	Depends on personal preference In lower income areas it also depends on availability	Depends on availability of food	Depends on personal preference	As per the area where they live
<i>Livestock</i>	Chickens in Hillshaven and Glenharvie.	Cattle, goats, sheep, pigs, chickens and horses	Commercial farmers farm mainly with cattle. Some have sheep. Cattle is for meat and dairy.	As per the area where they live
<i>Social infrastructure</i>	Most likely similar to previous report: Hillshaven - Primary school and two crèches, mobile clinic, supermarket, library at school, small gym, sport facilities at school Glenharvie – Crèches, combined school, play area and sport complex.	Most likely similar to previous report: Crèche, home-based care centre, clinic, sport fields, play area, spaza shops and taverns.	Most likely similar to previous report: In residential areas. Pub, filling station and take-away store in area.	As per area where they live.
<i>Socio-economic status</i>	Most likely similar to previous report: Hillshaven – residents owned or rented dwellings, therefore in most households there were at least one person that was employed. Residents reported high levels of unemployment, especially among youth. Alcohol and drug abuse was a challenge. Glenharvie – not known, but was anticipated to be similar to Hillshaven.	Most people are unemployed and are living under the poverty line.	Varies – some are comfortable, while others battle to make a living.	As per the area where they live.

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1. Introduction

The National Nuclear Regulator regulates all mining activities and it is a legal requirement for mines to be able to indicate that they are not exposing the public to radiological risks above certain levels. Viewed simplistically, the public safety assessment process evaluates the potential radiological impact on members of the public from mining and mineral processing operations.

The most significant pathways through which members of the public can be exposed to radiation originating from mining operations can be generalized as follows:

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

Following a source-pathway-receptor analysis approach, it is not difficult to see that human habits and behavioural characteristics in the vicinity of the mining operations has a direct influence on the level of public exposure and thus on the safety of the mining and mineral processing operation. The human health impact can thus be expressed in terms of a total effective dose, as the sum of all exposure pathways, namely:

- External gamma radiation dose from exposure to contaminated water, soil or air;
- Internal exposure from the inhalation of contaminated air (dust and gasses); and
- Internal exposure from the ingestion of contaminated food, water or soil.

The ideal for determining exposure would be to observe exposure levels of each individual on a real-time basis. Such an exercise is impractical and deemed almost impossible. The alternative approach is to use a modelling approach whereby releases and subsequent migration of radionuclides in the environment is simulated for the mentioned primary and secondary pathways. Human behavioural assumptions would complete the process to calculate the human impact in terms of a total effective

dose. More realistic and representative human behavioural assumptions will contribute to a more defensible safety case.

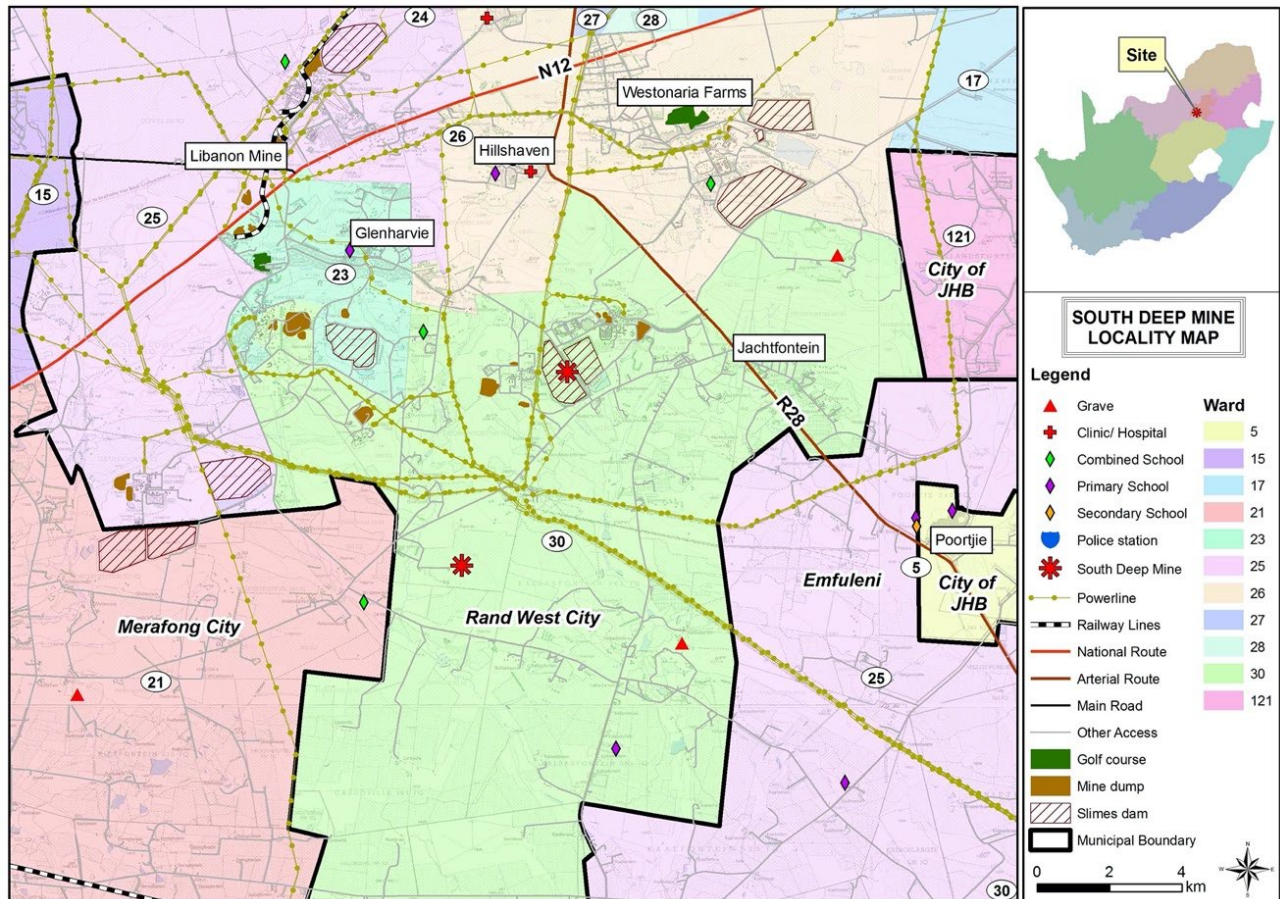
It is with this objective in mind that Aquisim Consulting (Pty) Ltd contracted Equispectives Research and Consulting Services to explore human behaviour in relation to the different pathways of exposure in the communities surrounding the mining activities of Gold Fields' South Deep Operations. This report presents the findings of the second study conducted for this purpose. The first study was conducted in September 2016.

This report will mainly focus on changes that took place in the communities since 2016.

2. Project location

Gold Fields' South Deep Operations (referred to as South Deep in the remainder of the report) are situated in the Gauteng Province in the Rand West City Local Municipality that forms part of the West Rand District Municipality. The Rand West City Local Municipality was established in August 2016 by the amalgamation of the Randfontein Local Municipality and the Westonaria Local Municipality. There are approximately five gold mines in close proximity to the town of Westonaria and the Greater Westonaria consists of a number of satellite towns, namely Westonaria, Hillshaven, Glenharvie, Venterspost, Libanon, Waterpan, Bekkersdal and Simunye. Most of these communities were established in response to mining activities in the area.

South Deep is located in an area that is mainly rural in nature and is mostly surrounded by farms. The mine villages Hillshaven and Glenharvie are located relatively close to the mine, as well as an informal settlement named Thusanang. Sibanye Gold's Kloof and Cooke Operations are the closest other mining operations. Figure 1 shows South Deep in relation to the surrounding communities. South Deep is located in Ward 30 of the Rand West City LM, with Wards 23 and 26 within a 5 km radius from the operations. Ward 21 of the Merafong City is also located within a 5 km radius from the operations.

Figure 1: Location of the South Deep Operations in relation to surrounding communities.

3. Methodology

To meet the objectives of the project, it is not only necessary to have an understanding of the behaviour that takes place in the different communities, but also the extent to which different behavioural activities take place and the level of vulnerability of each community. This is obtained through creating a community profile of each area following a quantitative approach using secondary (existing) data.

Quantitative research as a research strategy usually makes inferences of particular instances by reference to general laws and principles and tends to emphasize what is external to or independent of the mind (objective) and incorporates a natural science model of the research process (David & Sutton, 2004). This approach usually emphasises quantification in the collection and analysis of data. Data collection takes place by using methods such as structured questionnaires and data is recorded in a numeric or some other standardised coding format. Data is expressed in numerical format and statistical techniques are usually used to assist with data interpretation. This approach is used when information needs to be generalised to a specific population and participants are usually selected using probability sampling techniques (although non-probability methods can be used depending on the characteristics of the target population).

For the 2016 study a combination of qualitative and quantitative approaches was used. Interviews, observations and photographs were used, supplemented by data from Census 2011 and Community Survey 2016.

For the 2020 study desktop research using secondary quantitative data from Statistics South Africa was utilised as well as visual comparisons of aerial maps of the area at different points in time. Census 2011 data was used according to the 2016 municipal ward demarcation and compared to Community Survey 2016 data. It must be noted that Community Survey 2016 data does not provide data on ward level, only on municipal level. As such limited comparisons are possible.

Census 2011 was a de facto census (a census in which people are enumerated according to where they stay on census night) where the reference night was 9-10 October 2011. The results should be viewed as indicative of the population characteristics in the area and should not be interpreted as absolute.

Some of the ward boundaries have changed in 2016 after the first report was submitted. StatsSA made Census 2011 data available that is grouped according to the 2016 boundaries.

The following points regarding Census 2011 must be kept in mind (www.statssa.co.za):

- Comparisons of the results of labour market indicators in the post-apartheid population censuses over time have been a cause for concern. Improvements to key questions over the years mean that the labour market outcomes based on the post-apartheid censuses have to be analysed with caution. The differences in the results over the years may be partly attributable to improvements in the questionnaire since 1996 rather than to actual developments in the labour market. The numbers published for the 1996, 2001, and 2011 censuses are therefore not comparable over time and are higher from those published by Statistics South Africa in the surveys designed specifically for capturing official labour market results.
- For purposes of comparison over the period 1996–2011, certain categories of answers to questions in the censuses of 1996, 2001 and 2011, have either been merged or separated.
- The tenure status question for 1996 has been dropped since the question asked was totally unrelated to that asked thereafter. Comparisons for 2001 and 2011 do however remain.
- All household variables are controlled for housing units only and hence exclude all collective living arrangements as well as transient populations.

- When making comparisons of any indicator it must be taken into account that the time period between the first two censuses is of five years and that between the second and third census is of ten years. Although Census captures information at one given point in time, the period available for an indicator to change is different.

For the purposes of this study communities were classified as belonging to one of the following groups:

- Communities living in formal dwellings

A formal dwelling can be described as “A structure built according to approved plans, i.e. house on a separate stand, flat or apartment, townhouse, room in a backyard or rooms or flatlet elsewhere” (Statistics South Africa, 2012). It must be noted that in some areas there may be a formal as well as an informal dwelling on a stand, creating a community with **mixed dwelling types**.

- Communities living in informal dwellings

An informal dwelling can be described as “A makeshift structure not approved by a local authority and not intended as a permanent dwelling. Typically built with found materials (corrugated iron, cardboard, plastic, etc.), and is contrasted with formal dwelling and traditional dwelling” (Statistics South Africa, 2012).

- Commercial agriculture

Commercial agriculture includes farms where the farmer earns a livelihood from agriculture, such as crop, livestock or game farming. Areas with smallholdings are categorised according to their character. If the residents of the smallholdings practise agriculture, they are grouped with commercial agriculture, if they just reside in the area or have a business on the smallholding not related to agriculture, the area is classified as formal residential.

- Small-scale subsistence farming

Small-scale subsistence farming can be described as food gardening taking place on a large scale on a piece of land that is not in someone’s backyard. The land is usually cultivated by different members of the community and they may belong to a formalised group. Food gardens in the backyard of an organisation like a school or crèche would also be grouped in this category. Keeping livestock in the community or on the outskirts of the community would form part of this group.

These groups will be detailed under the discussion of each area.

4. Community profile

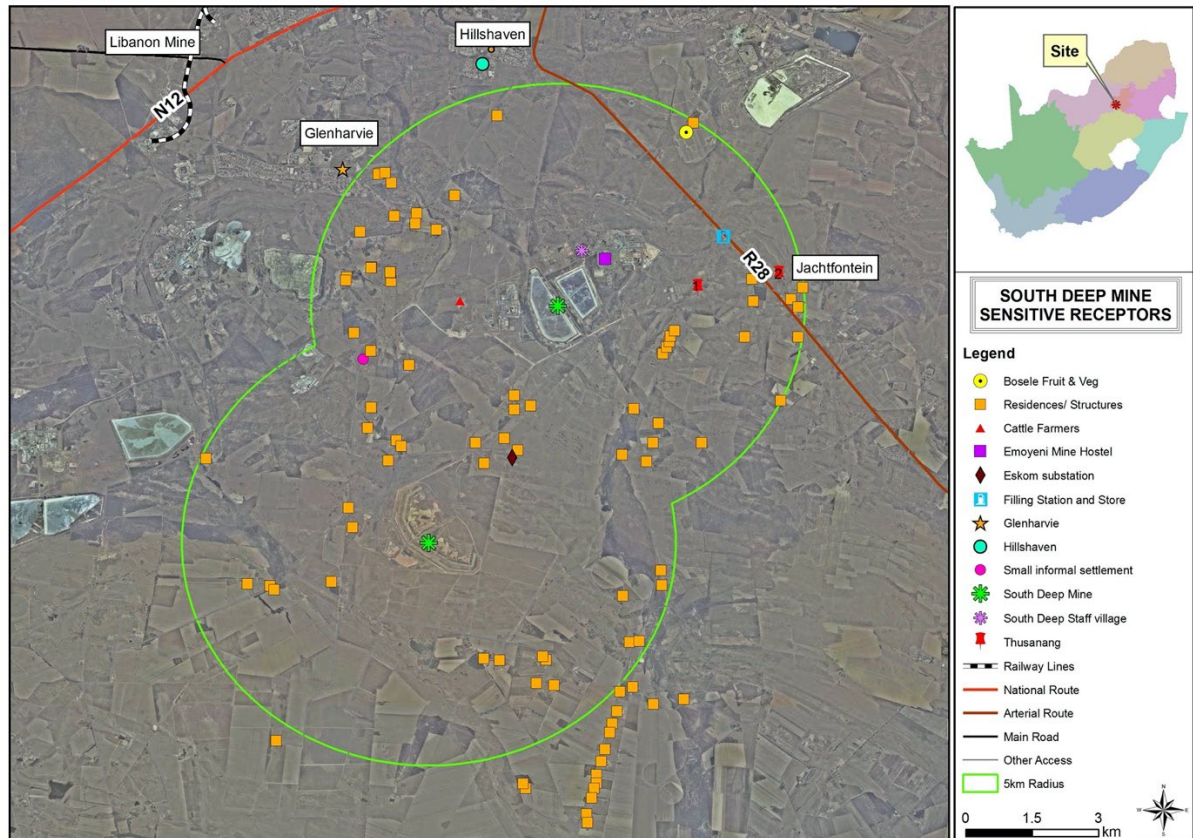
4.1. Location in municipal context

The South Deep Operations are located in a rural area near the town of Westonaria close to the N12 and the R28. There is a small staff village and an employee residence at the mine. In 2016 the mine residence consisted of single and double storey buildings, while the village consisted of small brick houses.

The closest residential areas are Glenharvie and Hillshaven, as well as the Thusanang, an informal settlement. In 2016 Hillshaven was a gated community with one entrance that was access-controlled and according to residents there was a number of houses that still belong to the mine. From recent aerial photography it appears that the community is still access-controlled. Glenharvie was similar in appearance to Hillshaven, with the exception that it was not a gated community and many street hawkers were visible. Thusanang is an informal settlement where almost all the dwellings are constructed of zinc. Aerial photography indicates that the settlement has expanded very little since 2016.

The mine is surrounded by farms. Farm residences consist of clusters of buildings and are scattered throughout the area. The farming community can be categorised in two broad groups, namely commercial farmers, some of which have been in the area for many years, and emerging farmers. On some farms there are dwellings that are rented out to people working in the area while some farm workers commute to work.

Figure 2 shows the location of dwellings and structures in relation to the South Deep Operations that are not located in a town or a village. The number of dwelling groups has remained more or less the same, and only one new dwelling group is observed through aerial photography. At some of the dwelling clusters new buildings have been observed.

Figure 2: Location of dwellings and structures in relation to the South Deep Operations.

Sibanye Gold's Cooke and Kloof Operations are in close proximity to South Deep as well as some of DRD Gold's operations.

Census 2011 has identified the following breakdown for households according to geo types in 2011 (Table 2). Most of the households in the area reside in areas classified as urban. Ward 30, where South Deep is located, is the area with the highest incidence of households living on farms.

Table 2: Geo types (households, source: Census 2011)

Geo Type	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Urban area	4,063,427	268,718	87,426	5,394	3,893	2,495	68,199	2,468
Tribal or Traditional Area	38,860	0	0	0	0	0	0	0
Farm area	62,355	19,564	7,074	0	114	562	2,207	259
Total	4,164,641	288,282	94,499	5,394	4,008	3,057	70,406	2,728

The population in the Rand West City LM showed an increase in population of 1.85% and an increase in households of 9.61% between 2011 and 2016, which is much lower than on provincial level (Table 3) while average household sizes have decreased. In the Merafong City LM the population has decreased, but the number of households showed a greater increase than on district and provincial level. This suggests an increased demand for housing and infrastructure, as well as open space that can be converted to residential areas.

Table 3: Change in population and number of households between 2011 and 2016 (source: Census 2011 and Community Survey 2016).

	Census 2011	Community Survey 2016	Difference
Gauteng Province			
Population	12 272 263	13 399 724	9.16%
Households	4 164 641	4 951 137	18.89%
Average household size	2.95	2.71	
West Rand DM			
Population	820 995	838 594	2.14%
Households	288 282	330 572	14.67%
Average household size	2.85	2.54	
Rand West City LM			
Population	261 053	265 887	1.85%
Households	94 499	103 584	9.61%
Average household size	2.76	2.57	
Merafong City LM			
Population	197 520	188,843	-4.39%
Households	66 624	79,834	19.83%
Average household size	2.96	2.37	

Residents on a provincial, district and local level view the cost of electricity as the main challenge of their local government (Table 4). The lack of, or inadequate, employment is regarded as the second greatest challenge in all areas, except Merafong City where it is regarded as the third greatest challenge. The second greatest challenge in Merafong City is regarded as the lack of a safe and reliable water supply.

Table 4: Main difficulties the municipality is facing (shown in percentage, source: Community Survey 2016).

Main challenge of municipality	Gauteng	West Rand	Rand West City	Merafong City
Lack of safe and reliable water supply	5.61	6.99	3.92	12.38
Cost of water	6.61	7.40	8.75	7.87
Lack of reliable electricity supply	7.18	8.60	9.50	7.74
Cost of electricity	15.22	20.10	20.85	15.08
Inadequate sanitation/sewerage/toilet services	3.21	2.72	1.91	3.13
Inadequate refuse/waste removal	3.12	1.30	0.72	3.39
Inadequate housing	6.81	6.36	6.44	6.22
Inadequate roads	7.85	3.39	5.50	3.51
Inadequate street lights	1.78	1.80	1.73	2.62
Lack of/inadequate employment opportunities	12.62	12.26	12.86	11.67
Lack of/inadequate educational facilities	0.67	0.66	0.76	0.78
Violence and crime	8.08	5.83	7.02	3.76
Drug abuse	4.15	3.58	3.94	0.64
Alcohol abuse	0.86	0.86	1.21	0.29
Gangsterism	0.59	0.72	0.91	1.06
Lack of/inadequate parks and recreational area	0.65	0.72	0.44	0.85
Lack of/inadequate healthcare services	0.80	0.52	0.47	0.93
Lack of/inadequate public transport	0.39	0.31	0.18	0.44
Corruption	2.81	2.37	2.42	1.67
Other	1.86	2.07	1.19	3.43
None	9.11	11.42	9.28	12.58
Unspecified	0.02	0.03	0.00	0.00
Total	100.00	100.00	100.00	100.00

Given the issues mentioned, respondents (CS 2016) were asked to what extent they agree that the municipality is trying to resolve the issue that was mentioned, more than half of the respondents (53.38%) in Merafong City strongly disagreed compared to 46.40% in Rand West City.

4.2. Population distribution

In most wards the majority of the population belong to the Black population group (Table 5). Ward 26, where Hillshaven is located, has the highest proportion of people belonging to the White population group (31.2%). Ward 26 also include Waterpan and a part of Westonaria town. Between 2011 and 2016 the proportion of residents belonging to the Black population group has decreased in the Merafong City LM from 86.52% to 83.43% while the proportion for the White population has increased from 11.79% to 15.07%. In all other areas the proportions have remained more or less the same.

Table 5: Population distribution (persons, source: Census 2011)

Population	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Black African	9,493,684	650,132	205,419	8,235	6,749	4,789	170,897	3,347
Coloured	423,594	20,550	15,368	48	116	12	2,130	942
Indian or Asian	356,574	9,433	990	29	90	7	564	26
White	1,913,884	137,041	37,809	1,307	3,165	465	23,291	4,238
Other	84,527	3,838	1,467	10	11	59	639	82
Total	12,272,263	820,995	261,053	9,630	10,131	5,332	197,520	8,636

In the Gauteng province the most dominant home languages area IsiZulu (19.79%), English (13.28%), Afrikaans (12.45%), Sesotho (11.55%), Sepedi (10.62%) and Setswana (9.06%) (Table 6). On a regional, local and ward level the language profiles vary slightly, with the most dominant home languages being IsiXhosa, Sesotho, Setswana and Afrikaans. In Ward 30 Xitsonga is the third most frequent home language. In Ward 21 of Merafong City most of the residents have Afrikaans as home language. CS 2016 shows that the proportion of residents with Afrikaans as home language has decreased on provincial level, but stayed more or less the same on district level and in Rand West City, but has increased in Merafong City between 2011 to 2016. In Rand West City the proportion of residents with English, Setswana or Xitsonga as home language have increased between 2011 to 2016, while the proportion of residents with IsiXhosa and IsiZulu have decreased.

Table 6: Language distribution (shown in percentage, persons, source: Census 2011)

Language	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Afrikaans	12.45	16.93	19.59	13.91	29.02	9.40	12.83	61.40
English	13.28	6.65	4.48	2.91	6.98	1.68	3.88	5.31
IsiNdebele	3.15	1.07	0.70	0.33	0.60	0.57	0.56	0.26
IsiXhosa	6.60	14.92	16.16	25.41	17.10	29.57	24.86	7.14
IsiZulu	19.79	9.04	7.99	11.85	7.59	8.52	6.34	2.09
Sepedi	10.62	3.07	3.05	1.38	2.05	1.62	1.48	0.57
Sesotho	11.55	10.80	11.77	17.31	12.99	28.00	19.32	11.88
Setswana	9.06	27.33	25.64	5.33	9.18	3.98	21.44	8.39
Sign language	0.44	0.51	0.48	0.47	0.46	1.07	0.59	0.49
SiSwati	1.13	0.92	1.05	5.27	1.95	1.81	1.47	0.45
Tshivenda	2.25	1.44	0.87	1.11	1.79	1.12	0.52	0.25
Xitsonga	6.60	5.22	6.39	12.55	7.23	10.53	5.14	1.23
Other	3.08	2.09	1.85	2.18	3.07	2.12	1.57	0.54
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Since 2011 the gold mining industry has seen large-scale retrenchments which has resulted in an increase in poverty and unemployment in gold mining areas. Traditionally a number of mine workers came from Eastern Cape and KwaZulu Natal where IsiXhosa and IsiZulu are widely spoken and a decrease in the proportion of residents with these languages as their main language can indicate that some of the retrenched mine workers have left the area.

4.3. Family structure

Census 2011 (Table 7) shows that more than half of households on provincial, regional, local and ward level consist of 1 to 2 people, except in Ward 21 of Merafong City where the incidence is just under half. Wards 23 (66.75%) and 30 (69.35%) had the highest incidence of households consisting of only one person. The proportion of single person households has decreased on all levels between 2011 and 2016. In Rand West City the proportion of single person households decreased from 38.04% to 28.29% while in Merafong City it has decreased from 40.11% to 30.72%. This can be indicative of people trying to cut their living expenses by sharing a dwelling. Average household sizes have decreased between 2011 and 2016.

Table 7: Household sizes (households, source: Census 2011)

Household size	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
1	1,297,565	102,274	35,952	3,600	1,862	2,120	28,238	637
2	940,172	60,653	18,781	713	658	400	13,387	694
3	665,019	43,339	13,700	449	477	233	9,677	457
4	559,265	36,449	11,417	348	449	154	8,207	473
5	318,101	20,457	6,505	166	283	67	4,651	233
6	174,213	11,350	3,627	62	144	31	2,737	119
7	91,121	6,235	2,106	32	69	21	1,555	47
8	50,696	3,414	1,073	11	30	22	904	32
9	28,045	1,746	590	3	21	4	422	14
10+	40,445	2,364	748	8	15	7	627	21
Total	4,164,641	288,282	94,499	5,394	4,008	3,057	70,406	2,728
Average household size	2.95	2.85	2.76	1.79	2.53	1.74	2.81	3.17

Census 2011 (Table 8) shows that more than two thirds of households in Rand West City and Merafong City are headed by males. On a ward level this proportion increases to more than three quarters, except in Ward 21 where the proportion is just below three quarters. CS 2016 shows that there has been a slight increase in female-headed households in Rand West City from 30.1% in 2011 to 32.69% in 2016 while the proportion in Merafong City has remained more or less the same. Female-headed households are often financially less well off than similar male-headed households and can be considered as more vulnerable.

Table 8: Sex of head of household (households, source: Census 2011)

Sex of head of household	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Male	2,740,859	200,514	66,069	4,867	3,297	2,604	49,583	2,038
Female	1,421,630	87,604	28,404	526	711	453	20,752	689
Total	4,162,489	288,118	94,473	5,393	4,008	3,057	70,335	2,728

Census 2011 (Table 9) shows a bias towards males on a district, local and ward level, except in Ward 21 that have a more or less equal split between males and females. In Wards 23 and 30 more than two thirds of the population are male. The split between males and females have remained more or less the same between 2011 and 2016.

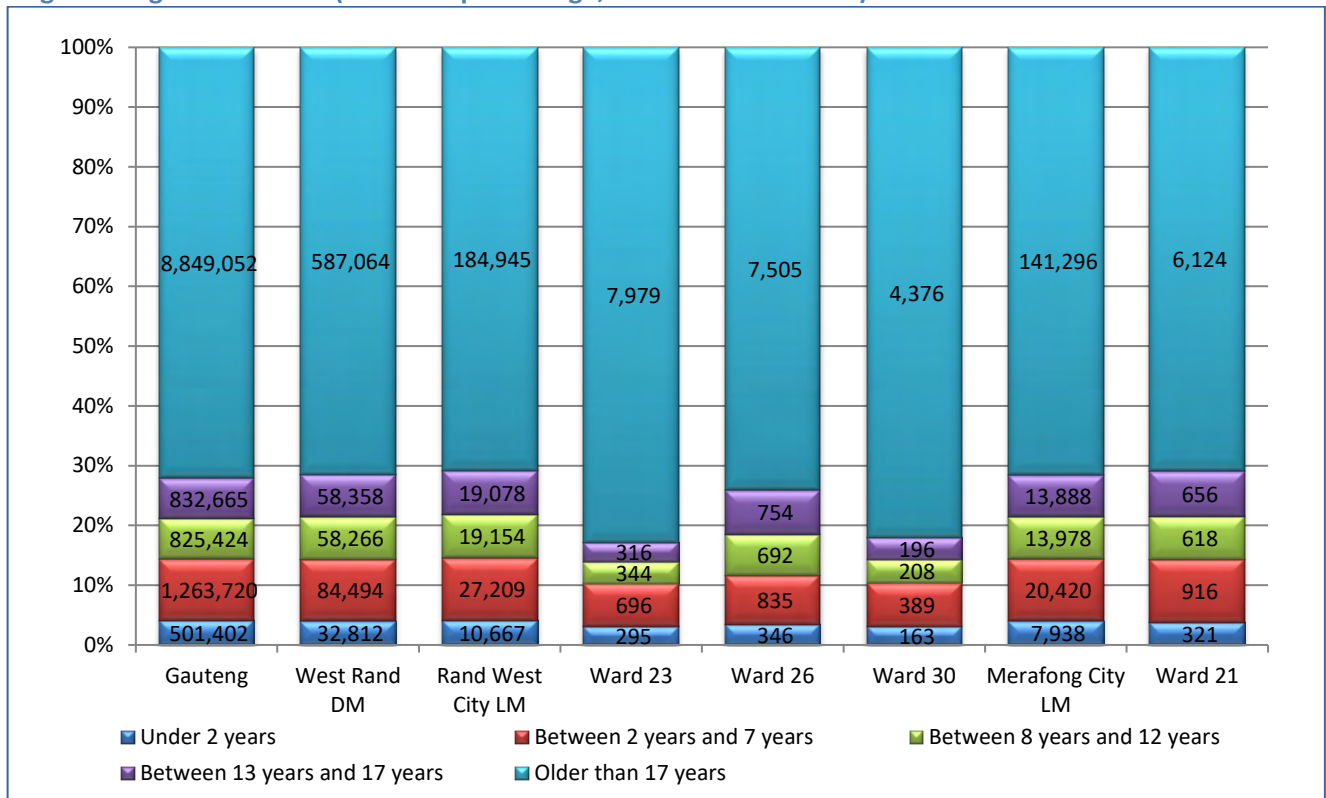
Table 9: Sex distribution (persons, source: Census 2011)

Sex distribution	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Male	6,189,875	428,175	136,038	6,627	5,623	3,594	107,157	4,339
Female	6,082,388	392,820	125,016	3,003	4,508	1,738	90,363	4,297
Total	12,272,263	820,995	261,053	9,630	10,131	5,332	197,520	8,636

Census 2011 shows that Wards 23 and 30 have the highest proportion of people older than 17 years of age while Ward 21 has the lowest (Figure 3). A portion of the town of Fochville is located in Ward 21, but it is more than 10 kilometres away from South Deep. The portion of Ward 21 located within

a 5-kilometre radius from South Deep contains farmland. Between 2011 and 2016 the proportion of people older than 17 years of age in Rand West City and Merafong City have increased slightly, while the proportion of people under 2 years has decreased slightly.

Figure 3: Age distribution (shown in percentage; source: Census 2011).



Child-headed households are considered extremely vulnerable as there is usually no adult that can provide them with food and other necessities and often these households need to rely on the kindness of neighbours and other family members for survival. A child that heads a household often do not have the experience and maturity required to raise his or her siblings and often has to drop out of school to do this. Census 2011 (Table 10) shows that Wards 30 (0.9%) and 21 (0.9%) have the highest incidence of child-headed households with the age of the heads of household between 10 and 19 years. This is still slightly below the incidence on municipal level for Rand West City (1%) and Merafong City (1%). The area with the highest incidence of heads of household that have reached retirement age is Ward 21 (12.7%). Between 2011 and 2016 the incidence of heads of households that are 19 years or younger has increased marginally, but the proportion of household heads that have reached retirement age (65+ years) have increase from 6.9% in Rand West City to 9.0% and in Merafong City the proportion has increased from 6.4% to 7.9%. This suggests that many people stay in the area after they have retired.

Table 10: Age of head of household (persons, source: Census 2011)

Age of head of household	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
10-19 years	42,610	2,529	946	20	18	28	694	24
20-34 years	1,431,254	92,309	30,506	1,916	1,319	1,252	22,139	676
35-64 years	2,297,822	169,506	55,913	3,422	2,495	1,729	42,568	1,651
65+ years	354,795	21,561	6,490	29	163	45	4,485	341
Total	4,126,482	285,906	93,855	5,387	3,994	3,054	69,888	2,692

4.4. Socio-economic status

Census 2011 (Table 11) shows that the employment levels for the economically active part of the population (aged 15-64 years) vary. Wards 23 and 30 have the highest levels of employed people, higher than on local, district and provincial level. In the previous report residents of Hillshaven have indicated that there are high levels of unemployment in the community, especially amongst the youth. In Thusanang most people were unemployed. According to residents there were a high number of illegal immigrants in the community that did not have the required documentation to access services such as health care. It must be noted that large scale retrenchments took place in the gold mining industry since 2012. On a national level the number of direct employees in gold mining has dropped from 142 201 in 2012 to 101 085 towards the end of 2018 (www.mineralscouncil.org.za). At South Deep just over a thousand workers were retrenched towards the end of 2018 / beginning of 2019. As such it is anticipated that the proportion unemployed people in the area have increased since 2016.

Table 11: Employment status (persons aged 15-64 years in age, source: Census 2011, shown in percentage)

Employment status	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Employed	50.59	49.72	49.29	71.82	62.01	66.12	46.51	57.12
Unemployed	18.10	17.78	19.36	12.18	10.38	15.24	17.37	8.71
Discouraged work-seeker	3.36	3.31	3.41	1.63	2.00	1.49	3.47	2.00
Other not economically active	27.96	29.19	27.93	14.38	25.61	17.15	32.66	32.17
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Statistics South Africa (2015) has calculated the Food Poverty Line (FPL) for the Gauteng Province as R339 per capita per month for 2011 where the FPL is the Rand value below which individuals are unable to purchase or consume enough food to supply them with the minimum per-capita-per-day energy requirement for good health. The FPL is one of three poverty lines, the others being the upper bound poverty line (UBPL) and the lower bound poverty line (LBPL). The LBPL and UBPL both include a non-food component. Individuals at the LBPL do not have enough resources to consume or purchase both adequate food and non-food items and are forced to sacrifice food to obtain essential non-food items, while individuals at the UBPL can purchase both adequate food and non-food items.

The LBPL for the Gauteng Province was R523 per capita per month in 2011 and the UBPL R963 per capita per month respectively. More recent poverty lines than the rebased poverty lines for 2011 are not available. Based on this, a household with three members needed an annual household income of approximately R18 800 in 2011 to be just above the LBPL.

Census 2011 (Table 12) shows that Wards 30 and 21 have the highest incidence of households with no income. In Ward 30 almost a fifth of households had no income in 2011 and only 12.7% of households had an annual household income of more than R76 400. In Ward 26 just over 40% of households have an income of more than R76 400, compared to 27.9% in Ward 23 and 46% in Ward 21. In Wards 30 and 21 just over 31% of households earned less than R19 601 in 2011 and as such would be below or just above the LBPL. In Ward 23 approximately 10.1% of households had a household income of less than R19 601 and in Ward 26 the figure was just below 20%.

Table 12: Annual household income (households, source: Census 2011, shown in percentage)

Annual household income	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
No income	17.17	16.08	16.51	4.94	8.24	18.68	15.97	16.87
R 1 - R 4 800	3.39	3.98	4.32	0.61	1.93	2.33	3.99	1.25
R 4 801 - R 9 600	4.85	5.84	6.16	1.83	2.58	3.28	5.88	3.07
R 9 601 - R 19 600	11.50	12.98	12.70	2.71	6.42	7.28	11.12	10.73
R 19 601 - R 38 200	16.77	17.40	17.56	10.86	20.24	22.64	14.94	10.31
R 38 201 - R 76 400	14.52	19.15	20.23	51.11	19.91	33.05	26.43	11.76
R 76 401 - R 153 800	10.71	10.32	10.10	13.88	13.14	8.12	10.99	14.30
R 153 801 – R 307 600	9.06	7.57	7.30	9.54	15.13	3.62	6.58	17.69
R 307 601 – R 614 400	6.98	4.46	3.81	3.27	9.60	0.81	3.01	10.30
R 614 001 – R 1 228 800	3.45	1.54	0.93	0.78	1.96	0.04	0.75	2.88
R 1 228 801 - R 2 457 600	1.06	0.41	0.18	0.27	0.23	0.00	0.19	0.38
R 2 457 000 or more	0.53	0.25	0.18	0.19	0.58	0.15	0.14	0.47
Unspecified	0.01	0.00	0.01	0.00	0.03	0.00	0.00	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Census 2011 (Table 13) shows that Wards 26 (14.53%) and 21 (14.96%) has the highest proportion of people aged 20 years or older that has completed tertiary education while Ward 30 has the highest proportion of people that have only completed their education up to some primary school. Lower levels of education are associated with lower employability and higher levels of unemployment.

Table 13: Highest level of education (persons aged 20+ years, source: Census 2011, shown in percentage)

Education	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
No schooling	3.64	5.20	4.95	6.24	2.34	5.66	6.52	4.84
Some primary	7.41	11.29	12.13	14.22	7.76	20.67	13.98	7.87
Completed primary	3.35	4.90	5.24	5.51	3.57	10.24	6.10	2.90
Some secondary	32.80	37.29	38.91	36.89	34.37	42.66	39.69	34.33
Grade 12/Std 10	34.66	30.66	30.04	29.57	36.78	18.00	26.88	34.72

Higher	17.59	10.33	8.43	7.40	14.53	2.53	6.59	14.96
Other	0.55	0.32	0.31	0.17	0.65	0.24	0.23	0.38
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

CS 2016 (Statistics South Africa, 2016) has reported that the poverty headcount in Merafong City has declined since 2011 (from 8.5% to 6.4%), as did the intensity of the poverty (from 44.5% to 43.6%). There are no combined scores available for Rand West City, but the available scores show that there is a greater level of poverty in the Westonaria part of the municipality than in the Randfontein part. In the Westonaria part the poverty headcount has decreased slightly from 15.4% to 14.9% but the intensity of poverty has increased from 44.5% to 46.7%. In Randfontein the poverty headcount has decreased from 4.9% to 4.2% and the poverty intensity has decreased from 45% to 42.4%. The poverty headcount refers to the proportion of households that can be defined as multidimensionally poor by using the poverty cut-offs of the South African Multidimensional Poverty Index (SAMPI) (Statistics South Africa, 2014), while the intensity of poverty experienced refers to the average proportion of indicators in which poor households are deprived. This suggests a bleaker picture in terms of poverty in the Westonaria part of the municipal area than in 2011.

4.5. Social infrastructure

The infrastructure that households have access to gives an indication of the vulnerability of the residents of a specific area. Lack of infrastructure, or using a specific type of infrastructure, can make residents more vulnerable to interacting with pathways of exposure. The 2019/20 Rand West City IDP indicates that on a municipal level there are currently 168 Early Childhood Centres, 33 primary schools, 12 secondary schools, two FET colleges and one school for the mentally handicapped (IDP 2019/20). In terms of recreational facilities, there are seven sport stadiums, three swimming pools, six community halls, 45 parks, two resorts, 17 libraries and five multi-purpose recreational community centres. There are 19 clinics in the municipal area, but no public hospital.

The previous report has indicated that social infrastructure around the site was fairly limited. There were schools in Hillshaven and Glenharvie. The children in Thusanang were transported by bus to a school at Poortjie. Not all the young children in the area could go to crèche as there were a limited number of crèches in the area. Hillshaven had a mobile clinic and a clinic sponsored by South Deep opened in Thusanang around the time the previous study was conducted. This clinic seems to be still operational. There was no public transport in Hillshaven such as taxis and while there were taxis in Thusanang, residents described them as expensive. There were some sport fields in the area as well as some open space. The area had a high incidence of bottle stores and taverns, but only one

supermarket and a few spaza shops. The closest town, with a greater variety of infrastructure, is Westonaria.

4.6. Community activities

Activities that take place in a community differs from community to community. Based on similar studies over time in other areas, people that live in areas where there are high levels of unemployment tend to spend more time outside. They socialise outside, children tend to play outside for most of the day as many households in these areas cannot afford to send their children for day care. Informal housing tends to be very cold in winter and very hot in summer, and is usually quite small inside, as such these residents prefer to rather be outside. In many lower income areas there are usually make-shift sport fields where residents can play soccer or other sport. Incidences of food gardens in areas with high levels of poverty and unemployment are usually higher than in other areas as many residents do not have the means to buy all their food and a higher proportion of people have time available to tend to a food garden. In the previous report residents have indicated that some of the people in Hillshaven who were unemployed did recycling, washing cars or did piece jobs. Some people cut grass or trees outside the community. The trees were used to make decorative wooden screens. In Thusanang some cleaned the yards of residents at work for payment and some community members played gambling games in an effort to put food on the table. On the farms the farmers and their employees spend most of the day outside, busy with farming activities. CS 2016 shows that 13.14% of people in Rand West City and 14.85% in Merafong City have indicated that they walk to their place of education.

4.7. Access to water

Census 2011 (Table 14) shows that more than 88% of households in the area have access to water from a regional or local water scheme that is operated by the municipality or other water services providers, except in Ward 30 where only 73% of households have access to water from a local or regional water scheme. Just over 10% of households in Ward 30 get their water from a water tanker while 2.6% get their water from a water vendor. The previous report indicated that in Thusanang, that is located in Ward 30, water was pumped from Hillshaven to water tanks in the area and each street had a tap where residents must fetch water, using containers. As the dwellings in Thusanang are still mostly zinc structures, it is unlikely that their source of water has changed to piped water closer to their dwellings since 2016.

Table 14: Sources of water (households, source: Census 2011)

Source of water	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Regional/local water scheme (operated by municipality or other water services provider)	3,877,117	254,983	84,295	5,318	3,832	2,231	64,953	2,423
Borehole	87,692	18,734	6,374	8	0	204	1,530	204
Spring	4,447	303	89	0	4	5	53	1
Rainwater tank	5,823	672	172	1	3	19	307	5
Dam/pool/stagnant water	6,452	722	111	0	6	33	51	6
River/stream	1,950	206	40	0	0	10	23	1
Water vendor	20,259	1,547	363	13	11	78	170	11
Water tanker	72,889	5,945	1,568	9	5	325	1,570	27
Other	88,012	5,171	1,487	45	146	151	1,749	50
Total	4,164,641	288,282	94,499	5,394	4,008	3,057	70,406	2,728

In Wards 23, 26, and 21 approximately more than 70% of households had access to piped water inside their dwellings in 2011 (Table 15), while in Ward 30 just over 20% of households have access to tap water inside their homes. About a third (34.0%) of households in Ward 30 have access to piped water inside their yards. CS 2016 shows that the incidence of households with access to piped water inside the dwelling in Rand West City has increased from 53.0% in 2011 to 55.5% in 2016, while in Merafong City it has increased from 51.0% to 62.1%.

Table 15: Piped water (households, source: Census 2011)

Piped water	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Piped (tap) water inside the dwelling	2,525,607	152,256	50,053	4,128	2,875	654	35,905	1,908
Piped (tap) water inside the yard	1,153,235	85,715	23,977	1,163	1,078	1,040	21,110	576
Piped (tap) water on community stand: distance less than 200m from dwelling	261,629	27,119	11,981	57	15	455	7,775	158
Piped (tap) water to community stand: distance less than 200m and 500m from dwelling	76,428	10,445	5,031	4	12	540	2,558	9
Piped (tap) water to community stand: distance less than 500m and 1000m from dwelling	33,170	4,159	1,483	11	3	264	1,423	5
Piped (tap) water on community stand: distance greater than 1000m (1 km) from dwelling	12,601	1,250	159	0	0	19	390	4
No access to piped (tap) water	76,133	6,025	1,414	13	6	68	893	36
Unspecified	25,839	1,312	401	18	19	17	352	31
Total	4,164,641	288,282	94,499	5,394	4,008	3,057	70,406	2,728

In CS 2016 approximately 9.1% of households in Rand West City and 6.7% in Merafong City have indicated that they do not have access to safe drinking water while about 8.8% of people in Rand West City and 12.6% of people in Merafong City rate the overall quality of water services as poor.

Approximately 22.2% of the households in Merafong City and 5.3% of households in Rand West City have indicated that they have experienced municipal water interruptions in the past three months while 15.0% of households in Merafong City and 2.5% of households in Rand West City have indicated that they had water interruptions that lasted for longer than two days. In Merafong City 40.8% of the households that experienced water interruptions have indicated that they used water from a water tanker, 22.6% an 'other' water source (it is not specified what the alternative sources are) and about 28% used no other alternative water source during interruptions. In Rand West City 27% of the households that experienced water interruptions have indicated that they used water from a water tanker, 27.7% an 'other' water source and about 32.5% used no other alternative water source during interruptions. The majority of people in Rand West City (76%) and Merafong City (80.9%) that do not have access to piped water inside their dwellings or yard, have access to a source of water within less than 200 metres.

4.8. Energy sources

More than 84% of households in Wards 23, 26 and 21 have access to electricity for cooking purposes (Table 16), but in Ward 30 the incidence is only 55.5%. Ward 30 has the highest incidence of households using paraffin (36.7%). Paraffin as an alternative to electricity is usually chosen due to economic circumstances. CS 2016 shows that the incidence of households in Merafong City that use electricity for cooking purposes have increased from 73.6% in 2011 to 83% in 2016. In Rand West City this incidence has remained more or less the same.

Table 16: Main source of energy for cooking (households, source: Census 2011)

Source of energy - cooking	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Electricity	3,447,564	221,110	68,722	5,274	3,881	1,688	51,578	2,284
Gas	124,850	8,590	2,900	14	52	78	1,296	127
Paraffin	498,198	51,561	20,600	67	19	1,117	15,736	199
Wood	25,336	3,655	1,239	6	28	100	869	73
Coal	15,026	469	158	0	2	3	123	0
Animal dung	1,506	125	30	0	1	4	44	0
Solar	6,680	421	128	8	2	1	108	2
Other	13,647	401	90	4	0	6	131	9
None	5,995	638	231	3	3	44	169	2
Total	4,138,803	286,970	94,099	5,376	3,989	3,040	70,054	2,697

For heating purposes, more than 71% of households in Wards 23, 26 and 21 use electricity, but in Ward 30 (Table 17) this incidence is much lower at 55.7%. Almost 30% of households in Ward 30 use paraffin for heating purposes. Ward 21 (8.8%) and Ward 30 (10.5%) have the highest incidence of

households using wood for heating purposes. CS 2016 distinguishes between space heating and water heating and as such the questions are not directly comparable.

Table 17: Main source of energy for heating (households, source: Census 2011)

Source of energy - heating	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 23
Electricity	3,074,370	196,647	60,877	5,261	3,473	1,693	45,407	1,923
Gas	152,160	8,960	2,757	20	127	45	1,171	157
Paraffin	263,700	25,951	10,146	69	22	901	9,819	51
Wood	134,403	20,252	8,146	9	52	320	4,164	238
Coal	102,855	3,839	1,412	0	4	5	862	7
Animal dung	3,859	257	60	2	5	1	71	3
Solar	12,199	537	147	9	4	3	121	4
Other	673	13	4	0	0	0	3	1
None	394,584	30,513	10,550	5	301	71	8,434	313
Total	4,138,803	286,970	94,099	5,376	3,989	3,040	70,054	2,697

Census 2011 (Table 18) shows that more than 93% of households in Wards 23, 26 and 21 use electricity for lighting purposes. In Ward 30 only 57.4% of households have access to electricity for lighting purposes while 27% use paraffin and 13.3% use candles. CS 2016 shows that the incidence of households that use electricity for lighting has increased from 81.6% in 2011 to 86.8% in 2016 in Merafong City while the proportion in Rand West City has remained more or less the same. The usage of candles has decreased from 16.8% in 2011 to 11.2% in Rand West City and in Merafong City the proportion have decreased from 13.5% to 7.1%. In Rand West City the incidence of households using paraffin has increased from 7.4% to 11.0%.

Table 18: Main source of energy for lighting (households, source: Census 2011)

Source of energy - lighting	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Electricity	3,590,552	232,874	70,630	5,284	3,953	1,746	57,182	2,519
Gas	8,874	587	256	3	9	10	95	8
Paraffin	108,510	12,763	6,943	32	5	822	2,957	13
Candles	411,609	39,264	15,814	43	14	405	9,438	146
Solar	9,016	606	175	9	4	6	144	6
None	10,242	877	281	5	4	51	237	4
Total	4,138,803	286,970	94,099	5,376	3,989	3,040	70,054	2,697

The previous report has indicated that there was no electricity in Thusanang, an informal settlement in Ward 30, and that residents use paraffin, candles and solar panels for lighting and for cooking they use paraffin, wood, gas, corn cobs or solar devices. Wood was gathered in surrounding areas. As the area is still informal, it is unlikely that this situation would have changed since.

Some households use one source of energy as their main source, but also use other sources. When considering other sources, CS 2016 shows that 74.1% of households in Rand West City uses electricity, 30.9% uses candles, 25.4% uses paraffin, 11.2% uses gas, 7.0% uses firewood, 1.2% uses

solar, 2.1% uses coal, 2.6% uses a generator, and 22.5% have indicated that they have no access to electricity. In Merafong City 84.0% uses electricity, 22.6% uses candles, 24.0% uses paraffin, 8.6% uses gas, 8.8% uses firewood, 0.7% uses solar, 2.2% uses coal, 1.1% uses a generator, and 12.0% have indicated that they have no access to electricity.

CS2016 indicated that 4.7% of households in Rand West City and 16.5% of households in Merafong City had interruptions in electricity in the three months preceding the survey while 54.6% of those in Rand West City that had interruptions, indicated that it lasted longer than 12 hours compared to 32.1% in Merafong City. In recent times most households with electricity are experiencing interruptions in the form of loadshedding, and as such the CS 2016 figures should be taken as an indication of unscheduled interruptions not mainly due to loadshedding (although it is possible that loadshedding might have contributed). In Rand West City about 48,1% of people rated the quality of electricity supply services as good in CS 2016 while in Merafong City 51.7% of people rated electricity supply services as good.

4.9. Refuse removal

The majority of households in the study area have indicated that they either have their refuse removed at least once a week by the local authority or a private company (Table 19), except in Ward 30 where only about 41.1% of households have their refuse removed at least once a week. The remainder of households in Ward 30 mostly make use of a communal (6.0%) or private (38.8%) refuse dump. In the previous report the farming community have indicated that their refuse removal methods vary with some farmers removing their refuse to a landfill, while others burying or burning it. In Thusanang residents had indicated that many residents burn their refuse as the municipality was not removing the refuse as they were supposed to. CS 2016 indicated that the proportion of households in Rand West City and Merafong City with refuse removal once a week has increased from approximately 74 % in 2011 to just over 79% in 2016. The proportion of households in Rand West City that use communal refuse dumps has increased from 4.4% in 2011 to 5.7% in 2016, while those using their own refuse dumps have decreased from 14.1% in 2011 to 9.0% in 2016. In Merafong City the proportion of households that use communal refuse dumps have decreased from 6.0% in 2011 to 3.6% in 2016 while those using their own refuse dumps have decreased from 9.6% in 2011 to 6.6% in 2016. In 2016 60.4% of residents in Rand West City rated the quality of refuse removal as good while in Merafong City 53.9% rated it as good.

Table 19: Refuse disposal (households, source: Census 2011)

Refuse disposal	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Removed by local authority/private company at least once a week	3,644,916	219,488	69,961	5,233	3,603	1,249	51,926	2,349
Removed by local authority/private company less often	62,091	7,850	2,346	46	155	299	3,239	21
Communal refuse dump	73,340	11,687	4,134	37	149	160	4,195	14
Own refuse dump	254,779	34,518	13,269	38	63	1,180	6,740	260
No rubbish disposal	86,288	11,273	3,704	15	10	94	3,334	49
Other	17,388	2,153	686	8	9	58	620	4
Unspecified	25,839	1,312	401	18	19	17	352	31
Not applicable	-	-	-	-	-	-	-	-
Total	4,164,641	288,282	94,499	5,394	4,008	3,057	70,406	2,728

4.10. Sanitation

Most households in the area have access to flush toilets that are connected to a sewerage system (Table 20), except in Ward 30 (33.9%) where a number of households use pit latrines with ventilation (23.7%), pit latrines without ventilation (12%) or have no access to sanitation (16.4%). The previous study showed that in Thusanang in Ward 30 many households did not have access to toilet facilities and people used the bushes outside the residential areas. Some parts of Thusanang had pit toilets without ventilation or flush toilets connected to a septic tank. CS 2016 shows an increase in both Rand West City and Merafong City in households with access to flush toilets connected to a sewerage system. In Rand West City households with access to flush toilets connected to a sewerage system has increased from 70.4% in 2011 to 73.4% in 2016 and in Merafong City it has increased from 78.3% in 2011 to 85.6% in 2016. In 2016 more than half of households in Rand West City (57.0%) and Merafong City (63.3%) have indicated that the main toilet facility is in the dwelling or house, while 38.9% of households in Rand West City and 34.2% of households in Merafong City have indicated that the toilet facility is in the yard. About a third of the households in Rand West City (33.8%) and Merafong City (39.0%) have indicated that they share their toilet facility with other households. The majority of households in Rand West City (66.9%) and Merafong City (75.4%) have indicated that they maintain the toilet facilities themselves while the municipality maintains the toilet facilities of 21.4% of households in Rand West City and 15.3% in Merafong City. Less than two thirds of households in Rand West City (61.8%) and Merafong City (60.8%) rated the overall quality of toilet/sanitation services as good in CS 2016.

Table 20: Sanitation systems (households, source: Census 2011)

Sanitation system	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
None	49,631	5,683	2,439	4	9	501	811	31
Flush toilet (connected to sewerage system)	3,422,923	217,394	66,500	5,253	3,882	1,035	55,096	2,282
Flush toilet (with septic tank)	94,759	12,621	4,167	34	47	260	1,458	133
Chemical toilet	51,029	4,616	562	17	1	4	442	3
Pit toilet with ventilation (VIP)	99,283	14,217	9,772	2	24	724	1,591	10
Pit toilet without ventilation	304,382	24,334	8,913	53	9	366	9,376	20
Bucket toilet	80,127	5,370	994	4	5	75	396	11
Other	36,669	2,735	751	8	11	75	885	207
Unspecified	25,839	1,312	401	18	19	17	352	31
Total	4,164,641	288,282	94,499	5,394	4,008	3,057	70,406	2,728

CS 2016 shows that the number of households with no access to a sanitation system in both the local municipalities has decreased since 2011, as has the number of households that have pit toilets with or without ventilation, except in Merafong City where the number of households with pit toilets with ventilation has increased slightly. The number of households that uses a bucket toilet that is collected by the municipality has more than tripled. The majority of households in Rand West City (95.8%) and Merafong City (97.5%) have access to toilet facilities within their dwelling or yard.

4.11. Dwellings

The majority of households live in dwellings that are brick or concrete structures (Table 21), such as a dwelling in a separate yard, a block of flats, cluster house or town house in a complex, or a semi-detached house, except in Ward 30 here more than a third of households (35.5%) live in an informal dwelling that is not in a backyard. Thusanang, an informal settlement, is located in Ward 30. The previous study has indicated that most of the dwellings in Thusanang consisted of zinc structures. Aerial photography shows that this still applies.

Table 21: Main dwelling types (households, source: Census 2011)

Dwelling Type	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
House or brick/concrete block structure on a separate stand or yard or on a farm	2,307,719	159,124	47,415	2,657	2,389	1,313	39,776	2,203
Traditional dwelling/hut/structure made of traditional materials	13,719	758	199	5	7	43	137	1
Flat or apartment in a block of flats	280,381	10,682	2,881	155	133	205	4,634	40
Cluster house in complex	85,181	3,197	516	5	20	5	846	15
Townhouse (semi-detached house in a complex)	137,728	3,546	883	1	84	3	204	51
Semi-detached house	45,782	1,252	399	4	11	41	174	11
House/flat/room in backyard	219,100	13,130	5,387	125	252	26	2,867	63
Informal dwelling (shack; in backyard)	305,675	29,108	7,078	5	9	10	3,576	38
Informal dwelling (shack; not in backyard; e.g. in an informal/squatter settlement or on a farm)	434,072	38,629	16,833	45	14	1,045	10,600	13
Room/flatlet on a property or larger dwelling/servants quarters/granny flat	45,031	3,457	799	3	23	10	1,292	13
Caravan/tent	2,903	252	71	1	0	2	36	1
Other	31,534	4,255	936	48	21	243	2,482	6
Unspecified	25,839	1,312	401	18	19	17	352	31
Not applicable	229,977	19,580	10,702	2,322	1,025	94	3,430	240
Total	4,164,641	288,282	94,499	5,394	4,008	3,057	70,406	2,728

CS 2016 shows that the number of households living in formal dwellings or houses on a separate stand has decreased in Rand West City from 56.9% in 2011 to 54.4% in 2016, while in Merafong City it has increased from 59.7% in 2011 to 64.5% in 2016. In Rand West City the proportion of households living in an informal dwelling in a backyard has increased from 8.5% in 2011 to 12.2% while the proportion of households living in an informal dwelling that is not in a backyard has decreased from 20.2% in 2011 to 13.6% in 2016. In Merafong City the proportion of households living in any type of informal dwelling has decreased between 2011 and 2016. In 2016 about a fifth (20.0%) of households in Rand West City and a quarter (24.8%) of households in Merafong City have indicated that they live in RDP or government subsidized dwellings. More than half of those living in RDP or government subsidized dwellings (58.5% in Rand West City and 61.3% in Merafong City) have rated the overall quality of the dwellings as good.

4.12. Food consumption

Food consumption is to a great extent based on personal preferences and beliefs and not only varies between households in an area, but sometimes also within a household. Affordability plays a role in the types and quantities of food consumed. Residents in the study area have not been interviewed

to explore their food consumption and the discussion in this section is based on trends that emerged from similar studies in other areas.

4.12.1. Source of food

In higher-income households residents tend to source almost all their food from formal stores such as supermarket chains, green grocers or butcheries that need to meet certain legal standards to operate. In areas where there are high levels of poverty, such as Thusanang, households tend to buy from informal stores or someone in the area that farm with a specific product such as vegetables, poultry, eggs or milk, or they have their own food garden. In some communities access to, or availability of, water poses a barrier to maintaining a food garden. In some instances access to land can also be a challenge. The previous report has indicated that the school in Hillshaven had a feeding scheme for needy children while in Thusanang residents often did not know where their next meal would come from. Some people harvested medicinal plants such as roots, African potatoes and aloes in the field.

4.12.2. Categories of food

Households in high-income areas tend to consume a greater variety of food products and tend to include processed food to a greater extent (based on personal preferences). Households that live in poverty tend to have meals that underwent very little processing. Bread and/or pap (porridge made of maize meal) is a staple and is usually consumed with vegetables such as tomatoes, onions, spinach or cabbage. Potatoes and beans are also consumed often in some households. Meat is included depending on income, and then it is usually chicken with red meat consumed at special occasions. Some households can only afford chicken once a week or less. Households that live in poverty often do not have access to a fridge and need to choose food that do not require refrigeration and any meat need to be consumed as soon as possible.

4.12.3. Food preparation

Food preparation depends on the dish that is prepared as well as the available facilities. Households that paraffin, wood or coal tend to cook outside at a designated area.

4.12.4. Volume of food

The volume of food consumed depend on personal preference as well as the available means to buy food. CS 2016 indicates that 16.8% of people in Rand West City and 25.3% of people in Merafong City ran out of money to buy food during the past 12 months, while 52.5% of people in Rand West City and 61.6% of people in Merafong City who ran out of money to buy food, ran out of money to buy food for five or more days during the past 30 days. Approximately 11.8% of the population in Rand West City and 18.7% of the population in Merafong City have indicated that they have skipped a meal in the past 12 months, and 56.9% of these people in Rand West City and 63.5% in Merafong City skipped a meal for five or more days during the past 30 days.

4.13. Agricultural activities

Some households in urban areas engage in agricultural activities. Some only for the enjoyment thereof or to produce their own organic food, while for others it is a livelihood strategy. Census 2011 did include questions on agricultural activities, such as where the household operate agricultural activities if they were involved in agriculture, as well as the type of agricultural activities and the number of livestock or poultry kept. The data available in the public domain seems to contain errors and the totals do not match the totals published in a publication of StatsSA on Agricultural Households (on provincial level) using Census 2011 data. The data seems to underreport agricultural activities to a great extent and logic checks between different questions do not hold up. For this reason the Census 2011 data on agriculture is not used in this report.

Similar studies that were conducted in other areas show that urban areas households in areas with high levels of poverty are more likely to engage in agricultural activities, especially if they are located close to open land, which is often found in mining areas or around tailings facilities. The agricultural activity with the highest incidence in these areas is food gardening, that consist mostly of growing vegetables such as spinach, cabbage, onions, tomatoes, beetroot, carrots, potatoes, beans, maize and pumpkin. In many township areas there are a lot of fruit trees, mainly peach and apricot, that were planted some years ago as part of a government project and it may be the case in some of these areas as well. Food gardens are mainly grown in backyards, but those living on the edge of an open space will often use space in this area to grow vegetables or crops on a greater scale. Cattle or goats are usually also kept on the edge of an open space. Most schools in areas with high levels of poverty have food gardens as to provide for the learners to some extent.

The previous report has indicated that the incidence of food gardens was very low in Hillshaven and that there were a small number of residents that were unemployed that grew vegetables for a living.

In Thusanang most people had their own food gardens, but the availability of water and the quality of the soil were challenges. At the time there were approximately 3-4 large food gardens in the area. Root vegetables grown in food gardens included turnips, beetroot, carrots, onions, potatoes and sweet potatoes, while leafy vegetables included lettuce, cabbage and spinach. Other vegetables grown included peas, beans, maize, pumpkin, tomatoes, peppers and chillies. A wide variety fruit trees were found, such as peach, fig, loquat, apricot, lemons, prickly pear, grape, mulberry, plum and apple. Crops grown commercially in the area included maize, beans, sunflower and soya. Sorghum, oats, sugargraze (a sorghum hybrid) and babala (a type of grass) were grown as feed for the cattle while one of the emerging farmers planned to start growing garlic commercially. Vegetables grown commercially in the area included spinach, cabbage and watermelon.

In Thusanang residents kept cattle on the outskirts of the area while other livestock included horses, chickens, ducks, geese and turkeys. In Hillshaven and Glenharvie municipal by-laws did not allow for the keeping of livestock, but some chickens were observed. The commercial farmers farmed mainly with cattle. Some had sheep, but were phasing them out, while one farmer was farming with cattle. The quality of water in the area was a challenge for cattle farmers. One of the emerging farmers had a dairy on the farm and there were plans for a piggery.

In CS 2016 6.5% of households in Rand West City and 8.1% of households in Merafong City have indicated that they are involved in agriculture. Although CS 2016 has asked where the households operate their agricultural activities (farmland, communal land, backyard, etc) and what the main purpose of the activity was, this data was not released in the public domain. A smaller proportion of households in Rand West City (2.4%) and Merafong City (2.2%) have indicated that they own poultry or livestock.

Households in the municipal area have indicated the following involvement in agricultural activities (Table 22):

Table 22: Agricultural activities (households, source: Community Survey 2016)

Agricultural activity	Gauteng	West Rand DM	Rand West City LM	Merafong City LM
Vegetable production	3.22	3.82	3.72	5.34
Grains and food crops (e.g. maize, wheat, beans, sorghum, millet, groundnuts)	0.60	0.72	0.78	1.02
Livestock production (e.g. cattle, goats, sheep, pigs)	0.47	1.01	1.43	1.25
Poultry production (e.g. chickens, ducks, geese, guinea fowl, ostrich)	0.99	1.50	1.69	1.76
Fruit production	0.80	0.59	0.82	0.58

Industrial crops (e.g. tea, coffee, cotton, tobacco)	0.02	0.04	0.03	-
Other	0.17	0.26	0.20	0.09

In terms of the type of farm practice for crop farming, 17.8% of households in Rand West City that farm with crops have indicated that in CS 2016 that they use irrigation, 37.2% use dry land, and 44.9% use both irrigation and dry land. In Merafong City 22.2% of households that farm with crops have indicated that in CS 2016 that they use irrigation, 34.7% use dry land, and 43.1% use both irrigation and dry land.

4.14. Vulnerability

Two broad criteria, namely proximity and level of vulnerability, were used to screen the areas surrounding the mining activities in terms of human behaviour. Proximity to the mining activities is based on the assumption that people who are closest to the mine, as well as the most vulnerable groups closest to the mine have the greatest risk of exposure, and if their exposure is at an acceptable level, so will be the level of exposure of those further away from the mine, or belonging to less vulnerable groups. Households within a 5 km radius from the mining activities were included. Households who live in poverty and are deprived are at a much greater risk of exposure through the dwellings they reside in, services they have access to, food and water sources, etc and as such have a higher level of vulnerability. Children, the aged and people in poor health are also considered vulnerable.

Based on the indicators used in the South African Multidimensional Poverty Index (SAMPI) (StatsSA, 2014), a list of indicators was compiled (using census 2011 data) and an average score was calculated for each ward to determine its level of vulnerability. Some indicators were added as they were deemed important for the project. The lower the average score the higher the level of vulnerability of the specific ward. The following indicators were used:

- Education – persons aged 20 years or older that have not completed high school;
- Energy source for lighting – households using paraffin, candles, wood, other or nothing;
- Energy source for heating – households using paraffin, wood, coal, dung, other, nothing;
- Energy source for cooking – households using paraffin, wood, coal, dung, other, nothing;
- Access to water – no piped water in dwelling or stand;

- Water source – not regional or local water scheme (borehole, spring, river, stream, dam, water tank, vendor, etc);
- Sanitation – no flushing toilet;
- Dwelling type – Informal dwelling;
- Unemployment – adults who are unemployed and discouraged work-seekers;
- Those not economically active (as they are likely to spend more time outside);
- Child-headed households – households headed by children aged 10-19 years;
- Aged heads of household – households with heads aged 65 years and older.

Table 23 shows the proportions of households or persons in each ward that meet the criteria for each indicator.

Table 23: Vulnerability indicators (source: Census 2011, shown in percentage)

Vulnerability Indicator	Gauteng	West Rand	Rand West City	Ward 23	Ward 26	Ward 30	Merafong City	Ward 21
Education	81.86	89.35	91.26	92.44	84.82	97.23	93.18	84.66
Lighting	13.03	18.64	24.75	1.54	0.80	42.38	18.17	6.34
Heating	21.75	28.17	32.22	1.59	9.63	42.73	33.34	22.72
Cooking	13.52	19.81	23.75	1.49	1.35	41.87	24.37	10.51
Access water	11.66	17.45	21.66	1.92	1.36	44.58	19.02	8.92
Water source	6.90	11.55	10.80	1.42	4.37	27.00	7.74	11.18
Sanitation	15.53	20.21	25.22	1.99	1.96	57.65	19.67	11.48
Dwelling type	18.93	25.33	28.67	1.66	0.77	35.82	21.28	2.08
Unemployment	21.45	21.09	22.78	13.80	12.38	16.73	20.84	10.71
Not economically active	27.96	29.19	27.93	14.38	25.61	17.15	32.66	32.17
Child-headed	1.03	0.88	1.01	0.37	0.44	0.93	0.99	0.89
Retired headed	8.60	7.54	6.91	0.54	4.07	1.49	6.42	12.66

The most vulnerable ward in the study area is Ward 30, the ward where South Deep is located. This ward consists mostly of farms and Thusanang is the only residential area in the ward. South Deep is surrounded by farmland and the only portion that does not contain farm dwellings is the area from the north to north east of the operations.

5. Conclusions

The South Deep Operations are located in a rural area near the town of Westonaria close to the N12 and the R28. The closest residential areas are Glenharvie and Hillshaven, as well as Thusanang, an informal settlement. The mine is surrounded by farms and is in an area where a number of other gold mining companies are operating. The first study exploring human behaviour in relation to the different pathways of exposure in the communities surrounding the mining activities of Gold Fields' South Deep Operations as conducted towards the end of 2016. From the available information it appears that very little has changed in the area, except for large-scale retrenchments that took place at South Deep towards the end of 2018. A downward trend in employment in the gold mining industry over the past decade and retrenchments at gold mining companies during this time resulted in greater unemployment in the area which in turn led to increased levels of poverty in the area. As such the community groups in the area can be considered as more vulnerable than when the 2016 study was conducted.

Table 24 give a summary of the results of the report.

Table 24: Summary of characteristics of different groups under investigation.

Characteristic	Formal urban settlement	Informal urban settlement	Commercial farmers	Subsistence farmers
<i>Location</i>	Hillshaven Glenharvie	Thusanang	Areas around mine	Thusanang
<i>Population distribution</i>	Hillshaven and Glenharvie – not known, but it appears that the majority of residents belong to the Black population group.	All from Black population group.	The majority of the commercial farmers belong to the White population group, while the all the emerging farmers belong to the Black population group.	All from Black population group.
<i>Family structure</i>	Not known for all the areas, but most likely family groups in Hillshaven and Glenharvie.	Mix between families and adults that live alone, or with a family member, friend or partner.	Mixed. The farmers mostly live on the farm with their families. Most of the farm workers that live on the farm, live alone. On some farms there may be farm workers living with their families.	As per the area where they live.
<i>Community activities</i>	Most likely similar to previous report: Hillshaven – people do not spend a lot of time outside.	People spend time outside gardening, drinking, socialising, gambling, occasionally	People spend the whole day outside, busy with farming activities.	Most of the day outside.

	Children play outside or practise sport for about an hour. Teenagers tend to wander in the street. Many people socialise at a tavern or close to the filling station. Not many people observed outside. Glenharvie – not known. Most likely similar to Hillshaven.	hunting. Small children play in the streets.		
<i>Access to water</i>	Access to piped water inside dwelling.	Access to a tap outside the yard in the street. Water that is pumped from Hillshaven is kept in tanks.	Boreholes and rainwater tanks.	As per area where they live.
<i>Energy sources</i>	Electricity. Alternative energy sources for lighting (mostly due to financial constraints) are paraffin and candles. Alternative sources for cooking are paraffin and gas, while wood is an alternative source of energy for heating.	Energy for lighting – paraffin, candles and solar panels. Generators to run equipment such as TV's. Energy for cooking – paraffin, wood, gas, corn cobs, solar devices. Energy for heating – wood.	Electricity. Wood sometimes used for cooking and heating.	As per the area where they live.
<i>Refuse removal</i>	Refuse removed by municipality or private company.	Refuse removed by municipality or burnt by residents.	Varies. Some remove to landfill, others burn or bury.	As per the area where they live.
<i>Sanitation</i>	Flush toilets connected to sewerage system.	Pit toilets without ventilation, flush toilets connected to septic tanks or no toilet facilities.	Flush toilets connected to septic tanks or French drains.	As per the area where they live.
<i>Dwellings</i>	Hillshaven – brick structures with mostly tiled roofs Glenharvie – brick structures with mostly zinc roofs (except in newly built area)	Zinc structures.	Brick structures with tiled or zinc roofs.	As per the area where they live.
<i>Source of food</i>	Mostly shops, in areas with high poverty people tend	Spaza shop Own vegetable garden / food	Shops in town Meat mostly from farm	As per area where they live

	to grow their own food. Most likely similar to previous report. Previously some residents got milk from dairy farm in area	garden in community Roots and small game from field	Vegetables from shop in town, own vegetable garden, farmer in area Farm workers source roots and plants as well as small game from field	
<i>Food production</i>	Most likely similar to previous report: Low incidence of food gardens in Hillshaven and Glenharvie, but there is a high incidence of fruit trees. Root vegetables: turnips, beetroot, carrots, onions, potatoes. Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, maize, pumpkin, tomatoes Fruit trees: peach, apricot, lemon, fig, prickly pear, grape, mulberry, loquat, plum, apple, mango, avocado	Most likely similar to previous report: High incidence of food gardens. Root vegetables: turnips, beetroot, carrots, onions, potatoes, sweet potatoes Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, beans, maize, pumpkin, tomatoes, peppers, chillies Fruit trees: peach, loquat, fig	Most likely similar to previous report: Commercially farmers grow maize, beans, soya and sunflower. One farmer grows spinach, cabbage and watermelon commercially. Another farm has an orchard that they intend to use commercially (not known whether this has materialised). Feed for livestock grown include sorghum, oats, sugargrass and babala. Vegetables for own use: Root vegetables: turnips, beetroot, carrots, onions, shallots, kale chou moullier, potatoes, sweet potatoes Leafy vegetables: lettuce, cabbage, spinach Other vegetables: peas, beans, pumpkin, tomatoes, chillies Fruit trees: peach	As per area where they live.
<i>Categories of food</i>	Most likely similar to previous report: Most food are store bought. A dairy farm from the area delivered milk to Hillshaven. Some people in Hillshaven bought vegetables from people in the	Most likely similar to previous report: Many residents made their own steamed or baked bread. Vegetables were sourced from their gardens when available and there were a vegetable	Most likely similar to previous report: Eating habits vary. Some farmers consumed red meat, milk, eggs, spinach, cabbage, tomatoes, onions, beans, carrots, pumpkin, sweet potatoes and	As per the area where they live.

	community with food gardens. In Glenharvie hawkers sold vegetables and live chickens.	truck that visited the community. Vegetables like onions, spinach, tomatoes and potatoes were consumed daily. Chicken were consumed about once a week and were sourced from a farm in the area. Other vegetables consumed once a week or more, but not daily, included beans, pumpkin and sweet potato. When a vegetable was in season, more would be consumed at the time, but not necessarily during the rest of the year, such as maize. Some harvested medicinal plants such as roots, aloes and African potatoes. Some hunted and would consume animals such as rabbits and small antelopes.	potatoes more than once a week to daily. Other farmers could not afford to eat meat daily, and their food consisted of cabbage, spinach, onions, mealie pap and eggs with chicken more than once a week. Some baked their own bread once or twice a week.	
<i>Food preparation</i>	Variety of methods used.	Variety of methods used.	Variety of methods used.	As per the area where they live.
<i>Volume of food</i>	Depends on personal preference. In lower income areas it also depends on availability.	Depends on availability of food.	Depends on personal preference.	As per the area where they live.
<i>Livestock</i>	Chickens in Hillshaven and Glenharvie.	Cattle, goats, sheep, pigs, chickens and horses.	Commercial farmers farm mainly with cattle. Some have sheep. Cattle is for meat and dairy.	As per the area where they live.
<i>Social infrastructure</i>	Most likely similar to previous report: Hillshaven - Primary school and two crèches, mobile clinic, supermarket, library at school, small gym, sport facilities at school.	Most likely similar to previous report: Crèche, home-based care centre, clinic, sport fields, play area, spaza shops and taverns.	Most likely similar to previous report: In residential areas. Pub, filling station and take-away store in area.	As per area where they live.

	Glenharvie – Crèches, combined school, play area and sport complex.			
<i>Socio-economic status</i>	Most likely similar to previous report: Hillshaven – residents owned or rented dwellings, therefore in most households there were at least one person that was employed. Residents reported high levels of unemployment, especially among youth. Alcohol and drug abuse was a challenge. Glenharvie – not known, but was anticipated to be similar to Hillshaven.	Most people are unemployed and are living under the poverty line.	Varies – some are comfortable, while others battle to make a living.	As per the area where they live.

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