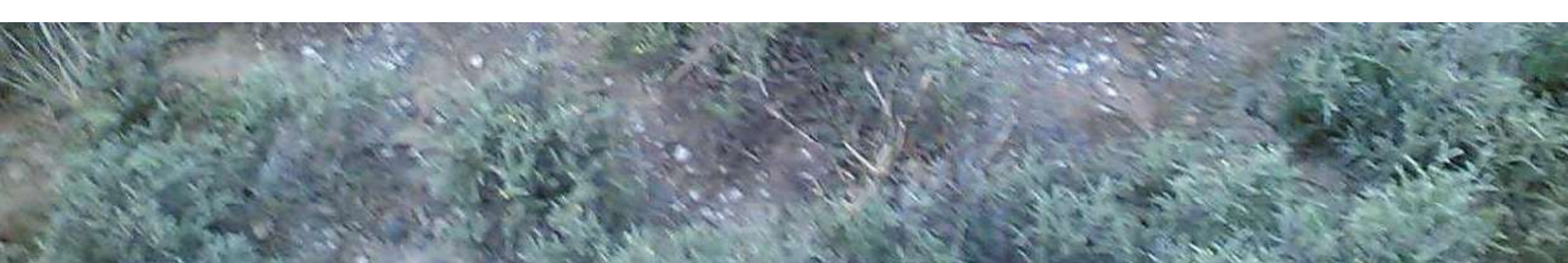
KAROO URANIUM PROJECT

Safety Assessment of Radiation Hazards to Members of the Public



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EXECUTIVE SUMMARY

Tasman Lukisa JV Company (Pty) Ltd (TLJVCO) and Tasman Pacific Minerals Limited (TASPAC) are the applicants for three mining rights applications submitted in terms of Section 22 of the Mineral and Petroleum Resources Development Act, 2002 (MPRDA) for uranium (U) and molybdenum (Mo) in the Karoo, referred to as the Karoo Uranium Project (KUP). The proposed uranium mining project will have multiple ore production centres (open pit and underground mining operations). These centres are designated into four main areas as follows in this report:

- Ryst Kuil consisting of ore production centres named Ryst Kuil Main, Ryst Kuil Extension, Ryst Kuil South and Ryst Kuil Abante, and a Central Processing Plant (CPP) where a tailings storage facility (TSF) will be located adjacent to it;
- Haanekuil ore production;
- Quaggasfontein ore production; and
- De Pannen ore production (Kareepoort).

The ore will be processed at the CPP to be located near the main ore body at Ryst Kuil Main and Ryst Kuil Abante in the Western Cape.

Conventional underground and open pit mining activities produce overburden mineralized waste and barren waste rock, which are generally low in their uranium and thorium contents and are left at the mine site. Economically valuable ore is stockpiled and processed at the CPP site, and the residual waste, mostly mill tailings, is disposed of in a TSF.

The mining and processing of uranium bearing minerals generate a variety of waste materials containing a number of radioactive and non-radioactive hazardous constituents. This waste requires appropriate management. Because some of the radionuclides contained in the various waste streams have long half-lives, the TSF must be effective for a long period of time after mining activities have ended.

Humans and all other living organisms on earth are continuously being exposed to natural background ionising radiation. Activities such as the proposed KUP could potentially add to the levels of existing background radiation and human radiation exposure. This report provides information on the radiological hazard to members of the public as a result of discharges from KUP activities. Liquid and airborne discharges with elevated levels of naturally occurring radioactive material (NORM) may result in low levels of exposure of members of the public by means of various pathways such as:

- external radiation;
- inhalation of radon and its short half-life decay products;
- inhalation of airborne dust;
- consumption of drinking water; and
- consumption of food produce in which bioaccumulation of radioactivity occurred.

The mine design does not allow liquid discharges during normal operations and no additional dose is expected from water exposure pathways. The results of the screening safety assessment of airborne exposure pathways indicate that the additional radiation doses to members of the public at farmsteads in the vicinity of KUP meet the national regulatory dose criteria.

The radiation dose results calculated for members of the public can be put in context as follows:

The regional background dose from natural sources to members of the public is not significantly different to the global average dose equal to

2.4 mSv/y.

The NNR public dose limit for additional dose from KUP above the background dose is

1 mSv/y

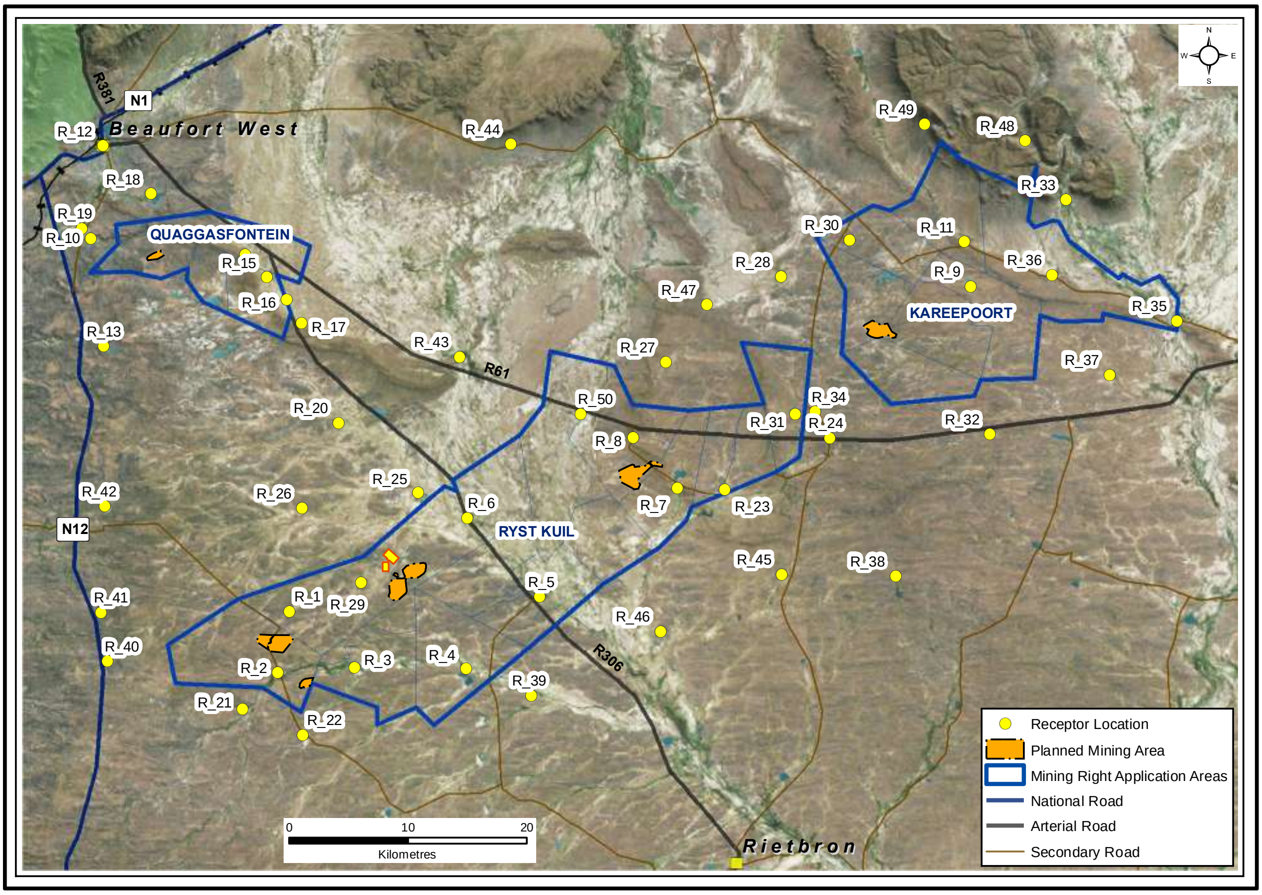
KUP must demonstrate compliance with the regulatory dose constraint equal to

0.25 mSv/yr

The highest predicted annual dose for a member of the public from KUP operations, in addition to the existing background dose is less than

0.15 mSv/y.

The annual doses from airborne exposure pathways were calculated at fifty sensitive receptor locations illustrated in the figure below. These receptor locations are farmsteads that are occupied permanently or for limited periods during the year. The radiation dose at each receptor location was calculated as if permanently occupied.



The result for each receptor location is listed in the table that follows. The table shows the dose attributable to each of the four main mine areas and a total dose which represents a bounding cumulative dose from all KUP mine areas.

Receptor	Ryst Kuil mines, TSF and CPP	Quaggas-fontein	De Pannen	Haanekuil	Bounding cumulative dose (mSv/yr)
R1 Kat Doorn Kuil	0.085	0.002	0.002	0.002	***0.091***
R2 Kant Kraal	0.127	0.001	0.002	0.002	***0.132***
R3 Klipstawels	0.094	0.001	0.002	0.002	***0.099***
R4 Klipkrans	0.134	0.002	0.003	0.003	***0.142***
R5 Eerstewater	0.092	0.002	0.003	0.007	***0.104***
R6 Ryst Kuil	0.028	0.002	0.003	0.005	***0.038***
R7 Lootsplaas	0.005	0.002	0.007	0.079	***0.093***
R8 Haanekuil	0.006	0.003	0.007	0.109	***0.125***
R9 Kareepoort	0.002	0.001	0.011	0.001	***0.015***
R10 Quaggasfontein	0.005	0.018	0.002	0.001	***0.026***
R11 Bokvlei	0.002	0.001	0.005	0.001	***0.009***
R12 Beaufort West	0.004	0.004	0.003	0.001	***0.012***
R13_Olive Grove	0.007	0.008	0.002	0.001	***0.018***
R14 Blouboskuil	0.006	0.035	0.003	0.002	***0.046***
R15 Oude Volks Kraal	0.007	0.025	0.003	0.002	***0.037***
R16 Uitsig	0.008	0.018	0.003	0.002	***0.031***
R17 Retreat	0.009	0.015	0.003	0.003	***0.030***
R18 Hansrivier	0.004	0.008	0.003	0.001	***0.016***
R19 Steenrotsfontein	0.005	0.014	0.002	0.001	***0.022***
R20 Saucyôs Kuil	0.019	0.004	0.003	0.003	***0.029***
R21 Amosvlei	0.034	0.001	0.002	0.001	***0.038***
R22 Vaalkraal	0.052	0.001	0.002	0.002	***0.057***
R23 Blydskap	0.004	0.002	0.009	0.024	***0.039***
R24 Rooidam Farmstall	0.003	0.002	0.028	0.005	***0.038***
R25 Toomitzkuil	0.021	0.003	0.003	0.004	***0.031***
R26 Hoekskuil	0.060	0.002	0.002	0.002	***0.066***
R27 Veerekuil	0.002	0.003	0.012	0.008	***0.025***
R28 Losboome	0.001	0.002	0.055	0.002	***0.060***
R29 Kat Doorn Kuil – Not occupied by humans – refer to discussion below	*0.479*	*0.002*	*0.002*	*0.002*	***0.485***
R30 De Pannen	0.001	0.002	0.033	0.001	***0.037***
R31 Nuwejaarskuil	0.003	0.002	0.023	0.004	***0.032***
R32 De Puts	0.004	0.001	0.024	0.003	***0.032***
R33 Oorlogspoort	0.001	0.001	0.003	0.001	***0.006***
R34 Nuwejaarsfontein	0.003	0.002	0.032	0.003	***0.040***
R35 Rooidraai	0.001	0.001	0.012	0.001	***0.015***
R36 Vaalvlei	0.001	0.001	0.005	0.001	***0.008***

Receptor	**Ryst Kuil mines, TSF and CPP**	**Quaggas-fontein**	**De Pannen**	**Haanekuil**	**Bounding cumulative dose (mSv/yr)**
R37 Upper Kiewietskuil	0.001	0.001	0.022	0.001	***0.025***
R38 Bosduiwerivier	0.008	0.001	0.016	0.006	***0.031***
R39 Rhenosterkop	0.068	0.001	0.003	0.003	***0.075***
R40 Bothasdale	0.022	0.001	0.001	0.001	***0.025***
R41 Goodhope	0.022	0.001	0.001	0.001	***0.025***
R42 Jonkersleegte	0.027	0.002	0.001	0.001	***0.031***
R43 Grootkraanvoelkuil	0.017	0.005	0.002	0.005	***0.029***
R44 Helvetia	0.004	0.003	0.005	0.003	***0.015***
R45 Eensaam	0.002	0.002	0.006	0.010	***0.020***
R46 Hoekraal	0.011	0.001	0.009	0.010	***0.031***
R47 Reyersvlei	0.038	0.002	0.004	0.004	***0.048***
R48 Beyerskloof	0.002	0.001	0.019	0.001	***0.023***
R49 Theefontein	0.001	0.002	0.002	0.001	***0.006***
R50 Neverset	0.001	0.003	0.002	0.019	***0.025***

The relatively high dose reported for the receptor location identified as R29 - Kat Doorn Kuil, represents a hypothetical habitation scenario. It is the only receptor location where the regulatory dose constraint criterion of 0.250 mSv/yr is exceeded because of its proximity to the CPP and TSF. Each of the other receptor locations complies with the dose constraint criterion. The relatively high dose is mainly a result of the conservative assumptions made in respect of CPP product drying and packing plant and the TSF, aspects that are discussed in the report. Further investigation that included a sensitivity study of source term parameter values indicated that more realistic values for the airborne radioactivity source terms should result in compliance with the dose constraint value at receptor R29.

The actual dose at each location will be less than the bounding value included in the table. There will be no period during the KUP operations that mining will be carried out simultaneously at all the mine sites, based on the mining schedule available at the time of preparing this report. The periods when operations will coincide at the different mine areas since start of mining designated as óyear 0ô are as follows:

Mine Area		Year 3	Year 5	Year 7
1	CPP	X	X	X
2	Ryst Kuil Main	X		
3	Ryst Kuil Extention	X		
4	Ryst Kuil South	X		
5	Ryst Kuil Abante	X	X	
6	Haanekuil		X	X
7	De Pannen		X	X
8	Quaggasfontein			X

The potential impacts on water resources are determined by mine design and mitigation aspects as well as monitoring programmes. The mine areas are designed to ensure a low risk of contamination of public water resources. The potential impacts and mitigation measures to avoid off-site water pollution are discussed in detail in the KUP environmental impact assessment report (EIA). Design pollution controls supported by monitoring programmes include:

- groundwater monitoring will be by means of boreholes up- and downstream from KUP operations;
- drains will be constructed around stockpiles to divert potential water run-off to lined sumps for evaporation;
- all stockpiles and the TSF will be located on engineered bases to prevent contamination of the groundwater;
- stockpile areas will be prepared in advance to avoid infiltration of seepage into the groundwater;
- pollution control dams will be constructed;
- storm water drains and trenches are included at material storage areas; and
- water collection provided at maintenance workshops;

The most important source of potential future contamination of water after mine closure is the TSF. The large volume of tailings wastes makes it unlikely to isolate the TSF completely from the environment over prolonged periods into the future. Poor practices in the placement and management of TSFs in the history of uranium mining have contributed to the negative perceptions of uranium mining. The company has expressed its commitment to international best practice in respect of post-closure mitigation measures. The TSF engineering design is especially important in respect of remediation and its cover design following closure.

It is important to note that a separate authorisation process is required in respect of the radiological hazards. Uranium mining in South Africa is regulated by the National Nuclear Regulator (NNR) in accordance with the provisions of the National Nuclear Regulator Act. Regulations require a prospective radiological safety assessment before mining may commence. It also requires, apart from a safety assessment of radiation hazards to members of the public, formal documented safety submissions in respect of waste disposal, worker protection, transport of radioactive material and environmental monitoring. Effective radiation exposure controls during the operational life of KUP are legally required and approved by the NNR. It includes an ALARA (As Low As Reasonably Achievable) programme requiring KUP to continuously monitor and optimise performance in terms of radiological safety.

A significance rating of radiological impacts in the traditional manner that is required for non-radiological environment impacts is normally not done in terms of the NNR authorisation process. However, the radiological impacts can be aligned with environmental impact assessment methodologies based on the following approach:

- High environmental significance; public dose likely to exceed the national public dose limit of 1 mSv/y.
- Medium environmental significance: public dose exceeds the regulatory dose constraint value of 0.25 mSv/y but is less than 1 mSv/y.
- Low environmental significance; the regulatory dose constraint for the public is met; i.e. the annual dose is less than 0.25 mSv/y for any member of the public.

The dose limit and the results of the significance rating for the different phases of the mine with and without adequate and effective controls in place are listed in the table that follows.

The results of the environmental significance rating are as follows:

Significance Rating	**Site preparation / construction**	**Mining operations**	**Decommissioning, rehabilitation and closure**	**Post-closure**
Inadequate control of dust and water discharges from the mine; closure conditions not meeting site release criteria determined by the NNR	Low	Medium	Medium	High
Effective control of dust and water discharges from the mine and post closure conditions on the site that meet NNR release criteria.	Low	Low	Low	Medium

A radiological exposure scenario that can potentially have a “high” significance rating is where material with elevated radioactivity remains accessible to the public after mine closure and radioactive effluent is released into the public domain. A safety assessment of post-closure exposure scenarios and mitigation measures based on the findings of such a safety assessment will be a legal requirement, subject to approval by the NNR.

GLOSSARY

Term	Description
Alpha Radiation	Emission of energy from the atomic nucleus as alpha particles. Alpha particles are comparatively large, positively charged nuclei of helium, and have a low penetrating power, e.g. being stopped by a few centimetres of air or a sheet of paper.
Background	The surrounding environment which is uncontaminated by a local source of pollution.
Background radiation	The radiation in the natural environment from the naturally occurring radioactive elements. It includes cosmic and cosmogenic radiation.
Beta radiation	Emission of energy from the atomic nucleus as beta particles. Beta particles are equivalent to electrons and are able to penetrate approximately a metre of air or a centimetre of water.
Bio-accumulation	The process by which contaminants in the environment are accumulated in fauna and flora.
Contamination	Radioactive substances on surfaces or within solids, liquids, or gases (including the human body) where their presence is unintended or undesirable, or the process giving rise to their presence in such places.
Cosmic radiation	Radiation of great penetrating power reaching the earth from all directions of space.
Cosmogenic radiation	Radiation that results from the interaction of cosmic radiation with the earthôs atmosphere, for example radioactive carbon (C-14) is created in the earthôs atmosphere.
Critical Group	A group of members of the public (in the general population) which is reasonably homogeneous with respect to its exposure for a given radiation source and given exposure pathway and is typical of individuals receiving the highest dose by the given exposure pathway from the given source.
Dose (Annual Effective)	The radiation dose from external ionising radiation as well as the internal ionising radiation. The internal dose is a weighted measure of the radiation energy received or absorbed by the whole body following uptake of a certain amount of radioactivity in a year where the dose will be committed over the lifetime of the person taking into consideration of the sensitivity of the human body at the age when the uptake occurred. Radiation dose is measured in units of sievert (Sv).
Dose Limit	The regulatory value of the annual effective dose to individuals from controlled practices or working activities such as uranium mining that shall not be exceeded.
Exposure	The act or condition of being subject to ionising radiation.
Exposure pathway	A route by which radiation or radionuclides can reach humans and cause exposure, e.g. airborne radioactive dust.
Gamma radiation	High energy, short-wave length, electromagnetic radiation originating in the atomic nucleus. Gamma rays are the most penetrating when compared to alpha and beta radiation.

Intake	The process of taking radioactivity into the body either by inhalation (typically as dust with air) or by ingestion (drinking water and/or eating food).
NORM	(Abbreviation for Naturally Occurring Radioactive Material) The main contributions of human exposure to ionising radiation arise from natural radionuclides in the earthôs crust. Those that are found to be the main sources of human radiation exposure are potasium-40 (K-40), thorium-232 (Th-232), uranium-235 (U-235) and uranium-238 (U-238), and the decay products from the latter three radionuclides. Potassium is a common element and the radioactive isotope K-40 constitutes 0.012% of all potassium in its natural form. The three heavy radionuclides (Th-232, U-235, and U-238) decay to produce other radioactive elements. The term TENORM is also used NORM is enhanced through technology and processes such as mining and mineral processing.
Radionuclide	An element or isotope that is radioactive as a result of the instability of the nucleus of its atom (e.g. radium or uranium).
Pathway analysis	A method of estimating the transfer of radioactivity (e.g. radionuclides released in water and into the air) and either inhaled or ingested directly, or accumulated up the food chain to fish, vegetation, mammals and humans, and then resulting in a radiation dose to humans.
Potential exposure	Exposure that is not expected to be delivered with certainty but that may result from an unplanned event at a source of radioactive material.
Practice	Any human activity that introduces additional sources of exposure or exposure pathways or extends existing exposure to additional people or modifies the network of exposure pathways from existing sources so as to increase the exposure or the likelihood of exposure of people or the number of people exposed.
Radiation	The emission and propagation of energy through space or matter in the form of electromagnetic waves (gamma rays) or fast-moving particles such as alpha and beta particles.
Radioactive	The condition of a material exhibiting the spontaneous decay of an unstable atomic nucleus into one or more different elements (e.g. the radioactive isotope uranium-238 (abbreviated as U-238) decays into various isotopes that include radium, thorium, and lead).
Radon gas, Rn-222	A naturally occurring radioactive gas within the decay chain of U-238.
Remedial Action	Action taken to reduce radiation doses that might otherwise be received.
Risk	A multi-attribute quantity expressing hazard, danger, or chance of harmful or injurious consequences associated with actual or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.

ABBREVIATIONS AND SYMBOLS

Abbreviation	**Description**
ALARA	As Low As Reasonably Achievable
AMAD	Activity Median Aerodynamic Diameter
Bq	Becquerel
Bq/L	Becquerel per litre
Bq/m^2	Becquerel per square metre
COR	Certificate of Registration
CPP	Central Processing Plant
DCF	Dose Conversion Factor, the dose per unit radioactivity of a radionuclide taken into the body
EIA	Environmental Impact Assessment
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
KUP	Karoo Uranium Project
LL-alpha	Long-lived alpha activity, and in the context of this report mainly the radio-isotopes U-238, U-234, Th-230, Ra-226, and Pb-210
NORM	Naturally Occurring Radioactive Material
ROM	Run of Mine, the uranium ore delivered for processing and extraction of the uranium product
TASPAC	Tasman Pacific Minerals Limited
TLJVCO	Tasman Lukisa JV Company (Pty) Ltd
Sv	Sievert
t	tonne
TLD	Thermoluminescent dosimeter
TSF	Tailings Storage Facility
mBq	10^{-3} Bq (one thousandth of a Becquerel)
mg/m^3	milligrams per cubic metre
mSv	10^{-3} sievert (one thousandth of a sievert)
NNR	National Nuclear Regulator
UTM	Universal Transverse Mercator
µSv	10^{-6} sievert (one millionth of a sievert)
εg/m^3	micrograms per cubic metre
Various notations used for expressing quantities, results, and parameter values	10 can be expressed as 1E01 or 10^1 100 can be expressed as follows in scientific notation: 1E02 or 10^2 0.1 is 1E-01 or 10^{-1} (one tenth) 0.01 is 1E-02 or 10^{-2} etc.

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STRUCTURE OF THE REPORT

This report consists of four distinct sections:

Section 1	The purpose and scope of the safety assessment is stated. The reader, who is not familiar with radioactivity and ionising radiation, is provided with a brief introduction to the main concepts. A summary of the relevant South African radiation protection legislation and international criteria for radiation safety. The regional environment is briefly described and provides the background for the radiological baseline and the radiological impacts from the Karoo Uranium Project mine sites.
Section 2	The results of the background radiation and baseline monitoring performed to date in the region are discussed. An overview is provided of historical mining near Beaufort West and remedial actions that have been carried out.
Section 3	The methodology used for the prospective safety assessment of radiation hazards is described. The results of the annual doses to members of the public are presented and a screening assessment of the potential radiological impact on non-human species is discussed.
Section 4	A significance rating of radiological environmental impacts and conclusions are presented.

SECTION 1

- **Purpose and Scope of the Radiological Impact Assessment**
- **Uranium Radioactivity and Radiation Dose**
- **Legislation and International Guidelines**
- **Overview of the Regional Setting**

1-1 PURPOSE AND SCOPE OF THE SAFETY ASSESSMENT

The purpose of this report is to provide supporting information for the Karoo Uranium Project (KUP) environmental impact assessments (EIA) required mining right applications and to address public concerns in respect of radiological hazards. Open pit and underground mine operations will supply uranium ore to a Central Processing Plant (CPP) facility to be located at Ryst Kuil where uranium oxide in the form of ñyellowcakeò will be produced.

When uranium-bearing ore is extracted and processed, its natural state is modified. The changes in physical and chemical composition of the naturally occurring radioactive material (NORM) could result in dispersion into the environment and exposure of members of the public. The potential exposure pathways associated with mining projects are illustrated in Figure 1-1. The actual pathways depend on the environmental characteristics of the region in which a mine is located. It is therefore important to identify the potential exposure pathways and associated radiological hazards associated with the KUP prior to the start of mining.

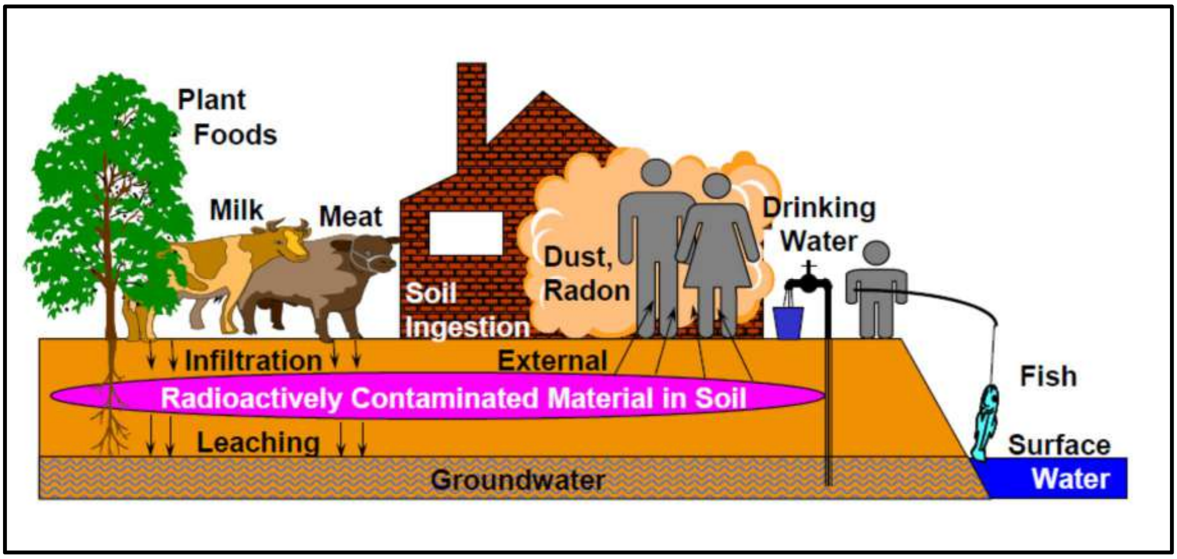

Figure 1-1: Potential exposure pathways

1-2 URANIUM RADIOACTIVITY AND RADIATION DOSE

This section is intended for the reader not familiar with radioactivity and ionising radiation dose. It provides a brief overview of the main concepts that are important as background information to the radiological impact assessment.

Uranium oxide is produced in a concentrated form called yellowcake of which an example is illustrated in Figure 1-2 [1].

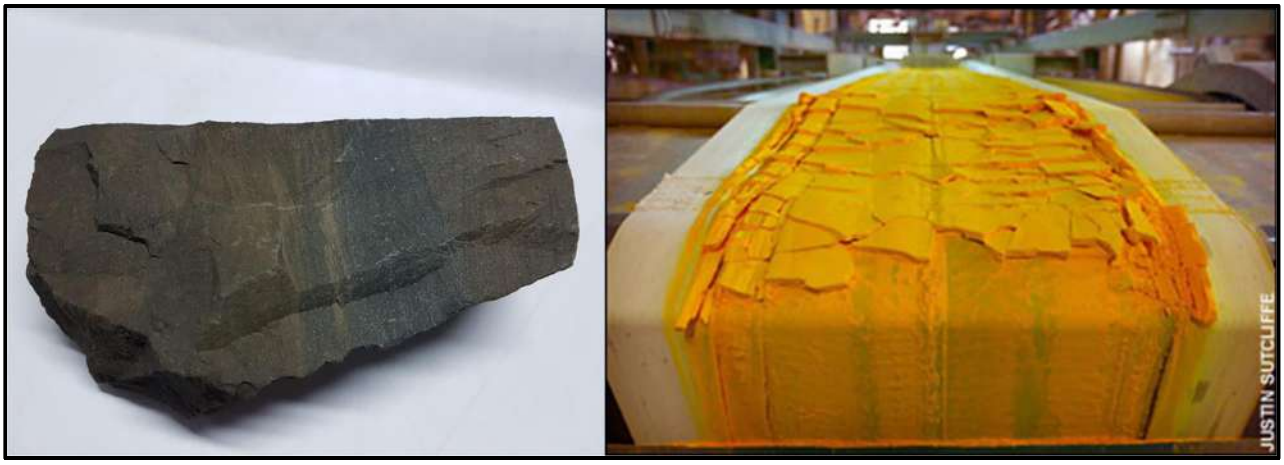

Figure 1-2: An example of sandstone uranium ore and the final uranium oxide product (yellowcake)

Uranium is an element first discovered in 1789 by Martin Klaproth, a German chemist. A little more than 100 years later in 1896 Henri Becquerel, a French physicist, discovered that radioactivity is associated with uranium.

Radioactivity is the term used to describe the disintegration of atoms. The atom can be characterised by the number of protons and neutrons in its nucleus. Some elements have atoms that are chemically identical, but with different neutron numbers and referred to as isotopes of an element. Isotopes with unstable nuclei are known as radionuclides. Their nuclei disintegrate or decay, thus releasing energy in the form of radiation.

The term “radiation” is very broad, and includes light and radio waves. In the context of this report, radiation refers to “ionising” radiation, which means that when it passes through matter, it can cause the matter to become electrically charged or ionised. In living tissues, the electrical ions produced by radiation can affect normal biological processes.

Radioactive decay is expressed in units called becquerels (Bq). One Bq equals one disintegration of a radioactive atomic nucleus per second. Each radionuclide decays at a characteristic rate that remains constant regardless of external influences, such as temperature or pressure. The time that it takes for half the radionuclides to decay is called half-life. This is different for each type of radionuclide, ranging from fractions of a second to billions of years. For example, the half-life of iodine-131 (I-131), an artificial radionuclide produced in nuclear reactors, is eight days. The uranium radionuclide, U-238, which is naturally present in varying amounts in the earth’s crust, is 4.5 billion years. Potassium-40 (K-40), a member of NORM and the main source of radioactivity in our bodies, has a half-life of 1.42 billion years.

The radionuclides in NORM contributing most of the ionising radiation to humans and non-human species, apart from K-40, are the radioactive decay chains of U-238 and Th-232. These decay chains and their decay progeny (also referred to as radioactive daughter products) are illustrated in Figure 1-3 [2].

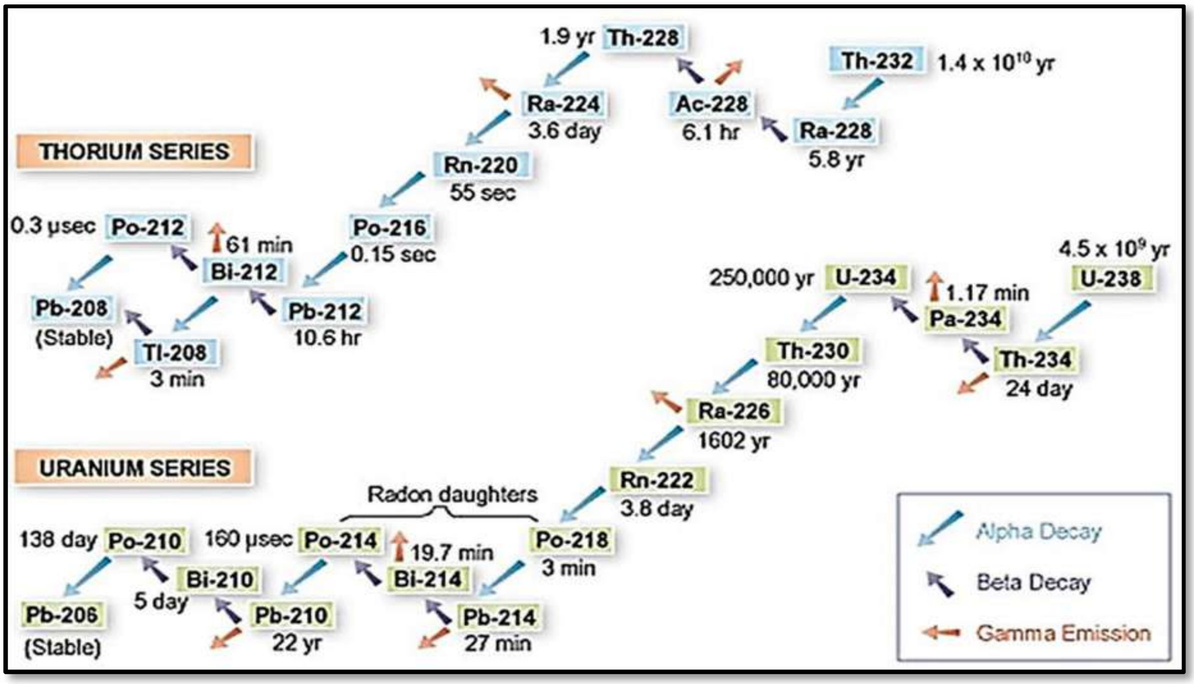

Figure 1-3: U-238 and Th-232 decay series

The common types of ionising radiation specifically relevant to uranium mining as a result of the U-238 decay series, are:

- Alpha radiation: This consists of heavy, positively charged particles emitted by large atoms of elements such as uranium and radium. Alpha radiation can be stopped completely by a sheet of paper or by the thin surface layer of our skin (epidermis). However, if alpha-emitting materials are taken into the body by breathing, eating, or drinking, they can expose internal tissues directly and may cause biological damage, depending on the radiation dose that is committed to the tissues.
- Beta radiation: This consists of electrons. They are more penetrating than alpha particles. In general, a sheet of aluminium a few millimetres thick will stop beta radiation.
- Gamma radiation: This is electromagnetic radiation similar to X-rays. Gamma rays, depending on their energy, can pass right through the human body, but can be attenuated to low levels by lead or thick walls of concrete.

The biological effects of ionising radiation vary with the type and energy. A measure of the risk of biological harm is the dose of radiation that human tissue receives. The unit of absorbed radiation dose is the sievert (Sv). Since one sievert is a large quantity, radiation doses normally encountered in uranium mining are expressed in millisievert (mSv) or microsievert (µSv), which is one-thousandth and one-millionth of a sievert respectively.

The typical components of human exposure to ionising radiation and their relative contribution to human radiation dose are illustrated in Figure 1-4 [3].

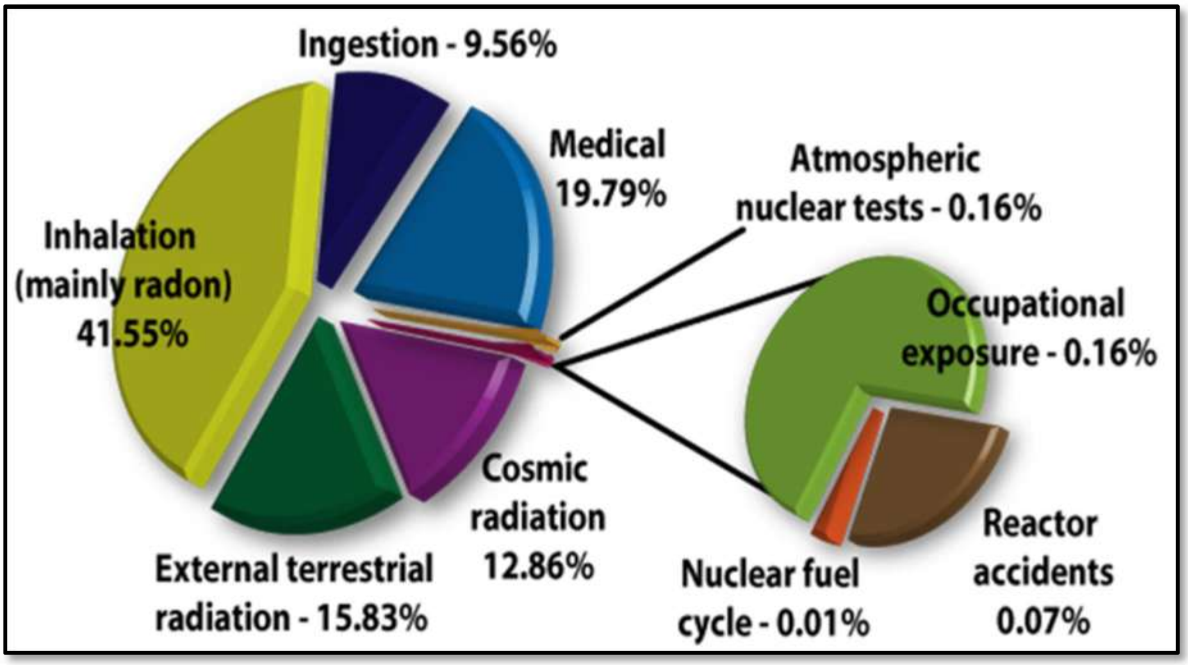

Figure 1-4: Relative contributions to human dose from typical exposure components

It is evident that the contribution to human dose, on average, is dominated by natural sources.

The regulatory dose limit for members of the public that applies to uranium mining is 1 mSv/yr and defines the maximum *additional* annual dose above the natural background dose resulting from human activities. The global average dose rates from *natural sources* are listed in Table 1-1 [4].

Table 1-1: Dose to humans from natural sources

Source		**Global average effective dose (mSv/yr)**	**Typical range (mSv/yr)**
External exposure:	Cosmic rays	0.4	0.3 to 1.0[a]
	Terrestrial rays (mainly gamma radiation)	0.5	0.3 to 0.6[b]
Internal exposure:	Inhalation (mainly radon and its decay products)	1.2	0.2 to 10[c]
	Ingestion	0.3	0.2 to 0.8[d]
Total		2.4	Typically ranges from 1 to 10 mSv, depending on circumstances at particular locations, with sizeable populations also receiving 10 to 20 mSv

(a) Range from sea level to high ground elevation;
(b) Depending on radionuclide composition of soil and building materials;
(c) Depending on radionuclide composition of soils;
(d) Depending on radionuclide composition of foods and drinking water.

1-3 SCOPE OF THE RADIOLOGICAL SAFETY ASSESSMENT

The purpose of the radiological impact assessment is to investigate, in a prospective manner, the KUP radiological impacts on the environment and the radiation dose to members of the public. Uranium mining is an *action* as is defined in terms of radiation protection terminology. An action may result in persons accumulating a radiation dose resulting from exposure to ionizing radiation as follows [5]:

- introduces additional sources of radiation exposure;
- increases the exposure pathways;
- extends exposure to additional people; and/or
- modifies the network of exposure pathways from existing sources.

The assessment of radiation hazards to the public consists of the following elements [5]:

- Mine site description;
- Process description ï A description of mining processes that could result in public exposure, e.g. the release of dust that contains elevated concentrations of radioactivity that emits alpha radiation (LL-alpha);
- Source term characterisation ï A description of all the relevant radionuclides in a source such as the tailings storage facility (TSF) that could result in public exposure, an estimate of their quantities, chemical and physical form, decay constants, dose conversion factors, absorption classes in respect of the human body, and any other relevant information for a radiological safety assessment;
- Exposure pathways ï Identification of all intake and radiation exposure pathways relevant to mining operations;
- Critical group identification ï Identification of all members of the public potentially receiving radiation doses above baseline conditions, their habitat, agricultural and social activities that could affect radiation doses;
- Assessment criteria ï The dose criteria for members of the public, contained in the national legislative and regulatory framework that must not be exceeded;
- Human dose assessment which takes into account all the exposure pathways and scenarios usually requiring some form of computer modelling. A screening dose assessment consists of an initial impact assessment using most likely exposure scenarios and conservative input data;
- Interpretation of results ï The results of the public exposure are quantified and expressed in radiation dose values and compared with the regulatory and international criteria. This process indicates whether any dose reduction design changes have to be considered to comply with the regulatory criteria.
- Public radiological impact assessment report ï The assumptions, data, models and calculation results, validations, uncertainties, and conclusions are included in a safety assessment of radiation hazards to members of the public.

The safety assessment process is illustrated in Figure 1-5.

Atmospheric discharges result in exposure to airborne radioactivity, external radiation from radioactive dust deposited on the ground, and the ingestion of affected farm produce. The dose from this exposure is calculated for various assessment points representative of the potential impact area. Critical groups of the public are identified based on the results for the assessment points.

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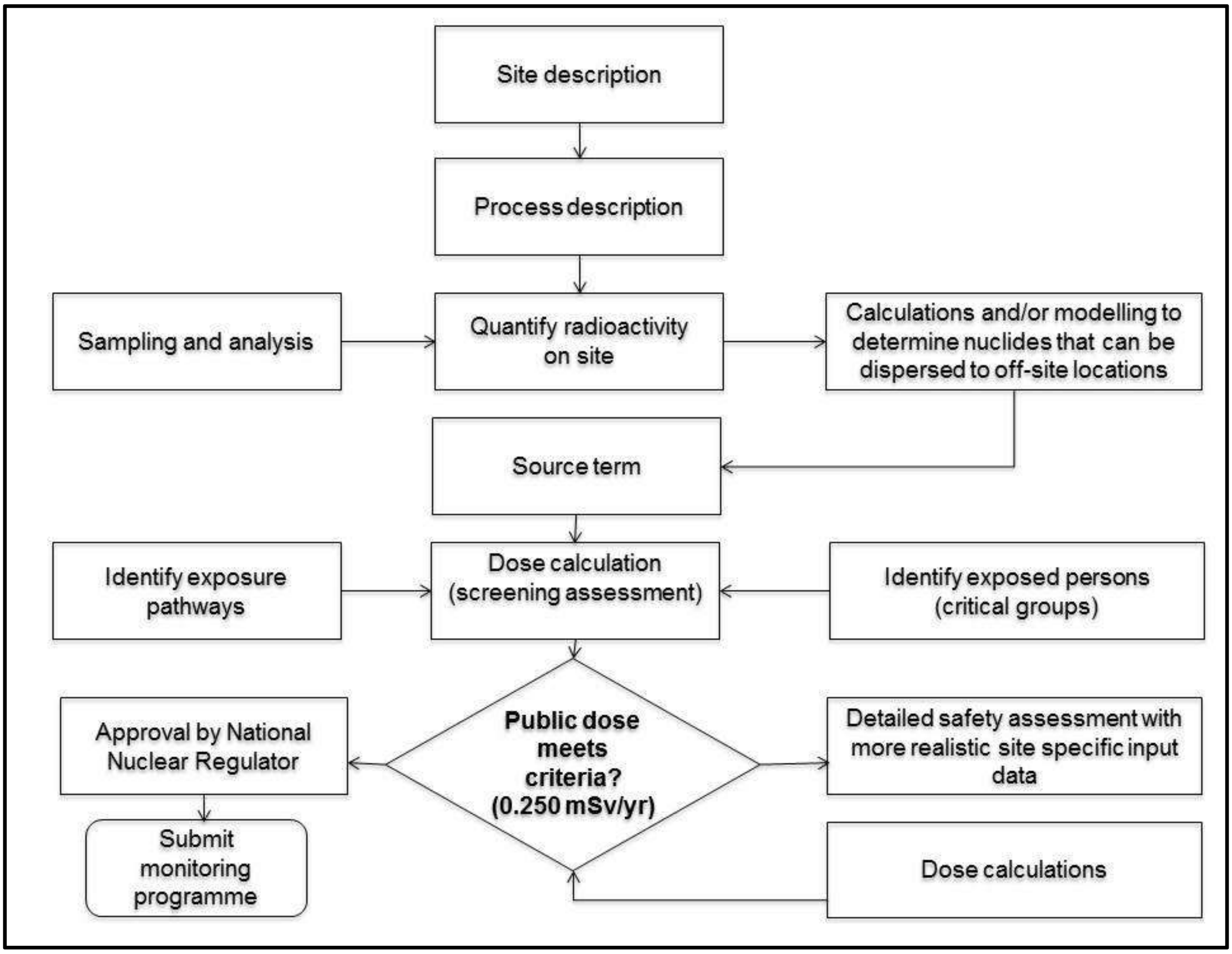

Figure 1-5: Assessment of radiation hazards to the public

A baseline study of background radiation is an important element of a radiological impact assessment. It describes the levels of radionuclide concentrations in different environmental media and existing radiological exposure conditions prior to mining. Baseline radiation values are used as reference values for remediation and to justify the release of mining areas from regulatory control at the end of operations. Some elements of background radiation in the region have been characterised as part of an on-going baseline monitoring programme and a summary of the results is included in this report.

Reference is made to the KUP EIA throughout the report and which should be consulted for more detailed information where required. One such area of KUP detail design information is the potential impacts on water sources. This report provides a qualitative discussion of potential radiological water impacts. Radioactivity is only one aspect of potential water impacts. The prevention of non-radiological impacts will in most cases also prevent radiological impacts. Whereas airborne radiological impacts are certain to occur during normal mine operations, albeit at very low levels, water borne impacts are avoided by design. It should only occur under conditions when KUP design criteria are exceeded, e.g. under extreme weather conditions which have a low probability of occurrence. Environmental monitoring programmes will be of cardinal importance to provide early warning against potential water impacts.

The radiological safety assessment relies on technical information provided by TASPAC. Any change in this information provided will impact the radiation dose results presented in this report.

1-4 RADIATION PROTECTION PRINCIPLES AND LEGISLATION

1-4.1 The International Framework for Radiation Protection

The international framework for ionising radiation protection is provided in the various recommendations and extensive international publications produced by the International Commission on Radiation Protection (ICRP) and the International Atomic Energy Agency (IAEA). These publications form the bases for regulatory control of almost all countries in the world, including South Africa. Three important publications that provide recommendations and guidance for public radiation protection are:

- The 2007 Recommendations of the International Commission on Radiological Protection (ICRP) Publication 103. These revised Recommendations for a System of Radiological Protection formally replace the Commission's previous 1990 recommendations. The revised recommendations update, consolidate, and develop the additional guidance on the control of exposure from radiation sources issued since 1990. They maintain the Commission's three fundamental principles of radiological protection, namely justification, optimisation, and the application of dose limits, clarifying how they apply to radiation sources delivering exposure and to individuals receiving exposure [6].
- International Atomic Energy Agency (IAEA) International Basic Safety Standards describing the principles of radiological protection, recommended by the International Commission on Radiological Protection [7].
- An IAEA publication titled "Safety Guide on the Regulatory Control of Discharges" describe the general principles governing the regulatory control of discharges to the environment [8]. A mine that can control its effluent and discharges to the environment in an optimised manner and following best international environmental practice should be able to keep the dose to the public well below regulatory dose criteria.

1-4.2 South African Legislation

1-4.2.1 Radiation Protection Criteria

Regulatory controls of NORM mining industries such as gold, copper, heavy mineral sands, as well as uranium, became much more formalised in South Africa in the 1990's. Regulatory control is exercised by the National Nuclear Regulator through the National Nuclear Regulatory Act [9]. This act and its regulations are aligned with the various recommendations and extensive publications on radiation safety produced by the ICRP and the IAEA.

Section 6(1)(c) of the National Nuclear Regulator Act provides to minimise the duplication of functions between the National Nuclear Regulator (NNR) and other organs of state and as such the review of radiological environmental impact assessments falls within the ambit of the NNR.

The primary responsibility of the NNR is to provide for the protection of persons, property, and the environment against nuclear damage through the establishment of safety standards and regulatory practices. The NNR exercises regulatory control related to nuclear installations and other actions involving radioactive material. Regulations supporting the act are provided in "Regulations on Safety Standards and Regulatory Practices" (SSRP) [10]. The SSRP contains the principal radiation protection and nuclear safety requirements. It requires a prior safety assessment, also referred to as a prospective safety assessment.

As part of a regulatory nuclear authorisation process, a Certificate of Registration (COR) has to be issued by the NNR prior to mining. Most gold mines in South Africa, for example, operate under the conditions of a COR because of uranium associated with the gold reefs. A COR provides written permission for a mine to carry out activities that are specified in the COR. The COR is the principal mechanism connecting the legal framework of the regulatory system with the responsibilities of the principal parties; namely, the regulator and the mine operator. The conditions in a COR cover aspects of radiation protection such as the following:

- radiation hazard assessments for workers;
- operational radiation protection of the workforce;
- prospective and operational safety assessments to determine the impact on public health and the environment;
- radioactive waste management;
- transportations of radioactive material;
- physical security;
- occurrences and emergency planning;
- operational limitations; and
- a radiation protection quality management system.

The occupational exposures of workers and members of the public have to be controlled so that the regulatory limits are not exceeded. These limits are listed in Table 1-2.

Table 1-2: Dose Limits in Planned Exposure Situations

Type of radiation dose limit	Occupational	Public
Effective dose	20 mSv/yr, averaged over defined periods of 5 years	1 mSv/yr
Annual equivalent dose in:		
• Lens of the eye	150 mSv	15 mSv
• Skin	500 mSv	50 mSv
• Hands and feet	500 mSv	ï

The annual effective dose limit for a member of the public of 1 mSv per year is in addition to the existing background radiation dose. The total effective dose (ET) to a person is calculated according to the following formula:

$$E_T = H_p(d) + \sum e(g)_{j,ing} I_{j,ing} + \sum e(g)_{j,inh} I_{j,inh}$$

where $H_p(d)$ is the personal dose equivalent from exposure to penetrating gamma radiation during the year; $e(g)_{j,ing}$ and $e(g)_{j,inh}$ are the committed effective dose per unit intake by ingestion and inhalation for radionuclide j by the group of age g; and $I_{j,ing}$ and $I_{j,inh}$ are the intakes via ingestion or inhalation of radionuclide j during the same period.

An important aspect of NNR legislation pertains to release of potentially contaminated land following closure. Contaminated areas will be part of the mineôs footprint at the end of operations. Proper design and operational practices optimised in respect of environmental impact should result in a radioactive footprint at the time of mine closure with less financial and environmental liabilities to a company than would be the case otherwise.

1-4.2.2 Radioactive Waste

Typical mining wastes are classified according to the following definitions of the South African Radioactive Waste Management Policy [11]:

- NORM-L (low activity):
    - Potential radioactive waste containing low concentrations of NORM.
    - Long-lived radionuclide concentration: < 100 Bq/g.
    - Unpackaged waste in a miscible waste form.
    - Disposal options:
        - Re-use as underground backfill material in an underground mine area.
        - Extraction of any economically recoverable minerals, followed by disposal in any mine tailings dam or other sufficiently confined surface.
- NORM-E (enhanced activity)
    - Radioactive waste containing enhanced concentrations of NORM.
    - Long-lived radionuclide concentration: > 100 Bq/g.
    - Packaged or unpackaged waste in a miscible or solid form with additional characteristics for a specific repository.
    - Disposal options:
        - Dilute and re-use as underground backfill material in an identified underground (mining) area.
        - 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.

1-4.2.3 Transport of Radioactive Material

It will be necessary to transport the uranium oxide concentrate as well as low-level radioactive waste or contaminated equipment on public roads. The transport of radioactive material in the public domain will be subject to the requirements of the IAEA Regulations for the Safe Transport of Radioactive Material and any applicable international convention [12].

1-4.3 Other Relevant Legislation

This report deals exclusively with elevated levels of NORM associated with uranium mining and therefore the NNR Act is the applicable legislation in terms of public and environmental impacts. However, mines also use sealed radioactive sources with a very high specific radioactivity content, e.g. density meters on plant process pipelines. The applicable legislation for these radiation sources is the Hazardous Substances Act, Act No. 15 of 1973 [13]. The Hazardous Substances Act provides for the control of Group IV hazardous substances (radioactive material not at nuclear installations or not part of the nuclear fuel cycle, for example fabricated radioactive sources like medical isotopes) and Group III hazardous substances (involving exposure to ionising radiation emitted from equipment). Radioactive waste arising from activities authorised under this Act falls under the regulation of the Department of Health’s Directorate of Radiation Control.

1-4.4 The General Environment

The information presented here is a brief overview of the environment where KUP is located. The reader is referred to the KUP EIA report for more extensive information on the different mining application areas.

The regional setting of KUP is indicated in Figure **1**-**6**. Yellow blocks indicate where mining will take place and the interconnecting roads between the mine areas are indicated in red. The general topography is characterised by gently rolling terrain with steeper terrain further away to the north and to the south. The topography is illustrated in Figure **1**-**7**. The region has a continental climate with pronounced temperature extremes (hot summers and the possibility of freezing conditions in winter).

The wind speeds and directions towards which the wind blows (as opposed to the normal wind roses indicating the direction from which the wind is blowing) for mine areas are illustrated in Figure 1-9. The differences in wind characteristics for each mine site have been considered in the impacts of radioactive airborne discharges.

Mean annual rainfall varies from less than 100 mm in the west to 500 mm in the east. Rainfall events are typically localised, short, intense thunder showers. Apart from small farm dams, surface water in the vicinity of the mine sites only exists during periods of high rainfall.

Groundwater is an important source for farming communities. It is used by all farmers for domestic purposes, watering livestock, and irrigation of fodder crops such as lucerne. Water from streams for irrigation only takes place following rainfall events.

The annual rainfall and soil conditions are not suitable for intensive agriculture. Arid conditions and dominance by plant species that have low forage value leads to low carrying capacity for livestock and game. The land is covered by natural Karoo bush and it is mainly used for sheep and goat farming, with some areas dedicated to game farming. Cultivation of crops is practised on relatively small areas and close to farmsteads. Stocks of sheep and goats are kept at low densities ranging from 25-35 per 100 ha.

1-4.5 Proposed Mining

Mining methods will include open pits at all mine areas. Underground mining will also be practiced except at De Pannen and Quaggasfontein. The ore will be transported to the CPP at Ryst Kuil where milling and uranium extraction will be carried out. Local crushing at the Quaggasfontein and De Pannen are being considered.

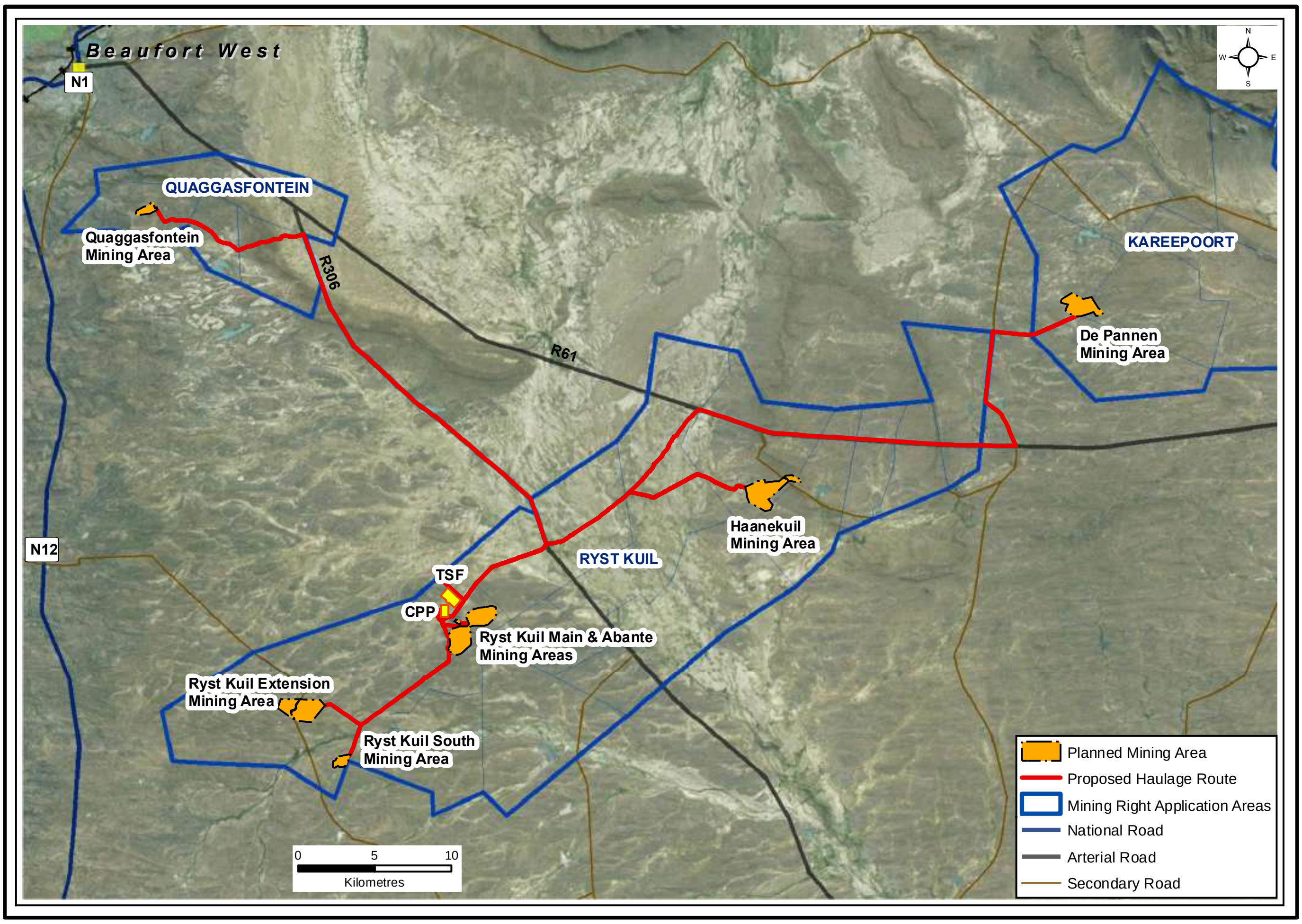

Figure 1-6: The regional setting of the mining areas, CPP and TSF

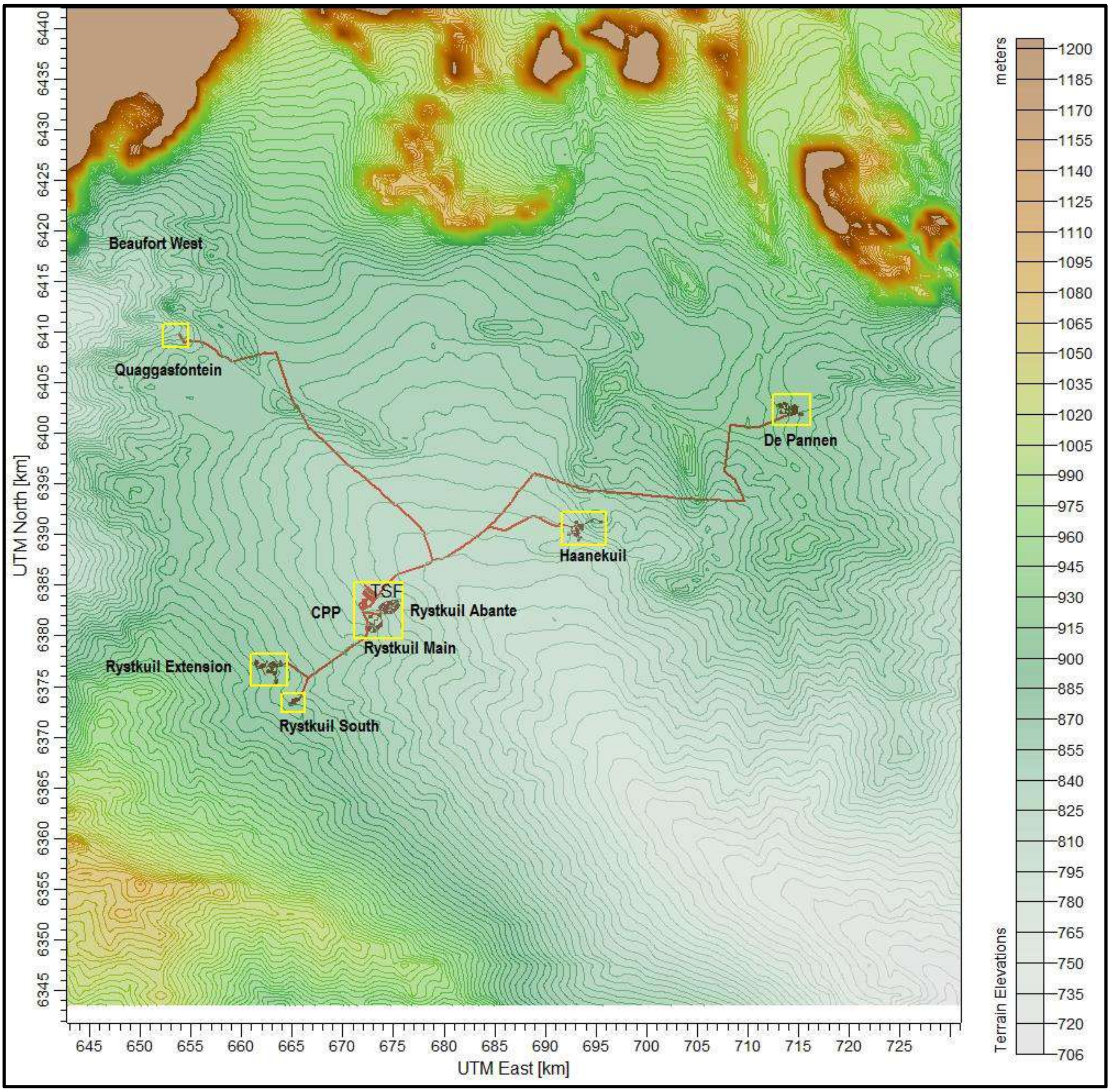

Figure 1-7: The regional topography

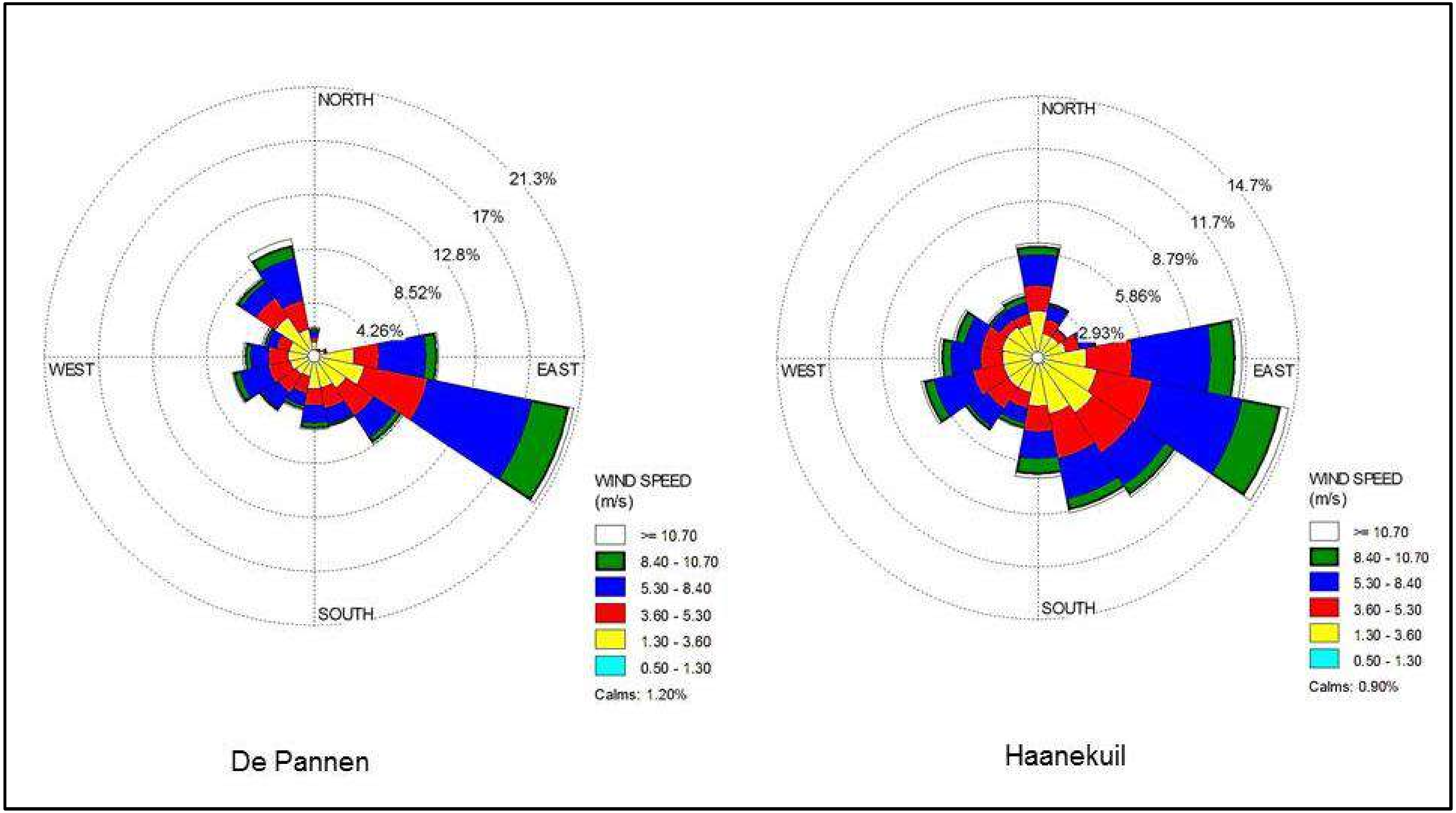

Figure 1-8: Wind flow directions for the De Pannen and Haanekuil areas

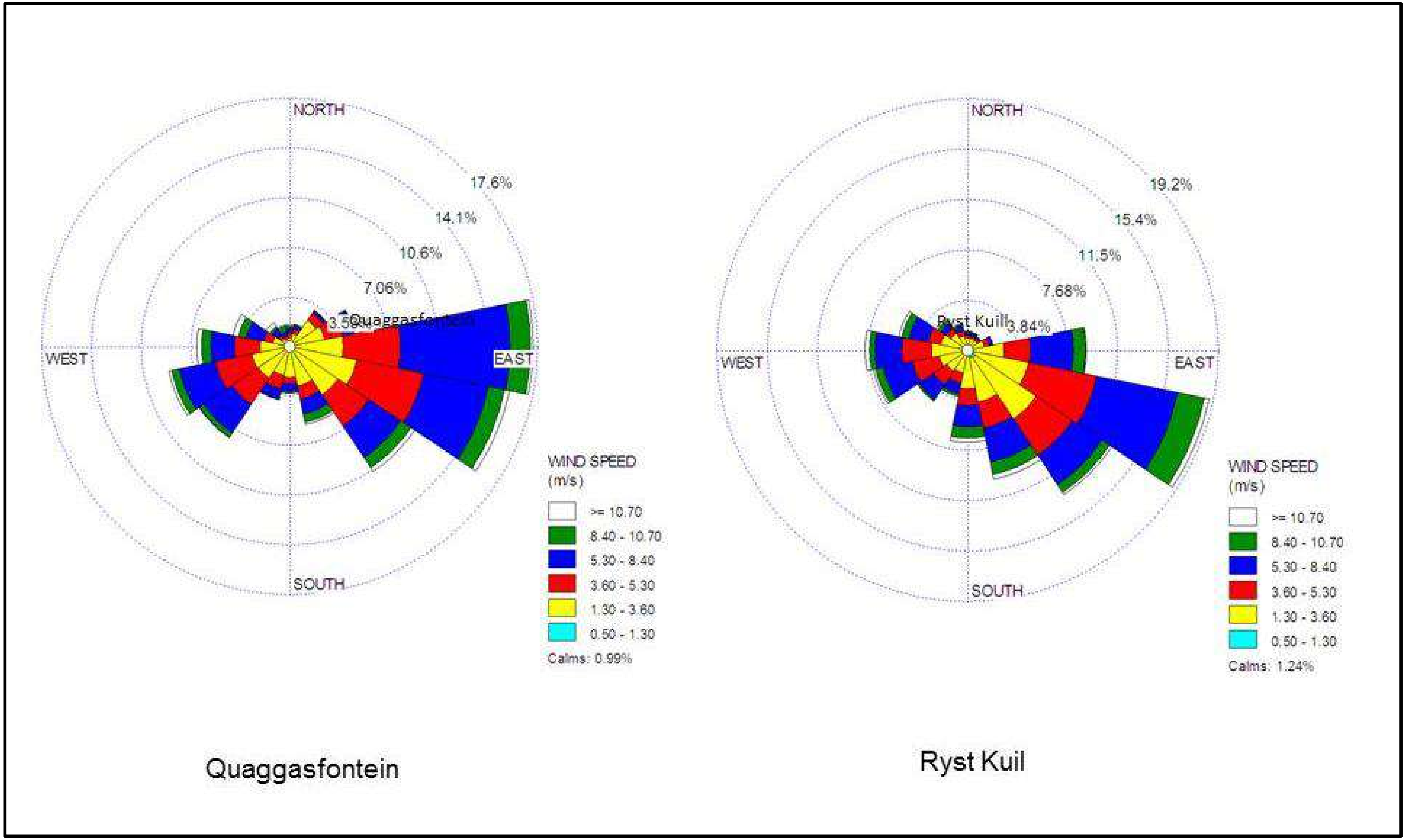

Figure 1-9: Wind flow directions for the Quaggasfontein and Ryst Kuil areas

SECTION 2

- **Natural Background Radiation**
- **Historical Mining Activities**

2-1 A BASELINE OF EXISTING RADIATION IN THE REGION

2-1.1 Introduction

A baseline study of background radiation has the following objectives:

- It provides an understanding of pre-mining spatial and temporal variations in environmental radioactivity concentrations.
- It establishes baseline measurements in the area against which potential changes due to mining can be assessed.
- It defines pathways of radionuclide movement and radiation exposure in the vicinity of the mine site thereby providing a basis for a prediction of radiological impact for operational and post-operational phases of mining.

The important exposure pathways for establishing a radiological baseline are:

- external radiation from terrestrial sources (land surface areas);
- inhalation of radon (Rn-222) and its short half-life decay products;
- ingestion of drinking water;
- ingestion of foodstuffs which constitute a large part of the diet and for which bioaccumulation of nuclides occur; and
- inhalation of airborne dust that contain NORM radionuclides (LL-alpha radioactivity).

The baseline study consists of two phases. Phase 1 has been completed and included exploratory environmental monitoring, limited biological sampling and a general radiological description of the proposed mine areas. Phase 2 consists of detailed radiation surveys of the future mine footprints and the adjacent off-site environment. The information will serve as reference for rehabilitation and closure criteria. Phase 2 monitoring will also continue further afield, e.g. airborne dust, biological samples, e.g. farm produce to be collected at farmsteads nearest to the mining activities and monitoring of the radiological quality of groundwater and surface water.

Two types of areas are discussed in the sections that follow:

- the natural background radiation of areas not affected by historical uranium prospecting and trial mining in the period 1970/1980ôs, and
- areas impacted during historical uranium prospecting and trial mining.

2-1.2 Natural Background Radiation in the Karoo

2-1.2.1 External Radiation Levels

The differences in external radiation in various environmental regions are attributable to variation in the terrestrial sources, i.e. the concentrations of gamma ray emitting radionuclides in the top soil layers. Gamma rays from uranium rich rock at deeper layers are effectively attenuated by the top soil and rock so that the dose rate above a soil surface generally arises almost entirely from radionuclides in the top metre of soil cover. The worldwide average of the annual external radiation dose is 0.48 mSv and generally within the 0.3 to 0.6 mSv range as shown in Table 1-1.

A survey of terrestrial gamma radiation was performed of areas not affected by historical trial mining activities. The soil surface activities and gamma radiation levels are low *except* for areas where natural uranium-bearing mineralisation occurs on surface (outcrops of uranium mineralisation). Some of these localised areas have extremely high levels of radiation when compared the surrounding land. Figure **2-1** shows some of these areas where radiation dose rates up to seven hundred and fifty (750) times higher than background are measured; i.e. 0.150 mSv/h compared to typical dose rates of less than 0.0002 mSv/h on non-mineralised surface areas. The high radiation level is an example of the radiation anomalies found in nature and at numerous locations in the Karoo.

Figure 2-1: Natural uranium rich outcrops with high radiation levels

The radiation results of surveys carried out over a wide region are included in Attachment 1. The initial surveys were done with two types of portable monitoring equipment, namely, an Electra GM Plus 1A surface contamination monitor, and a Canberra Inspector 1000 digital handheld multichannel analyser equipped with a sensitive 3-inch gamma probe. At each measurement location, the general area was first screened to confirm the absence of large variations in radiation fields. Gamma dose rate measurements on contact with the soil and at 1-metre height were then performed and recorded.

A further survey of external radiation was also done using thermoluminescent dosimeter (TLD) monitors at fixed locations. The locations represent the future KUP mining areas and nearby farmsteads. The TLDs for environmental monitoring were supplied and analysed by the SABS. The range of dose rates for the 28 locations in the different areas (excluding historical trial mining areas) are summarised in Table 2-1.

Table 2-1: TLD external dose rates

Range	Value
Average	1.50 mSv/yr
Minimum	1.10 mSv/yr
Maximum	2.03 mSv/yr

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2-1.2.2 Radon Concentrations

2-1.2.2.1 Radon Background Information

Radon is an inert radioactive gas produced by the decay of natural uranium and thorium in rocks and soils throughout the earth's crust. The radon isotope Rn-222 is normally the most significant component of human exposure from natural sources. Rn-222 has a sufficiently long half-life to migrate through rocks and soils to the atmosphere when compared to the other radon isotopes. Rn-220, a daughter product in the Th-232 decay series, has a very short half-life of 55.6 seconds, and Rn-219 is a daughter product in the in the U-235 decay series with an even shorter half-life of 3.92 seconds. In the rest of this report reference to radon means Rn-222.

Concentrations of radon in the general outdoor environment are affected not only by the magnitude of the release from soil surfaces (referred to as soil radon flux rates or radon exhalation) of a land area with a specific geology and uranium content, but also the local meteorological conditions (atmospheric pressure, wind, and precipitation). Solar heating during the daytime tends to induce atmospheric turbulence, so that radon is more readily transported upwards and away from the ground. At night and in the early morning hours, atmospheric (temperature) inversion conditions are often found, which tend to trap the radon closer to the ground. Outdoor radon concentrations can therefore vary diurnally by a factor as much as ten. Seasonal radon flux variations relate to the effects of rain or to changes in prevailing wind conditions (direction and speed).

Results of worldwide outdoor radon measurements indicate an average concentration of 10 $Bq.m^{-3}$ [4]. There is, however, a wide range of long-term average concentrations of radon and it can range from approximately 1 $Bq.m^{-3}$ to more than 100 $Bq.m^{-3}$. The low values are typical of isolated small islands or coastal regions and high values typical of sites where high radon exhalation occurs over a large surrounding area. Considering the range of radon exposures determined globally, one finds many large populations around the world where average annual radon doses differ from the global averages (1.1 mSv/yr) by a factor of more than 2, and many smaller populations where average exposures differ by a factor of more than 10. It is estimated that about 65% of individuals have exposures between 1 and 3 mSv, about 25% of the population have exposures less than 1 mSv, and 10% have exposures greater than 3 mSv [14].

Radon gas is not retained in the body to any great extent, although some traces will dissolve in the bloodstream and be distributed throughout soft tissues. The radiation dose associated with radon is mainly caused by its short-lived decay progeny which deposit in lung tissue. Direct measurements of the concentrations of all short-lived decay products of radon are estimated from considerations of equilibrium (or disequilibrium) between radon and its decay products. An equilibrium factor, F, is defined that permits the exposure to be estimated in terms of the potential alpha energy concentration (PAEC) from the measurements of radon gas concentration. This factor is representative of the age of radon in a volume of air which determines the radiation dose when inhaling the volume of air. "Older" air is closer to equilibrium and F is then closer to unity resulting in a higher dose when inhaling such air.

The ICRP has recently published a report on lung cancer risk from the inhalation of radon and radon progeny [15]. The report recommends changes to the dose conversion convention for estimating lung cancer risk from radon and radon progeny. These changes will result in new dose coefficients for inhalation of radon progeny, which are expected to be larger by a factor of two or more than the existing dose conversion factors. However, until such time as the ICRP publishes new dose coefficients for the inhalation of radon progeny, the dose coefficient published in the IAEA Basic Safety Standards and also the basis the NNR criteria, remain valid.

2-1.2.2.2 Radon concentrations at KUP

Radon concentrations were measured using passive polycarbonate track-etch devices supplied by PARC RGM (Radon Gas Monitoring) (Pty) Ltd. Two surveys were done and during each survey the monitors were deployed for approximately 3 months at outdoor locations in the region. The first survey involved monitoring locations representative of the larger region, including Beaufort West. The second survey involved monitoring locations at the proposed future mine areas where ore stockpiles and processing plants will be located.

The two sets of results are included in Attachment 2 and indicate very low environmental radon concentrations. A summary of the results is provided Table 2-2.

Table 2-2: Ambient radon concentration in the KUP region

Rn-222 monitoring at fixed locations to obtain a 3-months integrated concentration		Rn-222 Bq/m^3	Derived dose, mSv/yr
Survey 1 2009	Minimum	2.1	0.066
	Maximum	38.5	1.233
	Average	9.4	0.301
Survey 2 2015	Minimum	8.6	0.275
	Maximum	14.9	0.477
	Average	11.1	0.353

The low radon concentrations have to be interpreted against the fact that these concentrations are for outdoor areas. Radon concentrations inside buildings can be significantly higher than the outside ambient air concentrations. The higher concentrations normally result from low building ventilation rates compared to dispersion conditions in outside air, which means that the short half-life radon decay progeny can increase in concentration as radon decays. Other contributing factors to high radon concentrations inside buildings could be relatively high U-238 concentrations in building materials and in soils upon which a building is constructed. Additional baseline radon monitoring is planned and will include buildings/houses at the critical group locations identified from the list of sensitive receptors assessed in this report.

Six radon monitors were also deployed inside the old Cameron decline (trial mine), constructed by ESSO Minerals at Ryst Kuil in 1978, at the depth of the groundwater level. The radon concentration is significantly higher than on the surface, as can be expected for a non-ventilated underground area. The average radon concentration measured with the six monitors is 134 Bq/m^3 compared to the above-surface average concentration of approximately 10 Bq/m^3. The Cameron decline is now sealed off and is not accessible to the public. The measured radon concentration on surface at the Cameron decline and inside the Ryst Kuil controlled area where historical ore is located, was 5.7 Bq/m^3. This concentration is less than the regional average value. One would have expected a higher radon concentration than the regional average. It demonstrates the fact the atmospheric dispersion conditions at a specific site and radon exhalation from different material types, even though the radium concentration of the different material types may be the same, are determining factors for ambient radon concentration. The radon concentration measured in Beaufort West, for example, was 5.2 Bq/m3 and almost the same as at the Ryst Kuil controlled area.

The measured radon concentrations at proposed mine areas provide important reference data for future radon discharges to the environment from mining activities. The low background radon concentrations that were measured will allow a more sensitive detection of mining radon discharges.

Figure 2-2 illustrates a typical radon monitoring unit deployed in the region.

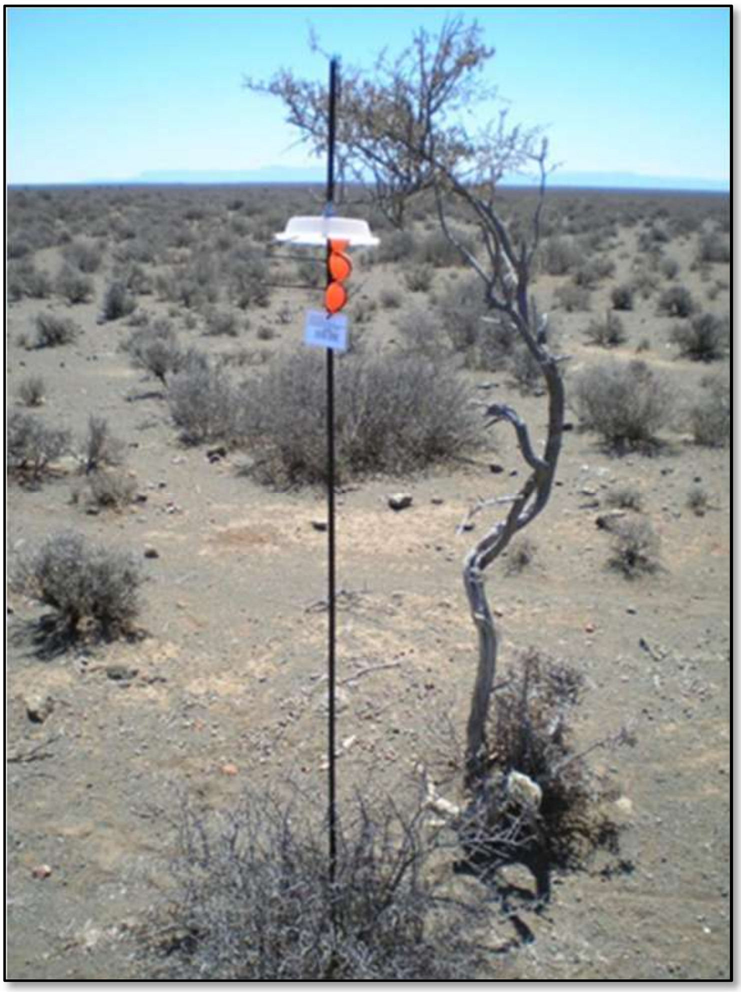


Figure 2-2: An example of environmental radon monitoring

2-1.2.3 Dust

Baseline monitoring of airborne dust will be introduced as part of Phase 2 of the on-going baseline monitoring. The dispersion patterns (isopleths) of airborne dust calculated for the purposes of this radiological assessment report will guide the identification of sensitive areas where dust monitoring units will be installed. The dust collected by the monitoring units will be analysed for their radioactive LL-alpha content. Assessment of dust concentrations and fallout dust against environmental non-radioactive criteria will also be carried out on the samples collected at these monitoring locations.

2-1.2.4 Water Radioactivity

All natural water sources contain NORM and in some areas groundwater radioactivity levels may be high because of purely natural phenomena, e.g. relatively high Ra-226 concentrations have been reported in areas with underlying granites, such as in the Namakwa Land region of South Africa [16]. Radioanalysis results for water samples from a number boreholes in the larger KUP proposed mining region indicate elevated levels of U-238, U-234, and Th-230. This is to be expected since uranium mineralisation is relatively common in the Great Karoo. It is mainly confined to channel sandstones from surface to relatively shallow depths as is reported in groundwater SRK Consulting studies and incorporated into the KUP EIA.

The radiological quality of water uses a classification scheme illustrated in Table 2-3 [16]. It is based on calculating the potential dose from drinking water using a conservative assumption that a person receives all the drinking water from the particular water source that is being assessed. The dose calculation is as follows:

Dose (mSv/yr) = Radioactivity in water (Bq/L) × Annual Consumption of water (L)
× Radioactivity Dose Conversion Factor (mSv/Bq)

Table 2-3: A classification scheme for the radiological quality of water

Class/ Colour	Dose range; mSv/yr	Health Effects and Typical Exposure Scenarios	Comments and Intervention Decisions
Class 0 (Blue – Ideal water quality)	≤ 0.10	There are no observable health effects. This is the range of exposure from ideal quality water sources. Most treated water falls in this water quality range. Additional doses that result from human activities that fall within this range are difficult or impossible to determine and/or to distinguish from variations in background doses with sufficient confidence.	Drinking water supplied by municipal water treatment plants at tap should be in this category.
Class 1 (Green – Acceptable water quality)	> 0.10 to 1	This is the exposure range from some natural and untreated water sources (e.g. groundwater/ wells). A dose between 0.2 and 0.8 mSv/yr is the typical world-wide range of ingestion radiation dose resulting from water as well as food. A dose equal to 1 mSv/yr additional to background corresponds to the regulatory public dose limit for human activities involving radioactive material.	ALARA and intervention considerations apply if mining practices contributes to public dose via water exposure and the regulatory dose constraint is exceed.
Class 2 (Yellow – Marginal water quality)	> 1 to 10	A small increase in fatal cancer risk is associated with this dose range. Only a small number of natural water sources of this quality exist, usually resulting from exceptional geological conditions. Abnormal/accident conditions at regulated nuclear and radiation facilities may result in a dose in this range when a person drinks untreated water. Intervention will most likely be required to improve the quality of water that is released into the public domain.	Regulatory intervention and mine mitigation is required if mining is the cause of this water class.
Class 3 (Red – Poor water quality)	> 10 to 100	Health effects are statistically detectable in very large population groups. This range represents excessive exposure. It is highly unlikely to find water of this poor quality in the natural environment.	Intervention is required and the time scales to be decided by the regulatory authorities on a case-by-case basis.
Class 4 (Purple – Unacceptable water quality)	> 100	Health effects may be clinically detectable and the dose represents a significant increase in the fatal cancer risk. A dose greater than 100 mSv can only occur during a major accident at a nuclear facility. These facilities have to demonstrate that such an accident has an extremely small likelihood.	Immediate intervention is required

A graded radioanalysis approach to characterising the radiological quality of water from natural sources such as farm boreholes and dams is used to establish baseline conditions prior to mining activities:

- A Basic Screening method (BS) is used for an initial radiological classification of water and to identify sources which could result in elevated doses and require further radioanalysis.
- An Advanced Screening method (AS) provides adequate information to radiologically classify the water quality.

- A Detailed Radioanalysis (DRA), measuring most of the individual radionuclides in the U-238 and Th-232 decay chains, allows a detailed dose assessment to be performed.

Table 2-4 describes the three methods. For routine monitoring purposes, one commences with the BS method and depending on the results as described in the column ñDecision Guideò, one would progress to more detailed analysis methods, i.e. AS and DRA methods.

Table 2-4 A graded approach to determining the radioactivity in water

Analysis Method	Description	Decision guide
Basic Screening Method (BS)	Gross alpha and gross beta radioactivity concentrations are measured. The chemical concentration of U (uranium) and K (potassium) are also determined This criterion is based on the fact that when one considers the dose conversion factors of all the relevant radionuclides and calculates the committed effective doses for the intake for these alpha and beta emitters (Ò1 Bq/L and Ò10 Bq/L) an annual dose less than 1 mSv is obtained.	1) If Gross Alpha radioactivity concentration Ò0.1 Bq/L and Gross Beta radioactivity concentration Ò1 Bq/L then Water Classification is **Blue** (annual dose Ò0.1 mSv/yr) 2) If Gross Alpha radioactivity concentration Ò1 Bq/L Gross Beta radioactivity concentration Ò10 Bq/L then Water Classification is **Green** (annual dose Ò1 mSv/yr) 3) If Gross Alpha radioactivity concentration > 1 Bq/L Gross Beta radioactivity concentration > 10 Bq/L then Water Classification is potentially **Yellow** and further nuclide specific radioanalysis is necessary.
Advanced Screening Method (AS)	This involves radionuclide activity measurement of two specific radionuclides, i.e. U-238 and Ra-226. Gross alpha activity and uranium chemical concentration are also measured and are used to check the validity of conclusions made based only on U-238 and Ra-226. Low-probability radionuclide behaviour, for example a high relative abundance of thorium radioisotopes, should be indicated by a low uranium chemical concentration (εg/L) and a high gross alpha-activity concentration. This would then indicate a requirement to analyse for more radionuclides in the U-235, U-238 and Th-232 decay series. This screening method is conservative at very low radioactivity concentrations (dose in the range 0.01 mSv/yr to 0.10 mSv/yr) when compared to a calculation using more or all measurable nuclides in the U-238,	Assume U-234 in equilibrium with U-238 and Pb-210 and Po-210 in equilibrium with Ra-226 Calculate U-235 = U-238 ÷ 21.7 Note: U-235 is included since it has a fairly constant natural abundance in relation to U-238. Result of dose calculation determines the water classification according to colour scheme.

Analysis Method	Description	Decision guide
	U-235 and Th-232 decay series. The assumption in the screening method of Pb-210 and Po-210 being in equilibrium with Ra-226 is used purely to introduce conservatism in the calculation and to flag a situation when the radioactivity concentration in the water may be high.	
Detailed Radioanalysis (DRA)	A wide spectrum radionuclide radioanalysis of the U-238 and Th-232 decay chains is performed, together with the chemical concentrations of U and K	Resultant dose calculation determines the water classification with a high degree of confidence

The World Health Organisation guideline radioactivity levels for the classification of drinking water relates to a *Blue* classification in Table 2-3. This quality of water is often only achievable for natural water from boreholes when further treatment is applied, for example a water treatment plant supplying a town/city. The water treatment plant removes a large fraction of NORM from the original source of water.

Seventeen water samples were collected during the 2016 hydrocensus survey reported in [17] and were submitted to the Necsa laboratory in Pretoria for gross alpha and beta activity analyses. A summary of the radioactivity results is given in Table 2-5. The basic screening results indicate a potential *yellow* water classification for 6 samples and that further radioanalysis would be required to achieve a more accurate radiological classification of these sources.

Table 2-5: Baseline water sample radioactivity results

#	Borehole identification	Alpha activity (Bq/L)	Beta activity (Bq/L)
1	DP6	2.36	0.96
2	LKL1	1.25	0.44
3	ERW5	1.59	0.47
4	RSK13	1.06	0.27
5	KPS9	0.397	0.0071
6	RSP6	2.46	0.35
7	KPT16	0.628	0.29
8	HKL13	0.778	0.402
9	LTS11	0.695	-0.0037
10	KGT9	1.42	0.24
11	KGT3	1.02	0.21
12	BDK1	0.997	0.16

#	Borehole identification	Alpha activity (Bq/L)	Beta activity (Bq/L)
13	1KS2	0.963	0.25
14	NFN3	0.11	-0.054
15	RD10	0.431	0.18
16	VV1	0.387	0.194
17	GP1	0.244	0.12

Examples of detailed radioanalysis results for various boreholes from earlier monitoring campaigns are included in Attachment 3. The water classification system is illustrated for the water from two boreholes, using a software code WaterRad [16]. The code provides dose results for various age groups as well as an age-weighted dose. An age-weighted dose assessment reflects the different sensitivity of the human body to radioactivity at the different ages, drinking from the same source. The sensitivity to radiation for different age groups is reflected in the differences in dose coefficients and intake quantity of water during the life of a person.

An interesting characteristic of groundwater is the U-234:U-238 radioactivity ratio. In surface waters the activity ratio U-234:U-238 is close to 1. In groundwater, the activity ratio is generally higher than 1. This can be observed in the groundwater results in Attachment 3. The phenomenon causing this disequilibrium is recoil damage during the radioactive decay process. After the emission of the alpha particle by the nucleus of U-238 bound in the crystalline structure of the host rock, the daughter product Th-234 is displaced from the original position of U-238. U-234 that forms from subsequent decay of Th-234 can then be more easily leached from the rock matrix than U-238 because of the structural damage (microscopic) caused by the recoil effect [18].

Radiological water quality is illustrated by the following two groundwater sample assessments. The one water sample was drawn from the aquifer at the historical Ryst Kuil trial mine which is in contact with the ore body; analysis reference RKNA 64. The second water sample was water from a borehole that is used for domestic purposes at a distance away from the historical trial mine; reference JOS5. The latter represents natural baseline conditions not affected by historic prospecting and trial mining. The results for the two water samples are as follows:

WaterRad results for RKNA 64 groundwater sample

Test Number:	RKNA64
Sample Date:	May 2008
User Name:	J Slabbert
Source:	Ryst Kuil Ore Body
Source Category:	B (water potentially affected by human actions)
Reasons for choosing category B:	Water sample from groundwater in contact with the Cameron Shaft ore body
Dose for different age groups:	
Dose for 0 - 1 years:	0.941 mSv/yr
Dose for 1 - 2 years:	0.208 mSv/yr
Dose for 2 - 7 years:	0.159 mSv/yr

Dose for 7 - 12 years: .... 0.146 mSv/yr

Dose for 12 - 17 years: .... 0.238 mSv/yr

Dose for 17 - 70 years: .... 0.201 mSv/yr

Lifetime Average Annual Dose: .... 0.207 mSv/yr

Water Class: .... 1 (**Green** ï Acceptable radiological water quality when considering the lifetime average dose)

WaterRad results for JOS 5 groundwater sample

Test Number: .... JOS5 (Necsa Job Reference RA-09172)

Sample Date: .... October 2008

User Name: .... J Slabbert

Source: .... Ryst Kuil Environment Baseline

Source Category: .... A (natural groundwater unaffected by human actions)

Reasons for choosing category A: .... Groundwater samples representative of water used for domestic purposes in the farming communities in the Ryst Kuil area (boreholes not in immediate proximity of ore body)

Dose for different age groups:

Dose for 0 - 1 years:..................................... 0.562 mSv/yr

Dose for 1 - 2 years:..................................... 0.099 mSv/yr

Dose for 2 - 7 years:..................................... 0.081 mSv/yr

Dose for 7 - 12 years:................................... 0.075 mSv/yr

Dose for 12 - 17 years:................................. 0.123 mSv/yr

Dose for 17 - 70 years:................................. 0.116 mSv/yr

Lifetime Average Annual Dose:...................... 0.117 mSv/yr

Dose range (mSv/yr): .... 0.10 to 1

Water Class: .... 1 (**Green** ï Acceptable radiological water quality) based on dose for most sensitive age group, 0 to 1 year

The radiological quality of the two groundwater samples are of similar radiological quality.

The radioanalyses of another borehole gave significantly higher results when compared to all the other borehole water results. The water sample taken from borehole KDK017 during November 2009 showed an as yet unexplained spike in respect of U-238 and U-234 concentrations. The concentrations remained high for at least four years, although gradually decreasing. The concentrations were still high compared to the sample results for the same borehole prior to November 2009. Water from this borehole will require treatment should it be used for human consumption. The results of the radiological quality assessment with WaterRad for KDK 017 are as follows:

WaterRad results for KDK017 groundwater sample

Test Number:	KDK017 (Necsa Job Reference RA-14671-01
Sample Date:	December 2013
User Name:	J Slabbert
Source:	Ryst Kuil Environment Baseline
Source Category:	A (natural groundwater unaffected by human activity)
Reasons for choosing category A:	Groundwater samples representative of water that could be used for domestic purposes if the high concentrations are not known
Dose for different age groups:	
Dose for 0 - 1 years:	1.901 mSv/yr
Dose for 1 - 2 years:	0.458 mSv/yr
Dose for 2 - 7 years:	0.353 mSv/yr
Dose for 7 - 12 years:	0.328 mSv/yr
Dose for 12 - 17 years:	0.537 mSv/yr
Dose for 17 - 70 years:	0.433 mSv/yr
Lifetime Average Annual Dose:	0.448 mSv/yr
Dose range (mSv/yr):	1.0 to 10
Water Class:	1 (**Yellow** ï Marginal water quality and some measure of intervention is required) based on dose for the most sensitive age group, 0 to 1 year

Apart from its radiological hazard, uranium can also pose a health risk because of its chemical toxicity; in most cases this is the dominant risk when high levels of uranium are present in water. In humans, the main toxic effect of short-term exposure to high concentrations of uranium is inflammation of the kidney. The World Health Organisation (WHO) provisional guideline for drinking-water quality is 30 µg/L of chemical uranium [19]. This value is considered to be protective for sub-clinical renal effects reported in epidemiological studies. The chemical uranium concentration in KDK017 is significantly higher than 30 µg/L and close to 100 µg/L. The elevated value should be considered anomalous and it is highly unlikely that prospecting or historical trial mining has had any impact on this borehole since it is located at least two kilometres away from the trial mining decline area (which has ñGreenò water quality). The borehole will be further researched in the future as part of the on-going monitoring programme. The water from the borehole is not currently used for human or agricultural purposes.

2-1.2.5 Sheep farming produce

2-1.2.5.1 Introduction

Sheep farming and its produce of meat and wool, is an important agricultural activity in the region. Other activities include game farming and mohair production. A limited number of samples were collected for radioanalyses to investigate the bioconcentration of NORM in mutton, sheep liver and wool. A single sample of venison (Springbok) was also collected and analysed. The radioactivity concentrations that were measured and reported here are the radioactivity that is attributable to the ubiquitous nature of NORM in the environment, unrelated to mining and prospecting activities. The range of radionuclides measured in the sheep samples also appear in humans and other organisms, a fact of living on earth.

Samples were collected with the following main objectives:

- obtain an indication of the primary radionuclides in respect of human dose from the ingestion of mutton and liver collected from the region under current and pre-mining environmental conditions (the baseline radiological dose to humans from ingestion of sheep mutton and liver is estimated);
- determine the relative importance of the different NORM radionuclides in different types of biological samples (the levels of NORM in sheep wool and mohair were also measured and are compared to the radioactivity concentrations in sheep tissue; and
- compare the results with similar studies reported in literature.

Samples were collected from the locations listed in Table 2-6.

Table 2-6: Biological samples collected for radioanalysis

Biological sample type	No. of samples	Farming area
Mutton	6	2 x Quaggasfontein 1 x Haanekuil 2 x De Pannen 1 x A butchery in Beaufort West (1)
Sheep liver	3	2 x Quaggasfontein 1 x Haanekuil
Wool	3	1 x Haanekuil 1 x Kat Doorn Kuil 1 x De Pannen
Mohair	1	1 x Quaggasfontein
Springbok venison	1	1 x De Pannen

(1) The sample collected from a local butcher and represents a random sample from the general region being sold to the public.

2-1.2.5.2 Radioactivity concentrations

The radioactivity concentrations measured in samples are listed in Table 2-7. Radionuclide concentrations relative to one another are illustrated in Figure 2-3 .

Table 2-7 Radioactivity concentration in samples (Bq/kg - fresh weight)

Nuclide	Mutton (Bq/kg)			Liver (Bq/kg)			Wool (Bq/kg)			Springbok venison (Bq/kg)
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	
U-238	2.15E-02	7.30E-03	4.66E-02	8.16E-02	2.65E-02	1.90E-01	3.82E+00	2.00E+00	5.30E+00	1.20E-02
U-234	2.17E-02	7.40E-03	4.70E-02	8.25E-02	2.67E-02	1.92E-01	3.85E+00	2.02E+00	5.35E+00	1.20E-02
Ra-226	5.35E-01	1.28E-01	1.61E+00	5.13E-01	9.53E-02	9.95E-01	3.11E+00	1.81E+00	3.73E+00	2.09E-01
Pb-210	9.60E-01	9.60E-01	2.60E+00	5.10E-01	5.10E-01	5.10E-01	2.72E+01	1.47E+01	3.97E+01	< MDA
Po-210	1.25E+00	4.00E-01	1.98E+00	1.46E+00	7.27E-01	1.84E+00	2.72E+01	1.47E+01	3.97E+01	2.10E+00
U-235	9.93E-04	3.40E-04	2.14E-03	3.76E-03	1.22E-03	8.76E-03	1.76E-01	9.20E-02	2.44E-01	5.40E-04
Th-232	-	-	2.00E-01	-	-	7.80E-02	3.65E+00	1.99E+00	5.16E+00	< MDA
Ra-228	1.31E+00	1.31E+00	1.31E+00	-	-	1.30E+00	4.28E+00	2.32E+00	5.17E+00	2.20E-01
Th-228	2.38E-01	6.00E-02	4.16E-01	5.76E-02	5.76E-02	5.76E-02	4.02E+00	2.19E+00	4.91E+00	< MDA
K-40	7.02E+01	5.54E+01	8.79E+01	6.60E+01	5.39E+01	8.70E+01	7.11E+02	3.39E+02	1.42E+03	9.35E+01

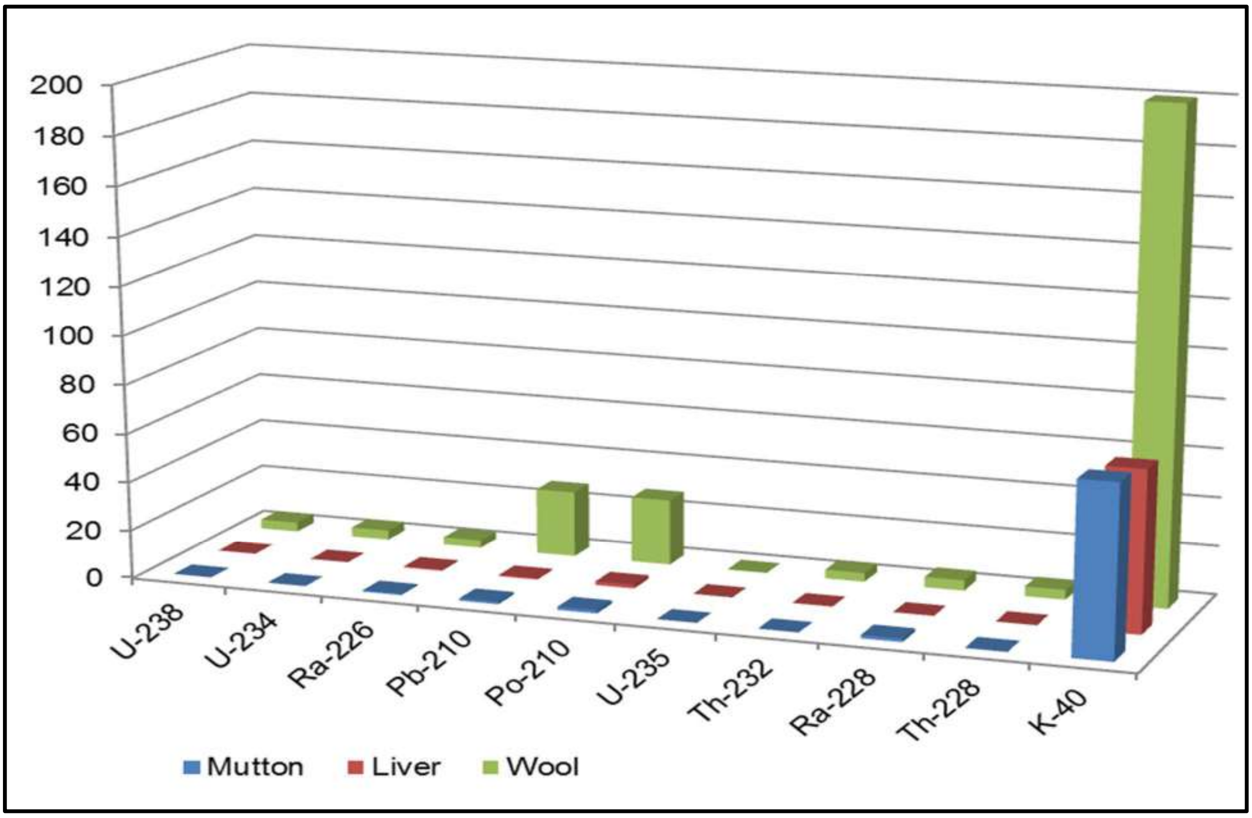


Figure 2-3: Radionuclide specific activities in sheep samples Bq/kg (average values)

Concentrations of radioactive potassium (K-40) are typical of concentrations reported in the literature and are normally high relative to the other radionuclide concentrations. Po-210 was not analysed for wool and mohair samples since they do not form part of the ingestion pathway. The Po-210 concentration is assumed to be in secular equilibrium with Pb-210 in wool and mohair samples.

The radioactivity concentrations in a single sample of venison (springbok) are at similar concentration levels to those recorded in the sheep samples.

The results for radioactivity in Karoo sheep can be compared with the results from two European studies. One of the studies determined the impact of natural radioactivity in animal products on the annual effective dose of a population group [20]. The following radioactivity concentrations were reported for mutton samples:

- U-238: 0.010 - 0.024 Bq/kg
- Ra-226: 0.014 - 0.035 Bq/kg, and
- K-40: 65.2 - 99.5 Bq/kg.

These values are of the same order of magnitude as those of the Karoo samples.

Another study provides results for a contaminated area and was carried out at the Boco mining area in Portugal, an area that experienced extensive radium and uranium mining in the past [21]. It was an area where no access controls existed and no rehabilitation was done, a situation that is very different to the legal requirements for controls and closure conditions for modern uranium mines. The mine was in operation during the 1960s and 70s. Mining waste and open pits were left uncovered since mine closure. During the 1990's, a quarry for sand extraction was operated in the same site and water from a local stream was extensively used in sand sieving. Agriculture land downstream from the mine area is used for cattle grazing. Water from the stream, water wells, soil, pasture and sheep meat were analysed for radionuclides of uranium decay chain. The radionuclide Ra-226 was generally the highest concentrations especially in soil, pasture and in internal organs of sheep. Ra-226 concentrations were 1.193 ± 84 Bq/kg in sheep meat. This value is approximately double the value for Karoo sheep. It is reported from the Boco samples that other sheep internal organs displayed much higher Ra-226 concentrations, such as the brain and kidneys with 1.850±613 Bq/kg and 6,043±6,023 Bq/kg, respectively.

The results of the two studies clearly demonstrate that remediation of mine sites to a level representative of pre-mining baseline conditions will be required for unconditional release of mining area.

2-1.2.5.3 Human dose from eating sheep mutton and liver containing radioactivity concentrations representative of baseline conditions in the region

Human dose estimates for the consumption of mutton and sheep liver listed in Table 2-8 are based on ICRP publication 72 dose coefficients [22] and the National Nuclear Regulator guideline values [5].

Table 2-8: Estimated age specific human consumption rates

Category	Kg per year fresh weight		
	Infant	Child	Adults
% of Adult	40	60	100
Mutton (kg/a)	10	15	25
Sheep liver	4	6	10

Table 2-9 lists radionuclide specific ingestion dose and total ingestion dose based on the average concentrations calculated for all sheep samples. Only the radioactivity concentrations reported by Necsa Radioanalysis Laboratory that measured above the minimum detectable levels were used in the dose calculations. The minimum detectable activity (MDA) is the radioactivity which, if present in a sample, produces a counting rate that will be detected (i.e. considered to be above background) with a certain level of confidence. The level of confidenceô is normally set at 95%, i.e. a sample containing exactly the minimum detectable activity will, as a result of random fluctuations, be taken to be free of radioactivity 5%of the time. The minimum detectable activity is sometimes referred to as the detection limit or lower limit of detection. The counting rate from a sample containing the minimum detectable activity is termed the determination level.

Table 2-9: Radionuclide specific and total annual effective dose per (mSv/y)

Nuclide	Infant		Child		Adult	
	Dose (max radioactivity concentration)	Dose (average radioactivity concentration)	Dose (max radioactivity concentration)	Dose (average radioactivity concentration)	Dose (max radioactivity concentration)	Dose (average radioactivity concentration)
K-40	0.052	0.041	0.024	0.019	0.019	0.015
U-238	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
U-234	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Th-230	0.001	< 0.001	< 0.001	< 0.001	0.001	< 0.001
Ra-226	0.019	0.007	0.020	0.009	0.012	0.005
Pb-210	0.042	0.042	0.030	0.033	0.018	0.020
Po-210	0.239	0.161	0.066	0.072	0.051	0.055
U-235	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Pa-231	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Nuclide	**Infant**		**Child**		**Adult**	
	Dose (max radioactivity concentration)	**Dose (average radioactivity concentration)**	**Dose (max radioactivity concentration)**	**Dose (average radioactivity concentration)**	**Dose (max radioactivity concentration)**	**Dose (average radioactivity concentration)**
Ac-227	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Th-227	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Ra-223	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Th-232	0.001	< 0.001	0.001	< 0.001	0.001	< 0.001
Ra-228	0.104	0.075	0.107	0.077	0.316	0.226
Th-228	0.002	0.001	0.001	0.001	0.001	< 0.001
Ra-224	0.003	0.000	0.002	< 0.001	0.001	< 0.001
Total dose (mSv/y)	***0.463***	***0.327***	***0.251***	***0.210***	***0.419***	***0.322***

The dose results can be compared to the global average background radiation dose from ingestion of food as well as water [4]. The dose to the infant old age group, the most sensitive age group, is higher than the global average dose of 0.3 mSv/y but still falls in the global range of annual ingestion dose from background radioactivity; i.e. between 0.2 and 0.8 mSv/y.

The radionuclide that contributes most to human dose is an isotope of polonium, Po-210. Po-210 is an emitter of energetic alpha particle radiation and is approximately 210 times more radiotoxic that U-238, for example. Po-210 is the daughter decay product of radon, the gaseous daughter product of Ra-226.

The potassium radioisotope K-40 that is part of the primordial radioactivity in the earth's crust, has the highest concentrations in samples but is significantly less radiotoxic than Po-210. Potassium is a common element and the radioactive isotope, K-40, constitutes 0.012% of all potassium in its natural form. Wool has a much higher concentration of K-40 than sheep muscle and liver tissue samples.

2-1.2.6 Conclusions Regarding Natural Existing Radiation Levels

The Phase 1 baseline monitoring results allow preliminary conclusions to be drawn in respect of the natural background radiation in the KUP region. These are:

- The external radiation levels are generally low in the area except where the uranium-bearing outcrops are found at the surface.

- Radon concentrations are low and any significant environmental radon contribution from the potentially large sources such as mining areas should be detectable before levels of concern are reached.
- Radioactivity concentrations in groundwater samples are mainly from U-238, U-234, and in some cases, Th-230. The other radionuclides in the U-238 and Th-232 decay chains are present at low concentrations. Most of the groundwater samples, although not of ideal radiological quality, indicate acceptable quality except for borehole KDK017 in the Ryst Kuil area.
- Baseline airborne dust with particle size fractions that can penetrate deeper regions of the human respiratory tract (smaller than 10 µm aerodynamic mean diameter) is assumed to be at very low concentrations in the KUP areas. The typical Karoo vegetation and rocky surfaces contribute to a low dust generation potential. Background dose from dust inhalation should be negligible. Dust concentrations will be measured during Phase 2 of baseline monitoring.

2-1.3 Radioactively Contaminated Areas that Resulted from Historical Uranium Prospecting and Trial Mining

Uranium exploration in the Karoo peaked in 1977/1978 when Union Carbide Exploration conducted open pit trial mining at Rietkuil approximately 42 km west of Beaufort West and ESSO Minerals conducted underground trial mining at Ryst Kuil approximately 43 km south-east of Beaufort West. At Ryst Kuil, a sample preparation crusher was constructed near the decline and about 4 500 tonnes of ore was extracted through underground test mining between August 1978 and September 1979. Access to the ore body was by a tracked decline approximately 500 m long to a depth of 50 m below surface. No yellowcake processing of the ore was done on the site.

The prospecting and trial mining that took place during this period did not implement proper remediation of contaminated areas and safe storage for the remaining uranium ore stockpiles was not provided. Figure 2-4 shows the area where the trial mining took place at Ryst Kuil. The site was abandoned and left accessible to members of the public. Some of the uranium ore was removed from the stockpiles and used as gravel to fill potholes on parts of nearby farm roads. An example is shown in Figure 2-5. Most of this radioactive ore has since been removed from the road surfaces for safe storage at the radiation controlled site at Ryst Kuil.

The NNR has since implemented regulations for exploration, mining, and mineral processes that involve elevated levels of NORM. Companies now require a Certificate of Registration (COR) from the NNR and it includes conditions that should avoid a repetition the ñradiological sinsòof the past.

Rehabilitation of prospecting drill sites and control of historical stockpiles at Ryst Kuil has been carried out under the current CORs, actions that still continue. The trial mine area shown in Figure 2-4 has been fenced off and access control is being implemented. Similar actions have been implemented at the Riet Kuil trial mine area. Figure 2-6 illustrates examples of the rehabilitation of prospecting drill sites and the improvement of safety at the underground trial mine entrance at Ryst Kuil. From the evidence available, it is fair to state that the current companies who are holders of the prospecting rights and CORs in the Karoo are rehabilitating legacy radioactive sites that would otherwise have been left in a hazardous state.

Figure 2-4: The main contaminated area where ore storage access to underground mine area (Cameron shaft) and the crushing plant were located

Figure 2-5: Radioactive uranium ore used to fill potholes on a farm road near at Ryst Kuil

Figure 2-6: Before and after illustrations of the Cameron shaft entrance and a drill sites

SECTION 3

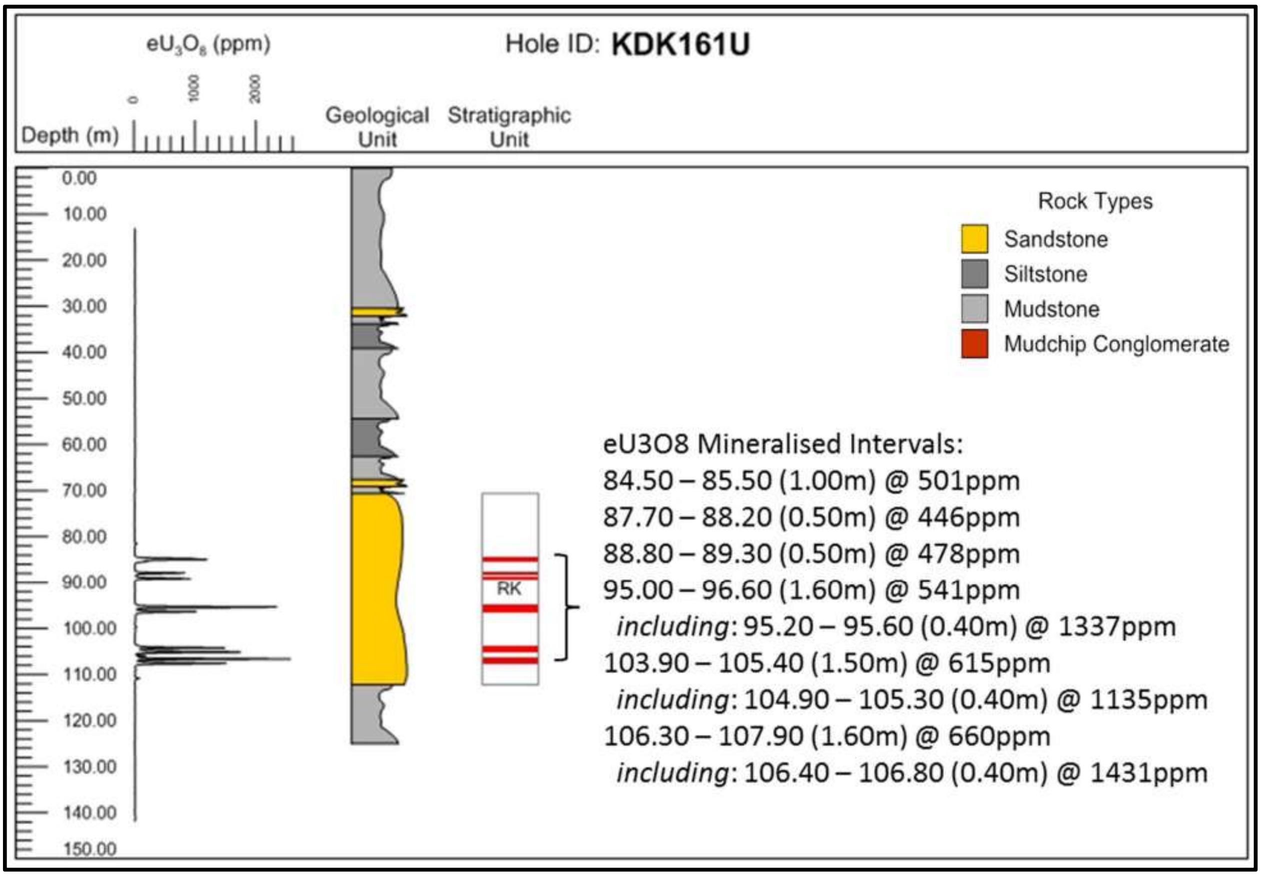
A Prospective Assessment of the Radiation Hazards to Members of the Public

3-1 SAFETY ASSESSMENT

3-1.1 Assumptions and Limitations

The doses to members of the public are calculated for airborne discharges and exposure pathways using conservative assumptions. The discharges of radon and dust from the TSF, for example, were assumed to be at end of mine life when a protective cover has not yet been installed. The source terms for the dose assessment models are discussed in §3-1.4.

Airborne dust discharges containing elevated levels of NORM are only generated when the uranium ore is exposed and processed. Dust generation during open pit mining, for example, involves mainly non-radioactive material containing radionuclide specific activities less than 0.5 Bq/g, the level below which the NNR does not consider material be classified as radioactive. This can be deduced from exploration borehole logging results, an example of which is illustrated in Figure 3-1. The depth of the uranium ore body is indicated by sharp radiometric spikes on the left of the figure. It shows that the overburden and waste rock material is non-radioactive. From this it can be seen that less than 10 per cent of all material mined at the open pits will contain elevated levels of uranium mineralisation. Non-radiological impacts of dust are reported in the air quality studies included in the KUP EIA prepared for the mining rights applications.



eU3O8 Mineralised Intervals:
84.50 – 85.50 (1.00m) @ 501ppm
87.70 – 88.20 (0.50m) @ 446ppm
88.80 – 89.30 (0.50m) @ 478ppm
95.00 – 96.60 (1.60m) @ 541ppm
including: 95.20 – 95.60 (0.40m) @ 1337ppm
103.90 – 105.40 (1.50m) @ 615ppm
including: 104.90 – 105.30 (0.40m) @ 1135ppm
106.30 – 107.90 (1.60m) @ 660ppm
including: 106.40 – 106.80 (0.40m) @ 1431ppm

Figure 3-1: Example of borehole exploration results from a future open pit

It was conservatively assumed that waste rock from all pits will be on surface and act as a source of airborne emissions. Open pits will however be backfilled as they become mined out except at those few pits where access will be provided for underground mining.

Naturally occurring ThO_2 at 30 ppm (approximately 1 Bg/g Th-232 in equilibrium with its decay products) has been included in the various source terms.

Exposure pathways associated with potential liquid discharges are discussed in a qualitative manner. The importance of liquid exposure pathways and its contribution to public dose are sensitive to mine design and water balance management. KUP is designed not to release water from the mine areas. These aspects of design are described in the KUP EIA. It is therefore assumed that there will be no additional dose to a member of the public from liquid exposure pathways during normal operation of the mine. Monitoring and mitigation measures in respect of potential water impacts are reported in the KUP EIA.

Liquid borne exposure pathways, although not likely to occur during mine operations, are important potential exposure pathways to be considered after mine closure. Closure design of the TSF based on international best practice decreases the risks associated with future water borne exposure pathways. The design aspects of the TSF are therefore critical to be assessed also in respect of closure conditions. A detail safety assessment of the design of the TSF falls outside the scope of this radiological safety assessment.

In this report, the term ñsensitive receptorò is used to indicate farming communities located in the same region as KUP. For the purpose of this report it is the collection of members of the public from which the representative person, the term used in radiation protection, will be selected. The representative person is defined as an individual receiving a dose that is representative of the more highly exposed individuals in the population [24]. In considering dose to the representative person, a number of factors should be taken into account, for example:

- the dose assessment must account for all relevant pathways of exposure;
- the dose assessment must consider spatial distribution of radionuclides to be assured that the group receiving the highest dose is included in the assessment;
- habit data should be based on the group or population exposed and must be reasonable, sustainable, and homogeneous; and
- dose coefficients have to be applied according to specific age categories.

The dose assessment for KUP is based on a deterministic approach. It involves the direct multiplication of selected point values of environmental parameters and radioactivity concentrations. The simplest form of deterministic method is screening based on conservative assumptions. Data on actual habits and lifestyles of the representative person can significantly influence the magnitude of radiation exposure and annual dose. The assumptions included in the dose assessment models in this report make it unlikely that the annual dose to a member of the public is underestimated.

The dose assessment has to consider different age groups because of the difference in sensitivity to radiation. The ICRP considers that three age groups are generally sufficient to encompass age-related exposure and dose variations. The ICRP recommends the use of three age groups for estimating annual dose to the representative person [24]. The age groups are:

- Infant: 0ï 5 years;
- Child: 6ï 15 years;
- Adult: 16ï 70 years.

Justification for selecting only three age groups includes the following:

- experience to date indicates that age categories can be combined without impacting on protection of members of the public, and
- the age groups being sufficient to characterise the radiological impact of an action and to ensure consideration of younger more sensitive population.

Reference points referred to as sensitive receptor locations have been selected for the mine region and are representative of the farming communities located in the potential impact zone of the KUP. Dose calculations were carried out at these sensitive receptor locations listed in Table 3-1 and illustrated in Figure 3-2.

Table 3-1: Sensitive receptors from which the potential representative person will be selected

Set of farmsteads from which critical exposure group is identified		**UTM coordinates (m)**	
		Easting	**Northing**
Kat Doorn Kuil	R1	663918	6379571
Kant Kraal	R2	662868	6374441
Klipstawels	R3	669318	6374745
Klipkrans	R4	678732	6374449
Eerstewater	R5	685029	6380458
Ryst Kuil	R6	679071	6387182
Lootsplaas	R7	696836	6389379
Haanekuil	R8	693147	6393690
Kareepoort	R9	721855	6405943
Quaggasfontein	R10	647827	6411312
Bokvlei	R11	721402	6409683
Beaufort West	R12	648963	6419118
Olive Grove	R13	648691	6402248
Blouboskuil	R14	660778	6409774
Oude Volks Kraal	R15	662567	6407796
Uitsig	R16	664212	6405900
Retreat	R17	665405	6403901
Hansrivier	R_18	652985	6415032
Steenrotsfontein	R19	647067	6412220
Saucyôs Kuil	R20	668403	6395402
Amosvlei	R21	659892	6371439
Vaalkraal	R22	664873	6369131
Blydskap	R23	700824	6389179
Rooidam Farmstall	R24	709736	6393349

Set of farmsteads from which critical exposure group is identified		UTM coordinates (m)	
		Easting	Northing
Toornitzkuil	R25	674940	6389363
Hoekskuil	R26	665148	6388265
Veerekuil	R27	696020	6399982
Losboome	R28	705873	6407046
Kat Doorn Kuil	R29	670030	6381944
De Pannen	R30	711706	6410045
Nuwejaarskuil	R31	706858	6395414
De Puts	R32	723244	6393436
Oorlogspoort	R33	730048	6413075
Nuwejaarsfontein	R34	708573	6395612
Rooidraai	R35	739194	6402652
Vaalvlei	R36	728754	6406780
Upper Kiewietskuil	R37	733420	6398237
Bosduiwerivier	R38	715072	6381614
Rhenosterkop	R39	684191	6372138
Bothasdale	R40	648546	6375672
Goodhope	R41	648061	6379825
Jonkersleegte	R42	648576	6388729
Grootkraanvoelkuil	R43	678642	6400798
Helvetia	R44	683309	6418651
Eensaam	R45	705499	6381951
Hoekraal	R46	695187	6377300
Reyersvlei	R47	699596	6404815
Beyerskloof	R48	726675	6418131
Theefontein	R49	718198	6419656
Neverset	R50	688775	6395786

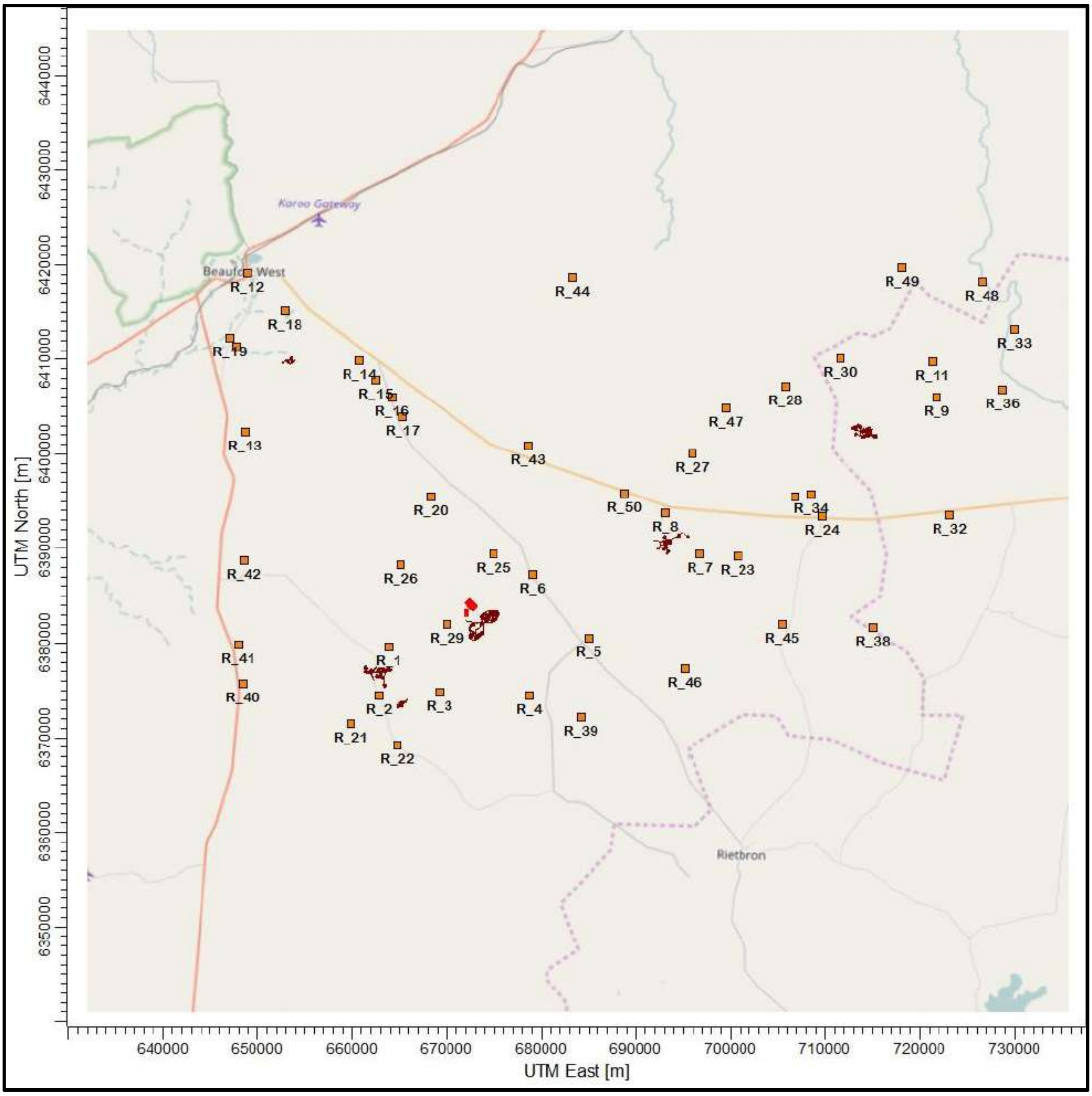


Figure 3-2: Sensitive receptor locations

The assumptions in respect of time spent indoors and outdoors and food consumption that are used in the dose assessment model are listed in Table 3-2 will be updated following a more comprehensive habit study and to confirm the conservatism in respect of these values.

Table 3-2: Habit data assumptions for each sensitive receptor location

Age Group	Indoor Occupancy Factor	Outdoor Occupancy Factor	Indoor Shielding Fraction	Vegetation Ingestion Rate (kg/yr)	Meat Ingestion Rate (kg/yr)	Milk Ingestion Rate (kg/yr)
Infant	0.5	0.5	0.5	40	30	48
Child	0.5	0.5	0.5	50	45	72
Adult	0.5	0.5	0.5	100	75	120

3-1.2 Meteorological Data

Meteorological data representative of the different mine sites is essential for determining radiation hazards from atmospheric exposure pathways. Since there are no weather stations at the sites, meteorological data consisting of hourly records were obtained for the year 2015 based on MM5 modelled meteorological data and prepared by Lakes Environmental Consultants in Canada. The Pennsylvania State University / National Center for Atmospheric Research (PSU/NCAR) meso-scale model (known as MM5) is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict meso-scale atmospheric circulation. This data type has been tested extensively internationally and has been found to be an accurate representation of conditions when data for a specific site are prepared. A data set covering a 100 km^2 area with a 4 km^2 grid resolution was obtained for the region in which the mine area is located.

The MM5 data was used to create joint frequency distribution (wind speed and stability categories) data format for use in the MILDOS-AREA software code. The MILDOS-AREA code is used for public dose assessment of airborne radioactivity (radon and dust containing LL-alpha radioactivity) arising from mining activities. The MM5 data set was also used in the advanced atmospheric dispersion modelling carried out with CALPUFF.

3-1.3 Dose assessment methodology

A deterministic approach was followed using conservative values for source terms to assess airborne exposure pathways. The dose assessment was carried out with the software code MILDOS-AREA Version 4 [25]. It is used by United States Nuclear Regulatory Commission as a primary licensing and evaluation tool for uranium mining. The code models the impacts of elevated levels of NORM radionuclides in the environment and originating from uranium mines. It is specifically designed to model airborne discharges. It calculates the external radiation and internally committed doses received by humans living 24 hours a day and 365 days a year at user specified locations. The environmental dispersion of airborne source terms is predicted by using a sector-averaged Gaussian plume dispersion model. The code models mechanisms such as radioactive decay, plume depletion by deposition, ingrowth of U-238 decay progeny (daughter products), and resuspension of deposited radionuclides. These mechanisms are accounted for in the site-specific models developed for KUP. The exposure pathways in the models for different age groups are inhalation, external exposure from ground-shine caused by deposited radioactivity and radioactive cloud immersion, and ingestion of foodstuffs produced at the sensitive receptor locations.

The scientific basis for dose assessment for MILDOS-AREA is described in ICRP Publication 26 and Publication 30 [26]. The dose coefficients in these publications have been revised and are described in ICRP Publication 72 [27]. Some further changes will be published as a result of ICRP Publication 103 [28]. These publications introduced modifications to the biological modelling used to calculate dose. In the case of some nuclides, the dose per unit radioactivity, referred to as the dose coefficient (DCF), became less, i.e. more of a specific radionuclide is now required to deliver the same dose. This implies that MILDOS-AREA calculates the dose conservatively for these radionuclides. For some other radionuclides, the opposite is true. The question therefore is whether MILDOS under-predicts or over-predicts public doses mining operations when considering the changes in ICRP DCFs.

The DCFs for U-238 and its decay products were investigated and compared to the latest available information in ICRP publications. It was determined that the MILDOS-AREA DCFs provide more conservative results for the exposure scenarios considered for KUP. The results of comparison tests are presented in Table 3-3 and Table 3-4. The results confirm the conservatism in MILDOS-AREA results for inhalation and ingestion of the KUP source term radionuclides.

Table 3-3: A comparison of the inhalation DCFs: MILDOS-AREA and ICRP 72

Inhalation Dose Coefficient; Sv/Bq			**U-238**	**U-234**	**Th-230**	**Ra-226**	**Pb-210**
AMAD = 1.0 µm	**Infant**	MILDOS	1.53E-04	1.72E-04	1.58E-04	2.78E-05	6.24E-06
		ICRP 72	2.50E-05	2.90E-05	7.40E-05	9.40E-07	2.90E-06
		Conservatism Factor	6.12E+00	5.94E+00	2.14E+00	2.95E+01	2.5E+00
	Adult	MILDOS	3.19E-05	3.59E-05	8.80E-05	2.31E-06	2.49E-06
		ICRP 72	8.00E-06	9.40E-06	4.30E-05	3.60E-07	9.00E-07
		Conservatism Factor	3.98E+00	3.82E+00	2.05E+00	6.43E+00	2.77E+00

Table 3-4: A comparison of the ingestion DCFs of MILDOS-AREA and ICRP 72

Ingestion Dose Coefficient; Sv/Bq		U-238	U-234	Th-230	Ra-226	Pb-210
Infant	MILDOS	4.35E-06	4.83E-06	5.70E-06	8.40E-06	8.40E-06
	ICRP 72	1.20E-07	1.30E-07	4.10E-07	9.60E-07	3.60E-06
	Conservatism Factor	3.62E+01	3.72E+01	1.39E+01	8.75E+00	2.33E+00

Ingestion Dose Coefficient; Sv/Bq		U-238	U-234	Th-230	Ra-226	Pb-210
Adult	MILDOS	6.89E-08	7.67E-08	3.56E-07	1.38E-06	1.38E-06
	ICRP 72	4.50E-08	4.90E-08	2.10E-07	2.80E-07	6.90E-07
	Conservatism Factor	1.53E+00	1.56E+00	1.70E+00	4.92E+00	2.00E+00

The dose coefficient used in MILDOS-AREA for radon, including its short-lived progeny in full equilibrium, is 135 µSv/yr per Bq/m^3. Without its decay progeny, it is 1.35 µSv/yr per Bq/m^3. Due to the relatively short half-life of radon, the downwind air concentrations are corrected for decay during transport. The concentration of radon daughters at a given downwind distance depends on their ingrowth during the transit time.

It is concluded that the calculation method does not underestimate the radon dose when compared to the current methodology for a radon DCF followed by the NNR [29]:

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

= 5.56E-03[(µJ/m^3)/(Bq/m^3)EEC] x F x 8760 [h/yr] x Occupancy x 1.1 [(µSv)/(µJ.h/m^3)]

The parameter values and assumptions normally used are:

F(indoors) = 0.4

F(outdoors) = 0.8

The above dose coefficients for radon and progeny are based on nominal values of radiation detriment derived from epidemiological studies. The ICRP now follows the same approach to intakes of radon and its progeny as that applied to other radionuclides, using reference biokinetic and dosimetric models. Dose coefficients are given for different reference conditions of domestic and occupational exposure, taking into account factors including inhaled aerosol characteristics and disequilibrium between radon and its progeny. The current dose conversion values shown above are continued to be used in South Africa used until such time that the NNR formally adopts the new ICRP dose coefficients. The change is likely to result in an increase in effective dose per unit Rn-222 exposure of around a factor of two as described in [30]. This change may then also have an impact on regulatory dose criteria.

3-1.4 Source Terms for Airborne Discharges

The sources of radon and dust containing LL-alpha radioactivity that are included in the MILDOS-AREA dispersion model are based on the KUP production rates and ore grades supplied by TASPAC. These are listed in Table 3-5.

Table 3-5: Annual production rates of uranium ore at different mining areas

Mine Area	U ore production rate (t/yr)	Radionuclide	Ore U-238 and Th-232 specific radioactivity (Bq/g)
Quaggasfontein	1.17E+05	U-238	14.4
	1.17E+05	Th-232	0.1
Haanekuil	4.07E+05	U-238	15.1
	4.07E+05	Th-232	0.1
De Pannen	2.19E+05	U-238	29.0
	2.19E+05	Th-232	0.1
Ryst Kuil Main	6.05E+05	U-238	13.4
	6.05E+05	Th-232	0.1
Ryst Kuil Extension	5.14E+05	U-238	11.4
	5.14E+05	Th-232	0.1
Ryst Kuil Abante	2.79E+05	U-238	12.0
	2.79E+05	Th-232	0.1
Ryst Kuil South	1.06E+05	U-238	9.2
	1.06E+05	Th-232	0.1
Central Processing Plant	1.21E+06	U-238	12.8
	1.21E+06	Th-232	0.1

The source terms that have been developed for KUP are listed in Table 3-6.

The natural occurrence of Th-232 and its principal decay products have been included in the source terms (approximately 3 Bq/g).

Table 3-6: Annual discharges from KUP sources to the atmosphere used in the safety assessment, Bq/yr

Mine Area	**Source**	**Rn-222**	**U-238**	**Th-230**	**Ra-226**	**Pb-210**	**Th-232**
Ryst Kuil Group: **Main, South, Extension, Abante**	RK Main Pit 01	5.44E+12	1.08E+08	1.08E+08	1.08E+08	1.08E+08	8.98E+05
	RK Main Waste Rock	1.87E+13	2.45E+07	2.45E+07	2.45E+07	2.45E+07	1.32E+06
	RK Abante Waste Rock01	1.03E+13	1.34E+07	1.34E+07	1.34E+07	1.34E+07	7.17E+05
	RK Abante Waste Rock02	3.08E+12	4.05E+06	4.05E+06	4.05E+06	4.05E+06	2.16E+05
	RK Abante Waste Rock03	1.69E+12	2.21E+06	2.21E+06	2.21E+06	2.21E+06	1.18E+05
	RK Extension Waste Rock01	2.26E+12	2.96E+06	2.96E+06	2.96E+06	2.96E+06	1.58E+05
	RK Extension Waste Rock02	1.93E+12	2.54E+06	2.54E+06	2.54E+06	2.54E+06	1.36E+05
	RK Abante Pit03	7.24E+12	1.45E+08	1.45E+08	1.45E+08	1.45E+08	1.48E+06
	RK Extension Waste Rock03	4.90E+12	6.39E+06	6.39E+06	6.39E+06	6.39E+06	3.43E+05
	RK Extension Waste Rock04	5.00E+12	6.53E+06	6.53E+06	6.53E+06	6.53E+06	3.50E+05
	RK Extension Waste Rock05	3.43E+12	4.52E+06	4.52E+06	4.52E+06	4.52E+06	2.41E+05
	RK Extension Pit01	3.57E+12	7.14E+07	7.14E+07	7.14E+07	7.14E+07	7.51E+05
	RK Extension Pit04	1.51E+12	3.01E+07	3.01E+07	3.01E+07	3.01E+07	3.17E+05
	RK South Waste Rock	4.76E+12	6.26E+06	6.26E+06	6.26E+06	6.26E+06	3.18E+05
	RK South Pit01	8.06E+11	1.62E+07	1.62E+07	1.62E+07	1.62E+07	2.27E+05
	RK South Pit02	9.79E+11	1.96E+07	1.96E+07	1.96E+07	1.96E+07	2.76E+05

Mine Area	Source	Rn-222	U-238	Th-230	Ra-226	Pb-210	Th-232
	RK South Pit04	6.15E+11	1.23E+07	1.23E+07	1.23E+07	1.23E+07	1.73E+05
	RK TSF	3.04E+14	3.98E+07	3.98E+08	3.98E+08	3.98E+08	3.43E+06
	CPP U Plant Drying Packing	0.00E+00	1.01E+10	5.07E+07	1.01E+07	1.01E+07	0.00E+00
	CPP Ore Pad	2.04E+13	2.67E+07	2.67E+07	2.67E+07	2.67E+07	2.11E+05
	CPP Crusher	5.71E+07	5.71E+08	5.71E+08	5.71E+08	5.71E+08	4.45E+06
	CPP Truck Unloading	0.00E+00	4.76E+08	4.76E+08	4.76E+08	4.76E+08	3.74E+06
Haanekuil	HK Truck Loading (in pits)	0.00E+00	1.87E+08	1.87E+08	1.87E+08	1.87E+08	1.25E+06
	HK Pit 05	2.25E+13	4.22E+07	4.22E+07	4.22E+07	4.22E+07	4.39E+05
	HK Pit 04	3.47E+13	6.46E+07	6.46E+07	6.46E+07	6.46E+07	6.70E+05
	HK Waste Rock	1.64E+13	2.15E+07	2.15E+07	2.15E+07	2.15E+07	1.15E+06
De Pannen	DP Crusher	4.69E+07	2.34E+08	2.34E+08	2.34E+08	2.34E+08	8.06E+05
	DP Waste Rock	3.71E+13	4.86E+07	4.86E+07	4.86E+07	4.86E+07	2.59E+06
	DP Pit 1A	1.17E+14	2.19E+08	2.19E+08	2.19E+08	2.19E+08	8.36E+05
	DP Pit 1B	6.12E+13	1.14E+08	1.14E+08	1.14E+08	1.14E+08	4.39E+05
	DP Truck loading/unloading	0.00E+00	3.91E+08	3.91E+08	3.91E+08	3.91E+08	1.35E+06
Quaggas-fontein	QF Crusher	6.19E+07	3.09E+08	3.09E+08	3.09E+08	3.09E+08	2.16E+06
	QF Waste Rock	2.29E+12	1.06E+08	1.06E+08	1.06E+08	1.06E+08	5.68E+06
	QF Pit 01	5.00E+12	9.35E+06	9.35E+06	9.35E+06	9.35E+06	7.21E+04
	QF Pit 02	2.79E+13	5.24E+07	5.24E+07	5.24E+07	5.24E+07	4.05E+05

Mine Area	**Source**	**Rn-222**	**U-238**	**Th-230**	**Ra-226**	**Pb-210**	**Th-232**
	QF Pit 03	2.66E+13	4.96E+07	4.96E+07	4.96E+07	4.96E+07	3.84E+05
	QF Truck Loading/Unloading	0.00E+00	1.03E+08	1.03E+08	1.03E+08	1.03E+08	7.17E+05

Drying and packing uranium: U_3O_8 Production rate; (t/yr)	**U-238 (Bq/yr)**	**≤ 0.1% Drying and packing plant stack release (Bq/yr)**			
		U-238	**Th-230**	**Ra-226**	**Pb-210**
1066	1.11E+13	1.11E+10	5.57E+07	1.11E+07	1.11E+07

The development of these source terms included the following information:

- elevation of discharges;
- area and location of discharges;
- discharge rates;
- radon and dust particle containing LL-alpha radioactivity size distribution; and
- meteorology and climatology (e.g. wind speeds, atmospheric stability and rainfall)

Source terms for ore loading, unloading and crushing are derived from US NRC [31] and Australian NPI methodologies [32]. The basic equation that governs these source terms is the following:

$$S = M \times C \times E \times N \times (1-R)$$

Where

- S = source term, such as radioactivity per unit time, Bq/s
- M = process or ore production rate, mass per unit time, such as tonne ore per year
- C = radioactivity concentration, Bq/g
- E = emission factor for a process, such as dust released per tonne of ore dumped
- N = radioactivity enrichment factor, dimensionless. It expresses the extent to which the radioactivity is higher in the suspended airborne particles of less than 20 εm than in the bulk ore material. A value of N=2.5 is used as default value.
- R = emission control factor, such as air filtration systems to limit dust emissions.

The TSF is normally the most important source of LL-alpha radioactive dust towards the end of mine life. It contains Th-230, Ra-226, and Pb-210, as well as a fraction of the U-238/234 not removed at the CPP. A TSF typically consists of a central wet area and a dry beach area on the periphery during its operational life. It is mainly the beach areas and dry side walls that give rise to airborne radioactivity. The dose assessment models in this report include the conservative assumption that the total TSF surface acts as a dust and radon source term as would be the case before remediation and closure. Studies have found that the effective TSF surface that acts as an airborne dust source, even in the case of poorly remediated surface areas, is normally smaller than a total barren surface area because of the following reasons [33]:

(i) The length of exposed tailings along the direction of the wind (the so-called fetch) has an influence on the emission of fine particles since the dominant motion of sand particles is creeping or saltation.
(ii) A high increase is seen for the first quarter of the exposed surface length, followed by a lower rate of release of particles.
(iii) Half the length of the dry and exposed surface area contributes at most 20% to the dust emission; the effective source from dry and exposed TSF surface areas is, in most cases, reported to be 30%.

The TSF is also the most important source of atmospheric radon. The concentration of radon in air following its release from the TSF depends on several factors, for example [34]:

- TSF properties in respect of moisture content, porosity, and radium-226 content; and
- meteorological conditions e.g. rainfall, temperature, pressure, and wind.

The beach areas of a TSF have tailings with a higher radon diffusion coefficient resulting from lower moisture content. Radon can diffuse from a depth of a few metres to the surface because of its relatively long half-life (3.8 days). However, the majority of the surface radon flux is due to Ra-226 in the top 500 millimetre thick layer of material. It is conservatively assumed that the

TSF releases Rn-222 at a constant rate of 1 Bq/m^2.s for every 1 Ra-226 Bq/g activity, thus 12.8 Bq/m^2.s from the total surface of approximately 80 hectares [31].

The CPP drying and packing plant of the yellowcake product, together with the TSF, are the principal potential sources of airborne radioactivity. The drying and packing plant is the dominant source term in respect of dose for receptors closest to the CPP plant. Figure 3-3 illustrates the contribution to annual dose for receptor R29 ï Kat Doorn Kuil, located nearest to the CPP, and receptor R50 (Neverset) that is approximately 20 km away. Radon gas released from the TSF becomes the main source term component over longer distances when compared to the dispersion of the uranium product (yellowcake).

Drying and packing of yellowcake are carried out in sealed rooms which are maintained under a slightly negative air pressure to prevent the escape of any airborne dusts. This negative pressure is achieved by a dust extraction fan. The extraction fan exhausts through filters which collects any entrained dust and thereby minimising any release to the environment. The design of the drying and packing rooms were not available at the time of this safety assessment. A conservative assumption based on the US NRC guidelines [31] is that 0.1 per cent of the product is lost through the ventilation system. This source term is used in the KUP safety assessment and is regarded as conservative. Modern plants, for example those using rotary vacuum dryers for processing uranium product are not expected to release particulates under normal operating conditions. The stack releases from plants designs using thermal drying has been estimated to be about 0.05% of the amount produced.

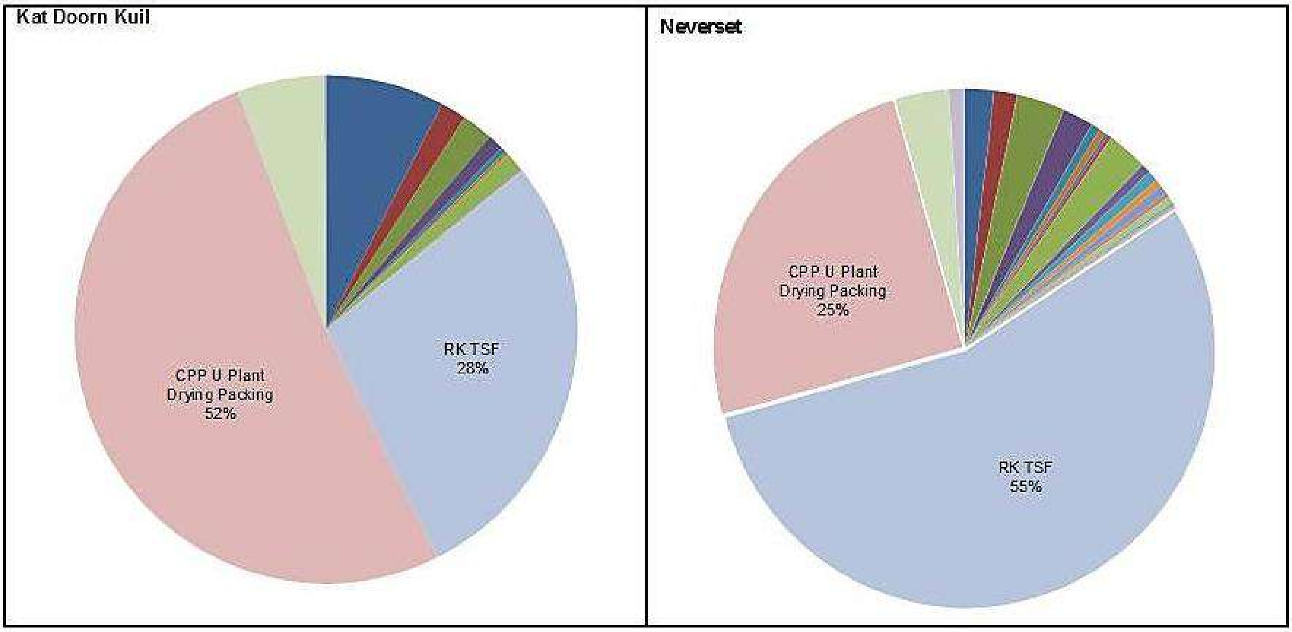


Figure 3-3: TSF and CPP relative contribution to dose at Kat Doorn Kuil and Neverset receptors

3-1.5 Radon discharge from underground ventilation shafts

The dose models created for KUP do not include radon discharges from the underground mine ventilation shafts. Preliminary design information of ventilation rates was used to derive source terms for ventilation shafts that will be active during mining. Only two ventilation shafts will be actively discharging radon at any stage of mining. It was assumed that the radon concentrations in the underground worker areas are at levels that approach the dose limit for workers (i.e. 50 mSv in a single year). The source terms are listed in Table 3-7.

Table 3-7: Underground mine radon release to environment

Mine area	Bq.m^{-3} per 50 mSv	Upcast ventilation speed; m^3/s	Bq/s
RK Extension	8.03E+03	255.75	2.05E+06
RK Main	8.03E+03	168.75	1.35E+06

The CALPUFF atmospheric dispersion software [35] was used to calculate the annual radon concentrations in the region. The results are illustrated in Figure 3-4. It shows that the radon is dispersed to very low concentrations within a short distance from the shafts. It can be concluded that the radon released from underground mining operations makes a negligible contribution to public dose.

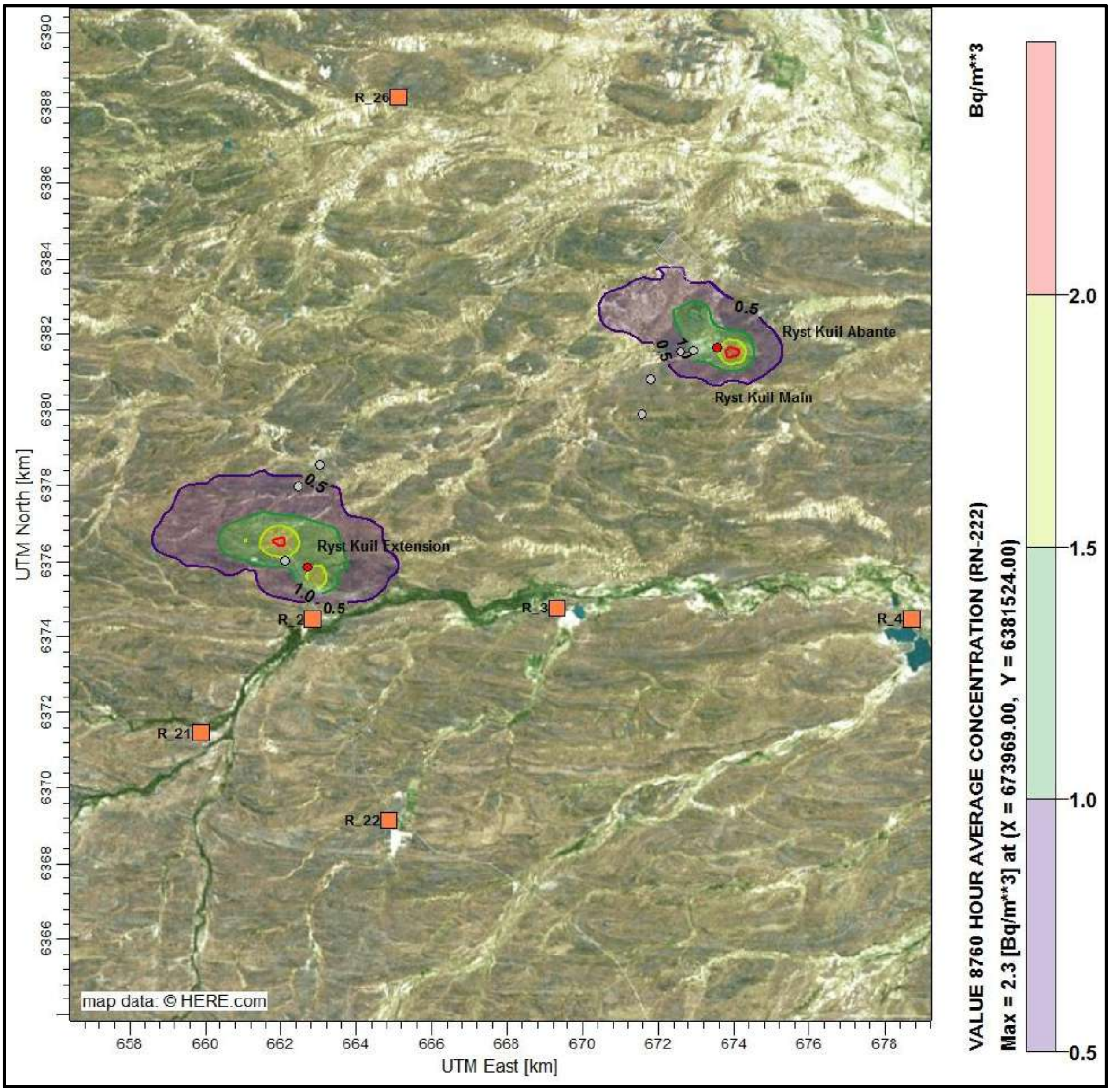


Figure 3-4: Environmental radon concentrations from upcast ventilations shafts servicing underground mining areas

3-1.6 Radiation dose from atmospheric exposure pathways

3-1.6.1 Ryst Kuil group of mining operations

The Ryst Kuil group consists of Ryst Kuil Main, Ryst Kuil Extension, Ryst Kuil South, Ryst Kuil Abante, the CPP and the TSF.

Table 3-8 lists the dose for the three age groups for each of the sensitive receptors locations. The age group for which the maximum annual dose was calculated is the ñinfantògroup located at R29 (Kat Doorn Kuil), receiving 0.479 mSv/yr.

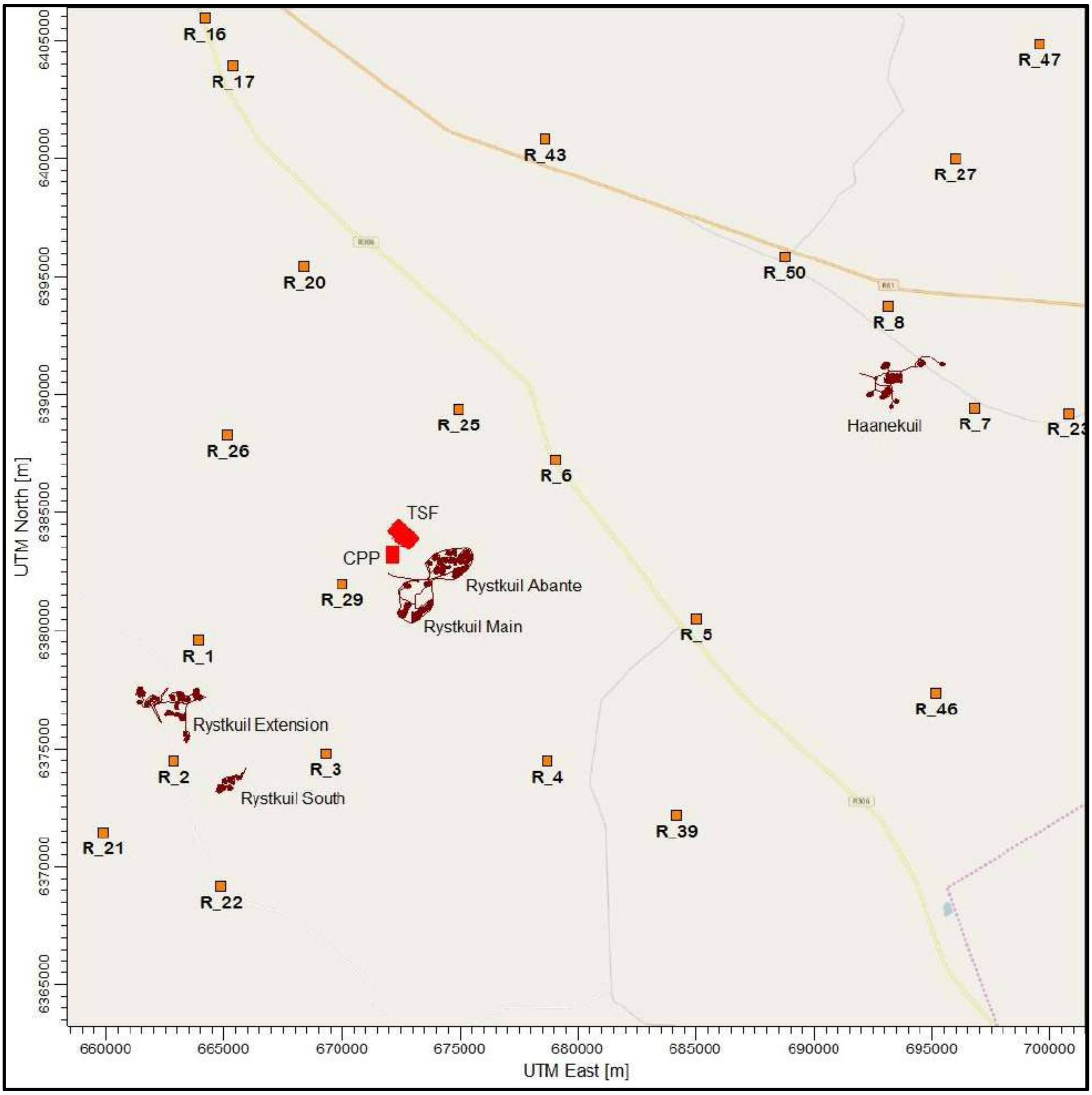


Figure 3-5: Sensitive receptor locations in the vicinity of Ryst Kuil and Haanekuil mine sites

The most sensitive age group for mining activities at Quaggasfontein, De Pannen and Haanekuil is also the infant age group. The maximum dose for all mining activities calculated for the infant age group is therefore measured against the regulatory dose constraint value of 0.250 mSv/yr.

The potential contamination of meat products is of specific concern to the Karoo farming communities. The dose calculations include the contribution from meat ingestion. The radioactivity concentrations calculated in meat is negligible compared to the natural occurrence of radioactivity reported in Table 2-7. The concentration of Ra-226, for example, is approximately a thousand time smaller than the maximum measure value. The calculated results are included in

Table 3-8: Maximum potential annual dose for the different age groups

Receptor	**Infant (mSv/yr)**	**Child (mSv/yr)**	**Adult (mSv/yr)**
R1 Kat Doorn Kuil	0.085	0.068	0.06
R2 Kant Kraal	0.127	0.098	0.088
R3 Klipstawels	0.094	0.076	0.068
R4 Klipkrans	0.134	0.11	0.099
R5 Eerstewater	0.092	0.072	0.064
R6 Ryst Kuil	0.028	0.023	0.02
R7 Lootsplaas	0.005	0.004	0.004
R8 Haanekuil	0.006	0.005	0.004
R9 Kareepoort	0.002	0.001	0.001
R10 Quaggasfontein	0.005	0.005	0.005
R11 Bokvlei	0.002	0.001	0.001
R12 Beaufort West	0.004	0.003	0.003
R13 Olive Grove	0.007	0.007	0.006
R14 Blouboskuil	0.006	0.005	0.005
R15 Oude Volks Kraal	0.007	0.006	0.006
R16 Uitsig	0.008	0.007	0.006
R17 Retreat	0.009	0.008	0.007
R18 Hansrivier	0.004	0.004	0.004
R19 Steenrotsfontein	0.005	0.005	0.005
R20 Saucyôs Kuil	0.019	0.016	0.015
R21 Amosvlei	0.034	0.029	0.027
R22 Vaalkraal	0.052	0.044	0.041
R23 Blydskap	0.004	0.003	0.003
R24 Rooidam Farmstall	0.003	0.002	0.002
R25 Toomitzkuil	0.021	0.016	0.014
R26 Hoekskuil	0.06	0.051	0.047
R27 Veerekuil	0.002	0.002	0.002
R28 Losboome	0.001	0.001	0.001
R29 Kat Doorn Kuil	0.479	0.321	0.249
R30 De Pannen	0.001	0.001	0.001
R31 Nuwejaarskuil	0.003	0.003	0.002
R32 De Puts	0.004	0.004	0.003
R33 Oorlogspoort	0.001	0.001	0.001
R34 Nuwejaarsfontein	0.003	0.002	0.002
R35 Rooidraai	0.001	0.001	0.001
R36 Vaalvlei	0.001	0.001	0.001

Receptor	Infant (mSv/yr)	Child (mSv/yr)	Adult (mSv/yr)
R37 Upper Kiewietskuil	0.001	0.001	0.001
R38 Bosduiwerivier	0.008	0.006	0.006
R39 Rhenosterkop	0.068	0.056	0.051
R40 Bothasdale	0.022	0.019	0.017
R41 Goodhope	0.027	0.023	0.021
R42 Jonkersleegte	0.017	0.014	0.013
R43 Grootkraanvoelkuil	0.004	0.004	0.003
R44 Helvetia	0.002	0.001	0.001
R45 Eensaam	0.011	0.009	0.008
R46 Hoekraal	0.038	0.031	0.028
R47 Reyersvlei	0.002	0.001	0.001
R48 Beyerskloof	0.001	0.001	0.001
R49 Theefontein	0.001	0.001	0.001
R50 Neverset	0.004	0.003	0.003

The doses that are reported are for end of mine life conditions when the sources terms are assumed to be at maximum values and deposition of radioactive dust has accumulated in the environment over the total period of mine operations.

The annual doses for receptors will only increase gradually over the life of mine. The TSF, for example and which is a principal contributor of radioactive dust and radon to the environment, presents only a small source term in the first year of operation and increases to be the largest source at mine closure. Table 3-9 illustrates the increase in public dose through mine life and lists the doses for each sensitive receptor location at the end of year one following start of mining operations, year five and year 10 of the Ryst Kuil group of mining operations.

Table 3-9: Increase in annual dose during mine life (infant age group)

Receptor	Year 1 (mSv/yr)	Year 5 (mSv/yr)	Year 10 (mSv/yr)
R1 Kat Doorn Kuil	0.051	0.066	0.085
R2 Kant Kraal	0.111	0.118	0.127
R3 Klipstawels	0.060	0.075	0.094
R4 Klipkrans	0.071	0.099	0.134
R5 Eerstewater	0.048	0.067	0.092
R6 Ryst Kuil	0.014	0.021	0.028
R7 Lootsplaas	0.002	0.004	0.005
R8 Haanekuil	0.003	0.004	0.006
R9 Kareepoort	0.001	0.001	0.002
R10 Quaggasfontein	0.002	0.004	0.005
R11 Bokvlei	0.001	0.001	0.002
R12 Beaufort West	0.002	0.002	0.004
R13_Olive Grove	0.003	0.005	0.007

Receptor	Year 1 (mSv/yr)	Year 5 (mSv/yr)	Year 10 (mSv/yr)
R14 Blouboskuil	0.002	0.004	0.006
R15 Oude Volks Kraal	0.003	0.004	0.007
R16 Uitsig	0.003	0.005	0.008
R17 Retreat	0.004	0.006	0.009
R18 Hansrivier	0.002	0.003	0.004
R19 Steenrotsfontein	0.002	0.004	0.005
R20 Saucyôs Kuil	0.009	0.014	0.019
R21 Amosvlei	0.023	0.028	0.034
R22 Vaalkraal	0.036	0.043	0.052
R23 Blydskap	0.002	0.003	0.004
R24 Rooidam Farmstall	0.001	0.002	0.003
R25 Toomitzkuil	0.012	0.016	0.021
R26 Hoekskuil	0.026	0.041	0.060
R27 Veerekuil	0.001	0.002	0.002
R28 Losboome	0.001	0.001	0.001
R29 Kat Doorn Kuil	0.355	0.411	0.479
R30 De Pannen	0.000	0.001	0.001
R31 Nuwejaarskuil	0.001	0.002	0.003
R32 De Puts	0.001	0.002	0.004
R33 Oorlogspoort	0.001	0.001	0.001
R34 Nuwejaarsfontein	0.001	0.002	0.003
R35 Rooidraai	0.000	0.001	0.001
R36 Vaalvlei	0.001	0.001	0.001
R37 Upper Kiewietskuil	0.001	0.001	0.001
R38 Bosduiwerivier	0.004	0.006	0.008
R39 Rhenosterkop	0.036	0.050	0.068
R40 Bothasdale	0.013	0.017	0.022
R41 Goodhope	0.014	0.020	0.027
R42 Jonkersleegte	0.008	0.012	0.017
R43 Grootkraanvoelkuil	0.002	0.003	0.004
R44 Helvetia	0.001	0.001	0.002
R45 Eensaam	0.006	0.008	0.011
R46 Hoekraal	0.019	0.027	0.038
R47 Reyersvlei	0.001	0.001	0.002
R48 Beyerskloof	0.000	0.001	0.001
R49 Theefontein	0.000	0.001	0.001
R50 Neverset	0.002	0.003	0.004

3-1.6.2 Quaggasfontein

The maximum annual dose from Quaggasfontein mining operations was calculated for receptor R14 (Blouboskuil), receiving 0.042 mSv/yr.

R14’s location relative to the mine is shown in Figure 3-6 and all receptor doses attributable to mining activities at Quaggasfontein are listed in Table 3-10.

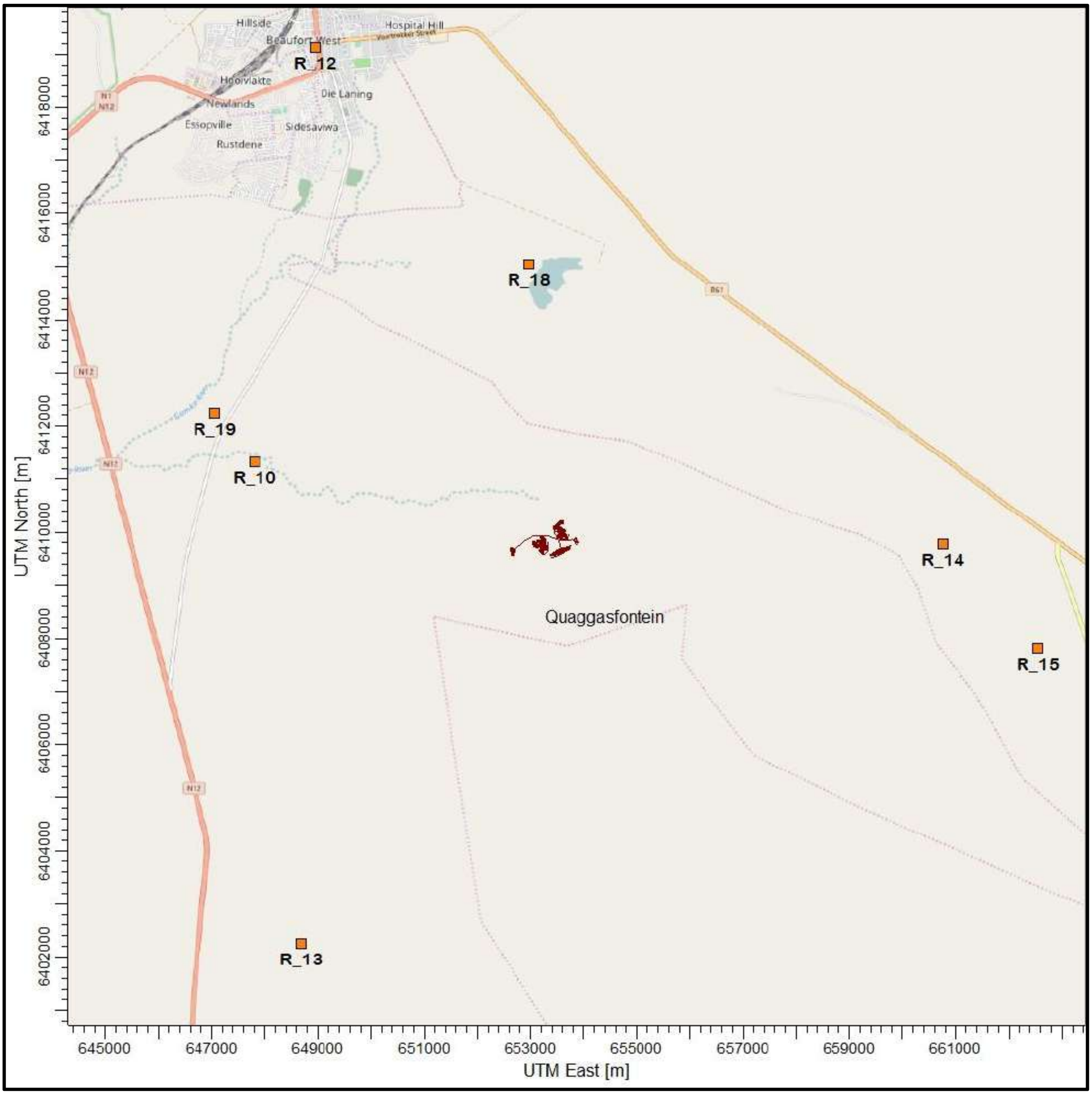


Figure 3-6: Sensitive receptor locations in the vicinity of the Quaggasfontein mine site

Table 3-10: Doses at sensitive receptor locations resulting from Quaggasfontein mine operations

Receptor	**Dose (mSv/yr)**
R1 Kat Doorn Kuil	0.002
R2 Kant Kraal	0.001
R3 Klipstawels	0.001
R4 Klipkrans	0.002
R5 Eerstewater	0.002
R6 Ryst Kuil	0.002
R7 Lootsplaas	0.003
R8 Haanekuil	0.003
R9 Kareepoort	0.002
R10 Quaggasfontein	0.021
R11 Bokvlei	0.002
R12 Beaufort West	0.005
R13 Olive Grove	0.009
R14 Blouboskuil	***0.042***
R15 Oude Volks Kraal	0.029
R16 Uitsig	0.021
R17 Retreat	0.017
R18 Hansrivier	0.010
R19 Steenrotsfontein	0.016
R20 Saucyôs Kuil	0.005
R21 Amosvlei	0.001
R22 Vaalkraal	0.001
R23 Blydskap	0.002
R24 Rooidam Farmstall	0.002
R25 Toomitzkuil	0.003
R26 Hoekskuil	0.003
R27 Veerekuil	0.003
R28 Losboome	0.002
R29 Kat Doorn Kuil	0.002
R30 De Pannen	0.002
R31 Nuwejaarskuil	0.002
R32 De Puts	0.001
R33 Oorlogspoort	0.001
R34 Nuwejaarsfontein	0.002
R35 Rooidraai	0.001

Receptor	Dose (mSv/yr)
R36 Vaalvlei	0.001
R37 Upper Kiewietskuil	0.001
R38 Bosduiwerivier	0.002
R39 Rhenosterkop	0.001
R40 Bothasdale	0.001
R41 Goodhope	0.002
R42 Jonkersleegte	0.003
R43 Grootkraanvoelkuil	0.006
R44 Helvetia	0.003
R45 Eensaam	0.002
R46 Hoekraal	0.001
R47 Reyersvlei	0.003
R48 Beyerskloof	0.001
R49 Theefontein	0.002
R50 Neverset	0.004

3-1.6.3 De Pannen

The maximum annual dose from De Pannen mining operations was calculated at receptor R28 (Losboome), receiving 0.055 mSv/yr.

R28ôs location relative to the mine is shown in Figure 3-7 and the receptor doses as a result of mining activities at De Pannen are listed in Table 3-11.

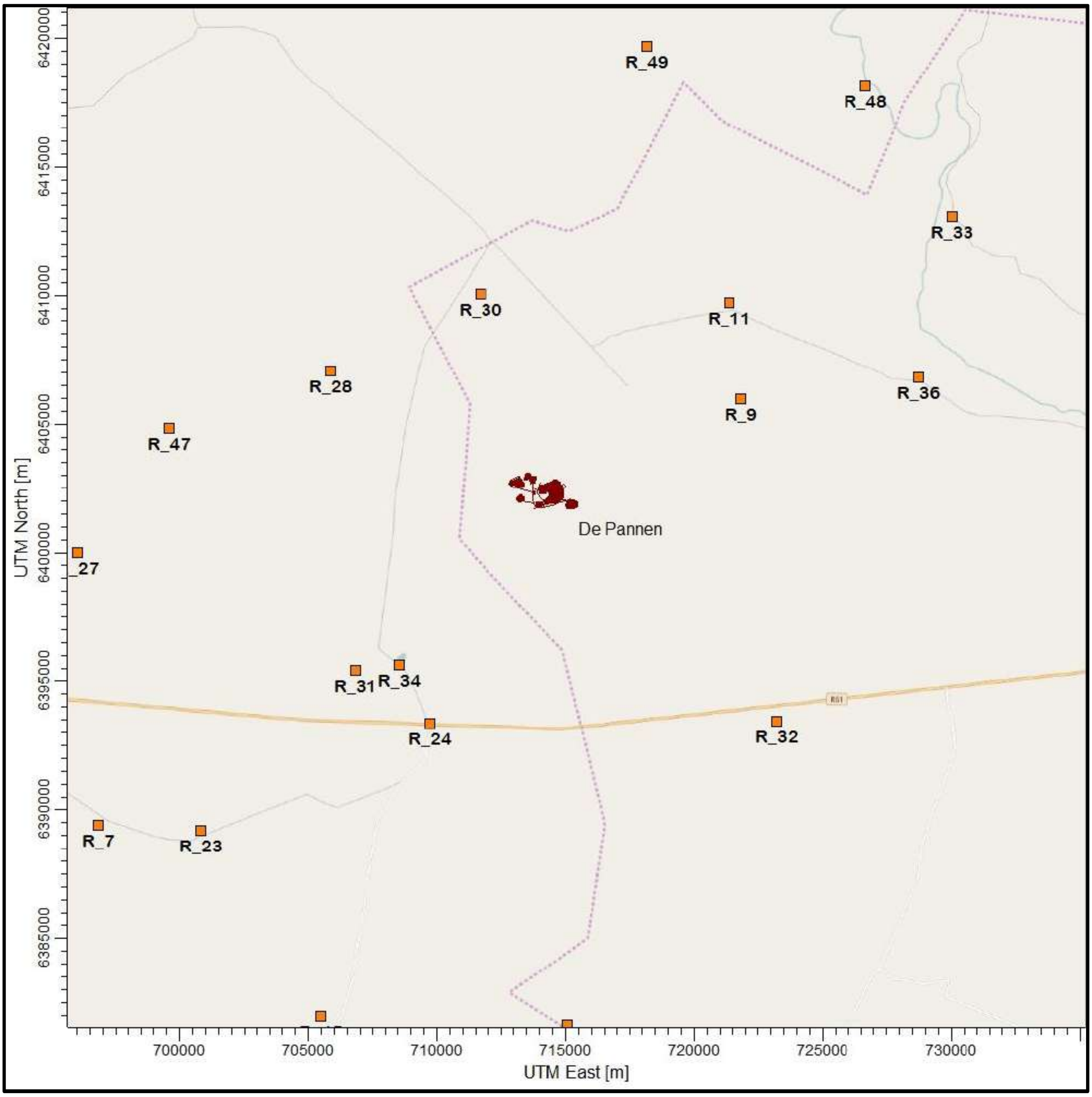


Figure 3-7: Sensitive receptor locations in the vicinity of the De Pannen mine site

Table 3-11: Dose at the different sensitive receptor locations from De Pannen mining operations

Receptor	**Dose (mSv/yr)**
R1 Kat Doorn Kuil	0.002
R2 Kant Kraal	0.002
R3 Klipstawels	0.002
R4 Klipkrans	0.003
R5 Eerstewater	0.003
R6 Ryst Kuil	0.003
R7 Lootsplaas	0.007
R8 Haanekuil	0.007
R9 Kareepoort	0.011
R10 Quaggasfontein	0.002
R11 Bokvlei	0.005
R12 Beaufort West	0.003
R13 Olive Grove	0.002
R14 Blouboskuil	0.003
R15 Oude Volks Kraal	0.003
R16 Uitsig	0.003
R17 Retreat	0.003
R18 Hansrivier	0.003
R19 Steenrotsfontein	0.002
R20 Saucyõs Kuil	0.003
R21 Amosvlei	0.002
R22 Vaalkraal	0.002
R23 Blydskap	0.009
R24 Rooidam Farmstall	0.028
R25 Toomitzkuil	0.003
R26 Hoekskuil	0.002
R27 Veerekuil	0.012
R28 Losboome	***0.055***
R29 Kat Doorn Kuil	0.002
R30 De Pannen	0.033

Receptor	Dose (mSv/yr)
R31 Nuwejaarskuil	0.023
R32 De Puts	0.024
R33 Oorlogspoort	0.003
R34 Nuwejaarsfontein	0.032
R35 Rooidraai	0.012
R36 Vaalvlei	0.005
R37 Upper Kiewietskuil	0.022
R38 Bosduiwerivier	0.016
R39 Rhenosterkop	0.003
R40 Bothasdale	0.001
R41 Goodhope	0.001
R42 Jonkersleegte	0.001
R43 Grootkraanvoelkuil	0.002
R44 Helvetia	0.005
R45 Eensaam	0.006
R46 Hoekraal	0.009
R47 Reyersvlei	0.004
R48 Beyerskloof	0.019
R49 Theefontein	0.002
R50 Neverset	0.002

3-1.6.4 Haanekuil

The maximum annual dose from Haanekuil mining operations was calculated for receptor R8 (Haanekuil), receiving 0.109 mSv/yr.

R8's location relative to the mine is shown in Figure 3-8 and the receptor doses attributable to mining activities at Haanekuil are listed in Table 3-12.

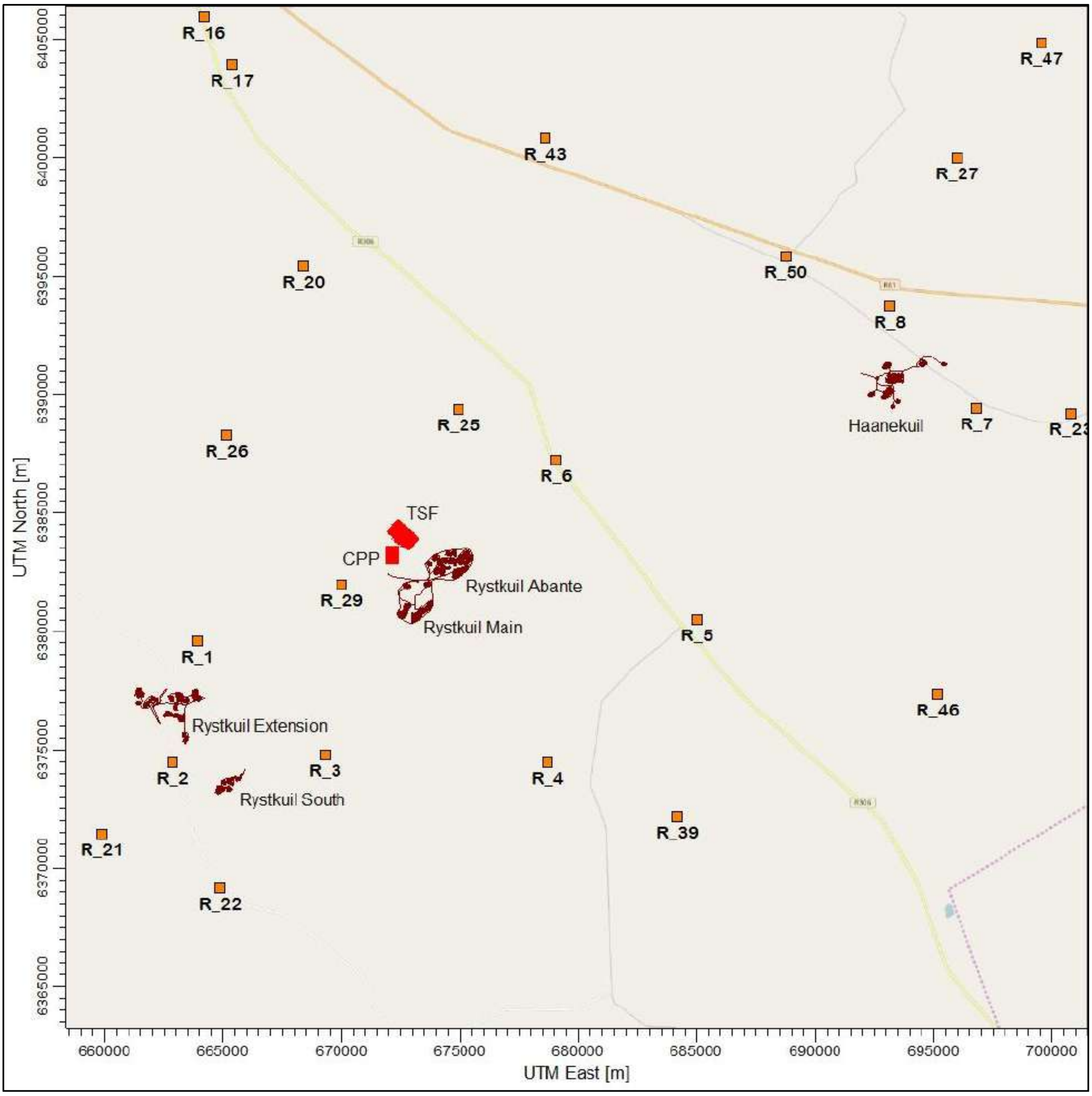


Figure 3-8: Sensitive receptor locations in the vicinity of Haanekuil and Ryst Kuil mine sites

Table 3-12: Infant doses for sensitive receptor locations from Haanekuil mining operations

Receptor	Infant (mSv/yr)
R1 Kat Doorn Kuil	0.002
R2 Kant Kraal	0.002
R3 Klipstawels	0.002
R4 Klipkrans	0.003
R5 Eerstewater	0.007
R6 Ryst Kuil	0.005
R7 Lootsplaas	0.079
R8 Haanekuil	***0.109***
R9 Kareepoort	0.001
R10 Quaggasfontein	0.001
R11 Bokvlei	0.001
R12 Beaufort West	0.001
R13 Olive Grove	0.001
R14 Blouboskuil	0.002
R15 Oude Volks Kraal	0.002
R16 Uitsig	0.002
R17 Retreat	0.003
R18 Hansrivier	0.001
R19 Steenrotsfontein	0.001
R20 Saucyôs Kuil	0.003
R21 Amosvlei	0.001
R22 Vaalkraal	0.002
R23 Blydskap	0.024
R24 Rooidam Farmstall	0.005
R25 Toomitzkuil	0.004
R26 Hoekskuil	0.002
R27 Veerekuil	0.008
R28 Losboome	0.002
R29 Kat Doorn Kuil	0.002
R30 De Pannen	0.001
R31 Nuwejaarskuil	0.004
R32 De Puts	0.003
R33 Oorlogspoort	0.001
R34 Nuwejaarsfontein	0.003
R35 Rooidraai	0.001

R36 Vaalvlei	0.001
R37 Upper Kiewietskuil	0.001
R38 Bosduiwerivier	0.006
R39 Rhenosterkop	0.003
R40 Bothasdale	0.001
R41 Goodhope	0.001
R42 Jonkersleegte	0.001
R43 Grootkraanvoelkuil	0.005
R44 Helvetia	0.003
R45 Eensaam	0.010
R46 Hoekraal	0.010
R47 Reyersvlei	0.004
R48 Beyerskloof	0.001
R49 Theefontein	0.001
R50 Neverset	0.019

3-1.7 The cumulative dose from all KUP mine areas

The cumulative dose was calculated for each sensitive receptor based on a hypothetical scenario of simultaneous mining operations at all KUP sites. The current KUP schedule indicates that only some mining areas will overlap during specific 12 month periods shown in Table 3-13 and indicated by an ñXò(start of mining is designated as óyear 0ô).

Table 3-13: Periods of simultaneous mine operations

Mine Area		Year 3	Year 5	Year 7
1	CPP	X	X	X
2	Ryst Kuil Main	X		
3	Ryst Kuil Extension	X		
4	Ryst Kuil South	X		
5	Ryst Kuil Abante	X	X	
6	Haanekuil		X	X
7	De Pannen		X	X
8	Quaggasfontein			X

The dose assessment model results show that even if the exposures at each sensitive receptor location from all KUP operations occur during the same twelve-month period, the dose is still less than the regulatory constraint value of 0.250 mSv/yr at each receptors location, except for R29 - Kat Doorn Kuil. The cumulative doses are listed in Table 3-14.

Table 3-14: The dose to sensitive receptors from the different mine areas and bounding cumulative doses

Receptor	Ryst Kuil mines, TSF and CPP	Quaggas-fontein	De Pannen	Haanekuil	Total dose (mSv/yr)
R1 Kat Doorn Kuil	0.085	0.002	0.002	0.002	***0.091***
R2 Kant Kraal	0.127	0.001	0.002	0.002	***0.132***
R3 Klipstawels	0.094	0.001	0.002	0.002	***0.099***
R4 Klipkrans	0.134	0.002	0.003	0.003	***0.142***
R5 Eerstewater	0.092	0.002	0.003	0.007	***0.104***
R6 Ryst Kuil	0.028	0.002	0.003	0.005	***0.038***
R7 Lootsplaas	0.005	0.002	0.007	0.079	***0.093***
R8 Haanekuil	0.006	0.003	0.007	0.109	***0.125***
R9 Kareepoort	0.002	0.001	0.011	0.001	***0.015***
R10 Quaggasfontein	0.005	0.018	0.002	0.001	***0.026***
R11 Bokvlei	0.002	0.001	0.005	0.001	***0.009***
R12 Beaufort West	0.004	0.004	0.003	0.001	***0.012***
R13_Olive Grove	0.007	0.008	0.002	0.001	***0.018***
R14 Blouboskuil	0.006	0.035	0.003	0.002	***0.046***
R15 Oude Volks Kraal	0.007	0.025	0.003	0.002	***0.037***

Receptor	Ryst Kuil mines, TSF and CPP	Quaggas-fontein	De Pannen	Haanekuil	Total dose (mSv/yr)
R16 Uitsig	0.008	0.018	0.003	0.002	***0.031***
R17 Retreat	0.009	0.015	0.003	0.003	***0.030***
R18 Hansrivier	0.004	0.008	0.003	0.001	***0.016***
R19 Steenrotsfontein	0.005	0.014	0.002	0.001	***0.022***
R20 Saucyôs Kuil	0.019	0.004	0.003	0.003	***0.029***
R21 Amosvlei	0.034	0.001	0.002	0.001	***0.038***
R22 Vaalkraal	0.052	0.001	0.002	0.002	***0.057***
R23 Blydskap	0.004	0.002	0.009	0.024	***0.039***
R24 Rooidam Farmstall	0.003	0.002	0.028	0.005	***0.038***
R25 Toomitzkuil	0.021	0.003	0.003	0.004	***0.031***
R26 Hoekskuil	0.060	0.002	0.002	0.002	***0.066***
R27 Veerekuil	0.002	0.003	0.012	0.008	***0.025***
R28 Losboome	0.001	0.002	0.055	0.002	***0.060***
R29 Kat Doorn Kuil	***0.479***	***0.002***	***0.002***	***0.002***	**0.485**
R30 De Pannen	0.001	0.002	0.033	0.001	***0.037***
R31 Nuwejaarskuil	0.003	0.002	0.023	0.004	***0.032***
R32 De Puts	0.004	0.001	0.024	0.003	***0.032***
R33 Oorlogspoort	0.001	0.001	0.003	0.001	***0.006***
R34 Nuwejaarsfontein	0.003	0.002	0.032	0.003	***0.040***
R35 Rooidraai	0.001	0.001	0.012	0.001	***0.015***
R36 Vaalvlei	0.001	0.001	0.005	0.001	***0.008***
R37 Upper Kiewietskuil	0.001	0.001	0.022	0.001	***0.025***
R38 Bosduiwerivier	0.008	0.001	0.016	0.006	***0.031***
R39 Rhenosterkop	0.068	0.001	0.003	0.003	***0.075***
R40 Bothasdale	0.022	0.001	0.001	0.001	***0.025***
R41 Goodhope	0.022	0.001	0.001	0.001	***0.025***
R42 Jonkersleegte	0.027	0.002	0.001	0.001	***0.031***
R43 Grootkraanvoelkuil	0.017	0.005	0.002	0.005	***0.029***
R44 Helvetia	0.004	0.003	0.005	0.003	***0.015***
R45 Eensaam	0.002	0.002	0.006	0.010	***0.020***
R46 Hoekraal	0.011	0.001	0.009	0.010	***0.031***
R47 Reyersvlei	0.038	0.002	0.004	0.004	***0.048***
R48 Beyerskloof	0.002	0.001	0.019	0.001	***0.023***
R49 Theefontein	0.001	0.002	0.002	0.001	***0.006***
R50 Neverset	0.001	0.003	0.002	0.019	***0.025***

Note that there are two receptors identified as Kat Doorn Kuil, i.e. R1 and R29. R29 is currently not occupied by humans whereas R1 is occupied. Farm workers temporarily occupied a shed next to a sheep kraal at R29. R29 was included in the list of sensitive receptors with the purpose to investigate potential exposures at a location in close proximity to the main mine operations, i.e. the Ryst Kuil group. The two Kat Doorn Kuil areas are illustrated in Figure 3-9 and Figure 3-10.

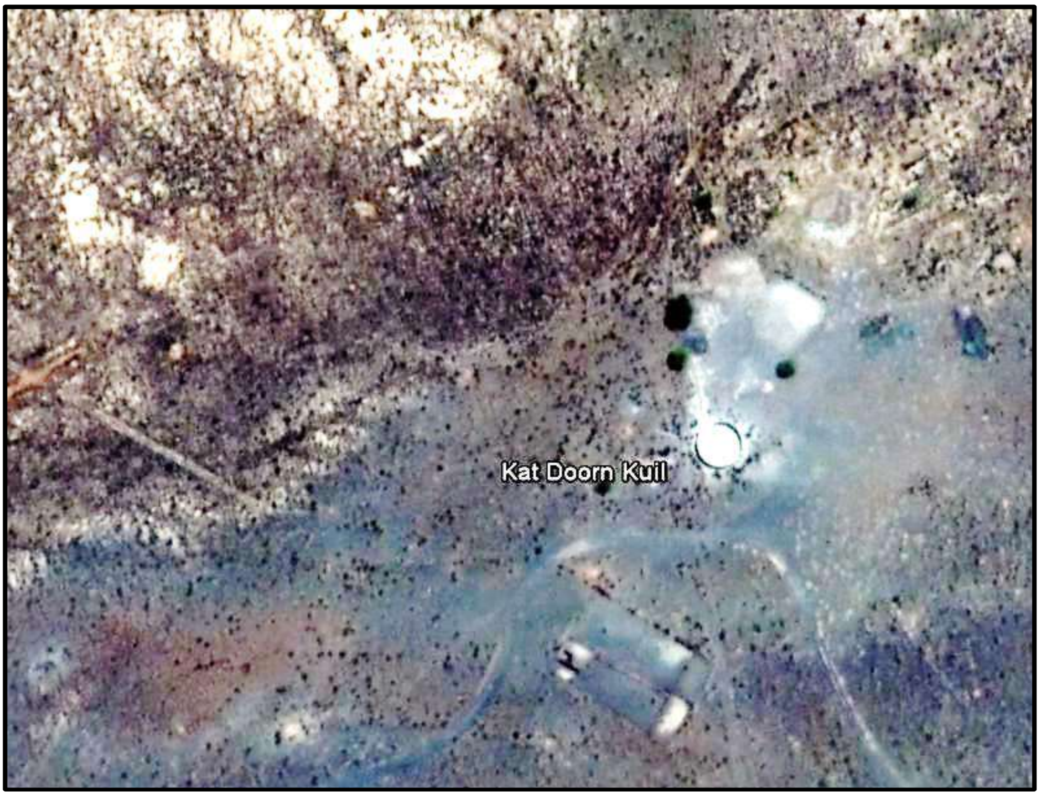


Figure 3-9: R29 - Kat Doorn Kuil

Figure 3-10: R1- Kat Doorn Kuil farm houses, sheds, dam and sheep kraals

3-2 WATER AND RADIATION HAZARDS

3-2.1 Background to the behaviour of radionuclides in water

The environmental mobility of the principal radionuclides associated with uranium mining are of specific importance, especially when considering the TSF during post-closure condition and discussed in §3-3.

Since uranium is of particular interest because of its radiological as well as chemical hazard, a brief overview of uranium’s chemical toxicity is included. Apart from its radiological hazard, uranium can also pose a health risk in water because of its chemical toxicity; in most cases this is the dominant risk when high levels of uranium are present in drinking water. In humans, the main toxic effect of short-term exposure to high concentrations of uranium is inflammation of the kidney. The World Health Organisation (WHO) provisional guideline for drinking-water quality is 30 µg/L of chemical uranium [36]. This value is considered to be protective for sub-clinical renal effects reported in epidemiological studies. The chemical uranium concentration in one of the boreholes that have been included in the baseline studies (KDK017) is significantly higher than 30 µg/L and close to 100 µg/L.

The two uranium isotopes U-234 and U-238 are rarely in secular equilibrium (i.e., present in equal radioactivity concentrations) because of the energetic recoil associated with the decay of U-238 resulting in a higher leaching probability for U-234.

Thorium (Th-230) is an important radioactive component of the TSF, together with the radium (Ra-226). Thorium has an extremely low solubility in natural waters. There is a close correlation of thorium concentration and particulate content of water. Thorium is almost entirely transported in particulate matter. Thorium is bound in insoluble minerals or is adsorbed on the surface of clay minerals.

Ra-226 and Ra-228 are important from a radiation dose point of view when these radium isotopes are present at elevated concentrations in water. Respectively produced by the decay of U-238 and Th-232, their concentration depends on the content of these “parent” nuclides and the geological characteristics of the host minerals in contact with the water. Earth has approximately a three times higher abundance of thorium compared to uranium. An approximately three times higher decay constant for thorium (Th-232) compared to uranium (U-238) should result in global inventories of Ra-226 (member of the U-238 decay chain) and Ra-228 (member of the Th-232 decay chain) to be roughly equal. However, local specific geological structures of terrains lead to a great variability in the ratio between these two isotopes. In general, the Ra-226 radioactivity concentrations in surface waters are low (0.4 – 40 mBq/L), and less than in most ground waters. Ra-228 occurs at even lower concentrations. Groundwater, when compared to surface water, may contain high radium concentrations. Some mineral and thermal waters exhibit extremely high Ra-226 concentration values, up to several Bq/L.

Radon (Rn-222), the decay product of Ra-226, forms a series of short-lived radionuclides (all solid elements) that decay within hours to Pb-210 (half-live 22 years). Radon is soluble in water, extremely volatile and is readily released from water. An important source of radon in nature is groundwater that passes through radium-bearing rocks and soils. In general, radon poses more of an inhalation health risk when compared to the health risk from drinking water in which radon is dissolved.

Radioactive polonium, Po-210, which has an extremely high ingestion dose coefficient and is a member of the U-238 decay chain, is largely insoluble although exceptions have been reported. In the hydrological cycle Po-210 generally follows its precursor lead, Pb-210. Po-210 is generally more readily adsorbed than Pb-210 onto particulate matter.

When apparently high levels of radioactive potassium, K-40, is reported in environmental media when compared to the other radionuclide concentrations, it has to be interpreted against the following background. Natural potassium is approximately 27g/kg of crustal rock and is present in humans at a homeostatic concentration of approximately 1.7 g/kg. K-40 natural abundance is 0,012% of all potassium in nature. Typical total potassium concentration in natural surface water is 10 mg/L. K-40 is therefore a naturally occurring long-lived radionuclide which is subject to metabolic control irrespective of uptake.

3-2.2 Water pollution risks

The potential impacts on water resources are determined by mine and mitigation designs as well as environmental monitoring programmes. The mitigation measures to avoid off-site surface water pollution are discussed in detail in the KUP EIA. Measures include for example the following:

- groundwater monitoring will be by means of boreholes up- and downstream from operations;
- drains will be constructed around stockpiles to divert potential water run-off to a lined sump for evaporation;
- all stockpiles and the TSF will be located on engineered bases to prevent contamination of the groundwater; stockpile areas will be prepared in advance to avoid infiltration of seepage into the groundwater;
- pollution control dams will be constructed;
- storm water drains and trenches are included at material storage areas; and
- water collection provided at maintenance workshops;

Acid Mine Drainage (AMD) is normally of great concern because of the potential mobilisation of radionuclides and their transport to off-site water sources. It is reported in the KUP EIA that the potential risk associated with AMD is low. No AMD is expected based on test results and specialist geochemical opinion included in the EIA.

The TSF is potentially the principal source of surface and groundwater impacts. The quantity of water seepage from a TSF that is required to be contained is dependent on seepage control measures, properties of the tailings, the nature of the groundwater in the area, and whether the TSF will be lined. Pollution of groundwater by seepage is unlikely when a TSF is constructed on impermeable natural clay formations or when an artificial liner is provided. The main contributors to a low seepage potential, apart from liners, are:

- high percentage of the water is returned to the CPP;
- a large fraction of the water in the tailings material is interstitial water that is retained; and
- a large surface area and a high net evaporation rate assure high evaporation losses.

SRK Consulting was appointed by the applicant to design the TSF and its safety aspects are described accordingly in the KUP EIA.

Radium (Ra-226) occurs at a much higher radioactivity concentration in the TSF than uranium. Radium generally has a low mobility in tailings, moving much slower than water in the tailings and generally resulting in low concentrations in seepage water. Studies performed on waterborne Ra-226 radioactivity from old dry tailings deposits on the Central Rand mining areas show that Ra-226 is effectively retained [37].

3-3 THE TAILINGS STORAGE FACILITY AND POTENTIAL FUTURE IMPACTS FOLLOWING MINE CLOSURE

3-3.1 Closure design requirements in respect of radiological hazards

Radioactivity concentrations are approximately ten times higher than the typical South African gold mine tailings. Radium (Ra-226), thorium (Th-230), and radon (Rn-222) and their decay products are the radionuclides present in uranium mill tailings that are of concern to human health and the environment in the long term.

All above ground level tailings disposal options, such as the option considered for KUP, have the disadvantage that the long term containment of the tailings will be at risk through erosive forces. It is therefore important to have TSF liners, surface runoff water containment and a cover design to control radiological hazards for at least 200 years and for 1,000 years to the greatest extent reasonably achievable [38].

The general design of the KUP TSF is reported in the EIA and considered the guidelines contained [38]. These guidelines include, amongst other factors, the following:

- *Cover needs over tailings waste deposits to serve as a radon barrier*: A provisional design is included in the KUP TSF design document.
- *TSF barrier liners*: The need to avoid active maintenance on closure is considered.
- *The impacts related to erosion*: An above ground facility is proposed, the impoundment walls of which are constructed with durable dump rock.
- *Below–grade disposal being a preferred option (i.e. underground or in pits)*: The TSF has been phased should the technology for below-grade become available on this project.
- *Dust control* is considered in the design.
- *Control of runoff from upstream rainfall catchment*: An above ground TSF is proposed, the impoundment walls of which are constructed with durable dump rock.
- *The need for final vegetation or rock cover over tailings* will be investigated
- Durability of rock cover: competent waste rock (sandstone) with a low acid rock drainage potential will be used.
- *Management of runoff on impoundment surfaces* are included in the design.
- *Monitoring the release of radon after closure*: This will be addresses as part of the environmental monitoring programmes for closure.
- *Stabilisation of that portion of the tailings surface that is not permanently wetted* is addressed.

3-3.2 The impact on radiological air quality when a TSF cover is provided

As assessment was performed of airborne radioactivity concentrations based on a scenario of a total dry TSF surface without a cover at the time of mine closure. The advanced atmospheric dispersion model CALPUFF was used [35]. The release of airborne dust containing LL-alpha radioactivity from the TSF surface was modelled as a function of local wind speeds. Tailings material only becomes airborne when a threshold wind speed is exceeded. The dust source terms as a function of wind speed are listed in Table 3-15 [31]:

Table 3-15: TSF airborne dust source term as a function of wind speed

Wind speed interval (m/s)	0 - 2.4	2.5 - 4.4	4.4 - 6.9	6.9 - 9.6	9.6 - ≥12.4
Surface dust flux (g/m^2.s)	0	3.92E-07	9.68E-06	5.71E-05	2.08E-04
Scaling factor for increased dust from the surface as a function of wind speed	0	1.88E-03	4.65E-02	2.75E-01	1.00E+00

Radon was modelled using a continuous release rate equal to 12.8 Bq/m^2.s.

The results for radioactive dust deposition and radon are illustrated in Figure 3-11, Figure 3-12 and Figure 3-13. The results presented as concentration isopleths show that the impacts are localised and provide more realistic results than the dispersion model in MILDOS AREA.

A dose assessment was also carried out using the MILDOS code for a hypothetical sensitive receptor group located 500 m downwind of the TSF. The dose was calculated for two cases:

(1) a TSF without a cover, and

(2) a TSF with an effective cover.

Table 3-16: Post-closure TSF annual airborne exposure pathway dose

Sensitive receptor located 500m downwind (direction ESE) of the TSF	Total dose (mSv/yr)
TSF with no post-closure cover to limit radon and radioactive dust	1.854
TSF with a cover limiting the radon flux to 0.74 Bq/m^2.s	0.142

The results are a further demonstration that the future TSF cover of high integrity and durability will be essential to ensure impacts on air quality and water quality.

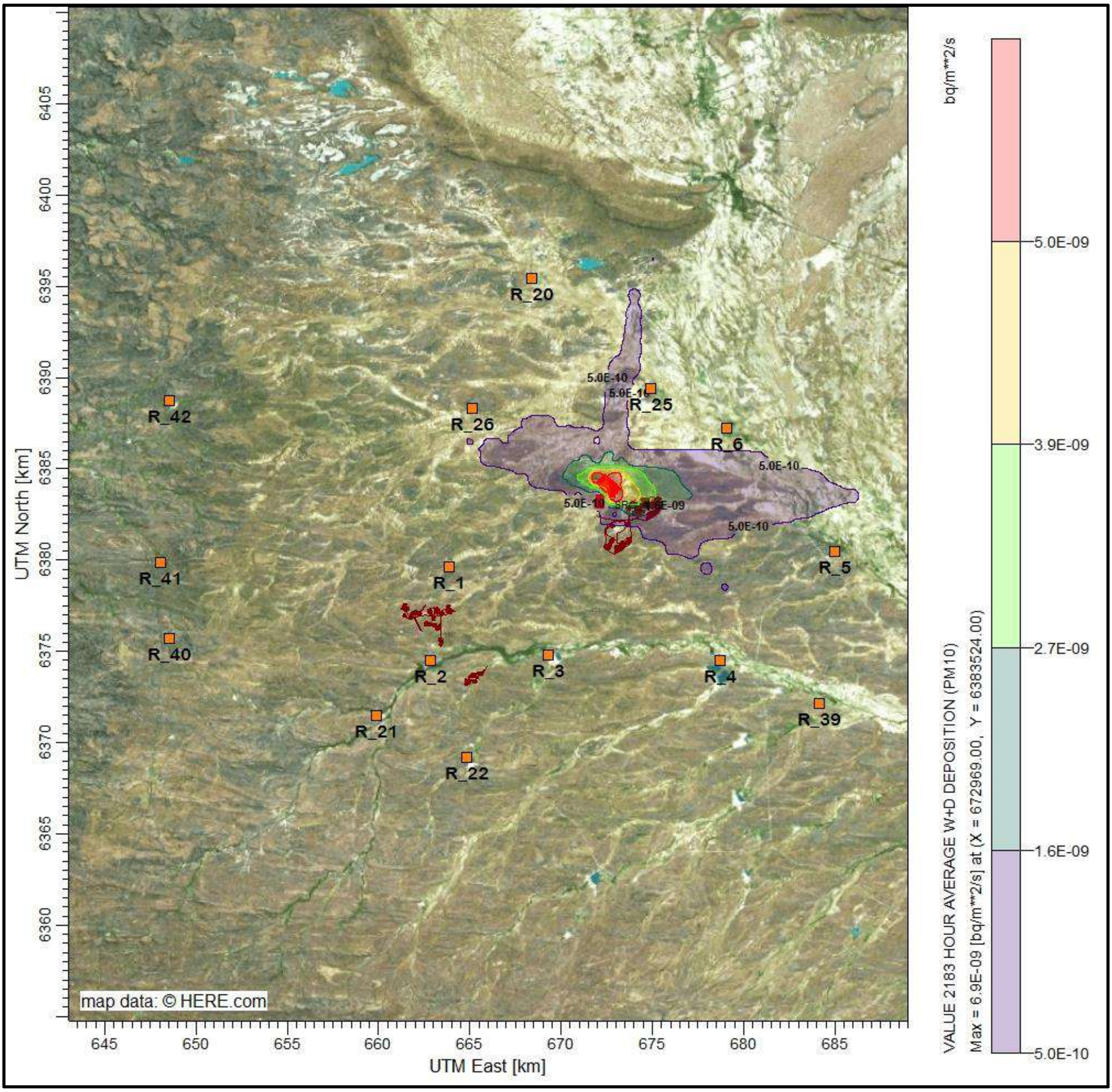


Figure 3-11: Deposition of radioactive dust released from the TSF

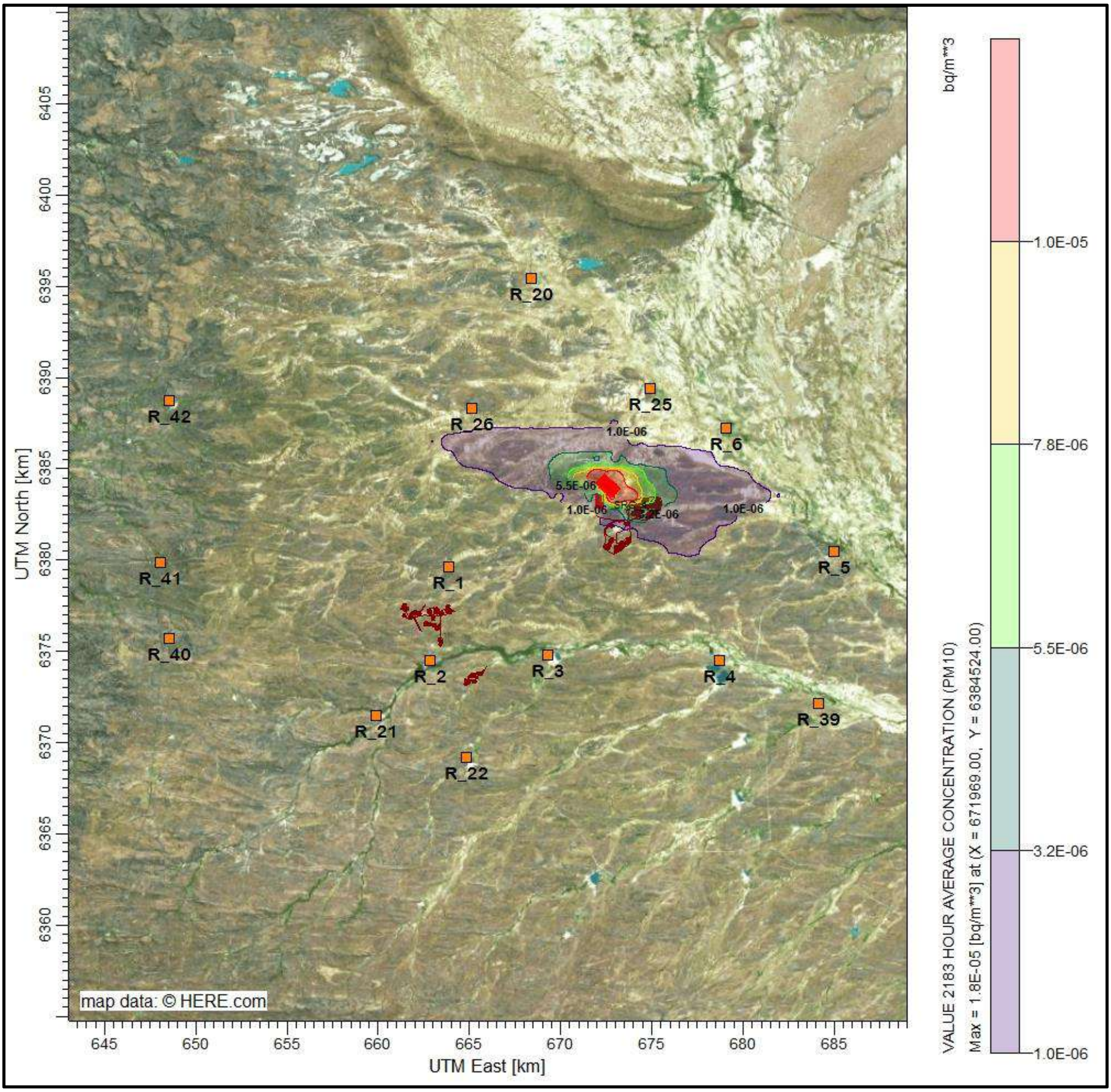


Figure 3-12: Air concentrations of radioactive dust released from a TSF with no post closure cover

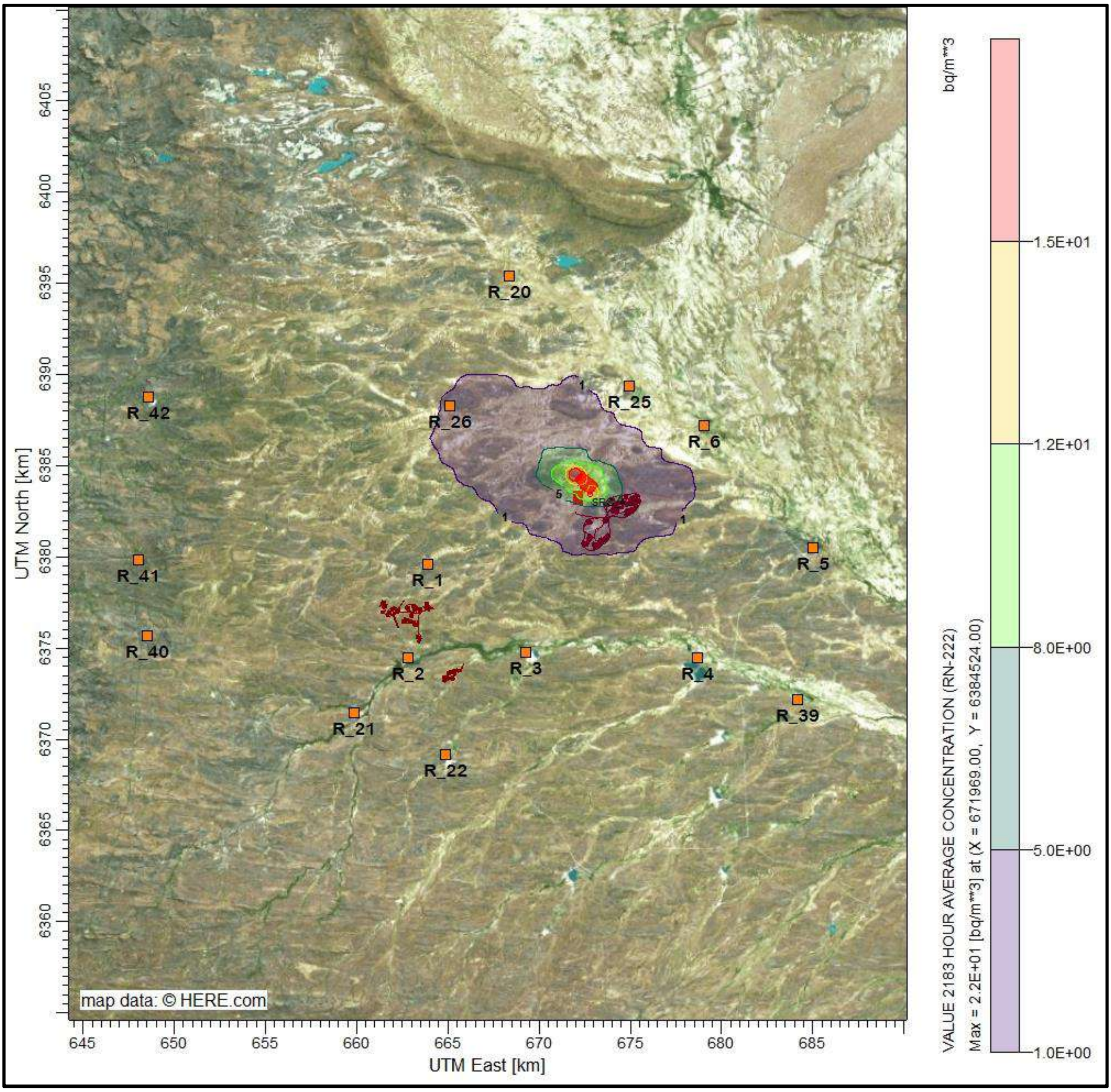


Figure 3-13: Air concentrations Rn-222 from a TSF with no post closure cover

Simple mathematical tools exist to assess local materials for suitability as cover material and their ability to adequately reduce radon exhalation [39]. Covers reduce radon flux density by increasing the time taken by radon in the tailings to be transferred to the surface, allowing for radon to decay before reaching the atmosphere. The effectiveness of a cover can be investigated as follows. One first has to determine the radon flux from the bare tailings. The flux can be assumed to be directly proportional to the radium activity concentration when the tailings thickness exceeds the radon diffusion length, as will be the case at KUP. The radon flux density can be estimated as follows:

$$F = RȽ_bE(ǝD_r)^{1/2}$$

where

F is the radon flux density

R	is the radium activity concentration
ρ_b	is the bulk density of the tailings
E	is the radon emanation coefficient
λ	is the radium decay coefficient; 2.1×10^{-6} 1/s
D_r	is the radon diffusion coefficient

The effectiveness of a TSF cover in respect of radon can then be estimated. Assuming that the radon fluxes are fairly uniform above the stockpile surface areas, the cover does not add to the radon flux and radon diffusion is the only transport process, (cracks and voids within a surface cover may negate this assumption), the effectiveness as a radon barrier of materials can be assessed as follows

At steady state conditions, the diffusion of radon through a surface cover is expressed as follows [40]:

$$C = C_0 \exp[-\tilde{a}(\text{ə}/D)\cdot Z]$$

With

C: radon concentration at height Z in the cover material

C_0: radon concentration at bottom of surface cover at the surface of the tailings

ə: decay constant of radon, 2.1×10^{-6} 1/s

D_c: diffusion coefficient through surface cover. Typical diffusion coefficients in soil, clay and concrete are $3\cdot10^{-6}$, $3\cdot10^{-7}$, and $3.1\cdot10^{-9}$ $s.m^{-1}$, respectively.

Cover material studies should commence early in KUP operational life with the purpose to inform the development of closure designs.

3-3.3 External radiation from tailings material

External radiation, apart from dust and radon, is a radiological hazard associated with large surface areas of a TSF and mineralised rock dumps. An assessment was performed with the software RESRAD to investigate external radiation for different soil cover thickness layers consisting of soil with typical background NORM concentrations. The RESRAD computer code was developed under the sponsorship of the U.S. Department of Energy and the U.S. Nuclear Regulatory Commission for site-specific dose assessment of residual radioactivity [41].

A bounding radioactivity concentration of Ò16 Bq/g for the U-238 decay chain was assumed. The results provide an indication of the relative shielding effect of different cover thickness. The sensitivity analysis is performed for a scenario where practically no cover (0.01 m) is provided, a 0.1 m cover and a 1 m cover. The results are shown in Table 3-17.

The conclusion that can be drawn is that a cover thickness of 1 m should provide adequate protection against external radiation. The cover soil characteristics will determine whether 1 m is also adequate for radon protection.

Table 3-17: Shielding against external radiation on a TSF surface

External radiation sensitivity analysis of soil cover thickness		
0.01 m cover layer (mSv/yr)	0.1 m cover layer (mSv/yr)	1 m cover layer (mSv/yr)
24.27	8.24	< 1

3-4 RADIOLOGICAL PROTECTION OF THE ENVIRONMENT

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

The IAEA Basic Safety Standards states that *"…the aim of radiation protection of the environment is to protect ecosystems, including non-human species within that ecosystem, against radiation risks…"* and further requires that legislation should provide for the protection of the human environment and the biosphere in accordance with the principle of sustainable development [7]. The environmental management programme of the mine will have to take cognisance of these international guidelines and NNR requirements.

A high-level radio-ecological screening assessment was carried out using the ERICA software tool developed in the European Union [43]. The purpose of this assessment is to illustrate the potential radiation dose to a variety of organisms. The reference dose values for screening purposes are 40 εGy/h for terrestrial animals and 400 εGy/h for terrestrial plants and aquatic biota. Below these values and under conditions of chronic exposure, no measurable population effects would occur, as suggested in international publications quoted in ERICA.

The reference organisms are the following:

- Amphibian
- Annelid
- Arthropod ï detritivorous
- Grasses & Herbs
- Lichen & Bryophytes
- Mammal ï large
- Mammal - small-burrowing
- Mollusc ï gastropod
- Reptile

- Shrub
- Tree

A risk quotient is calculated for each reference organism and is based on a dose calculated for an organism divided by the reference dose value for screening purposes. Habitation factors of these reference organisms are listed in Table 3-18 applied to the different species to illustrate potential doses.

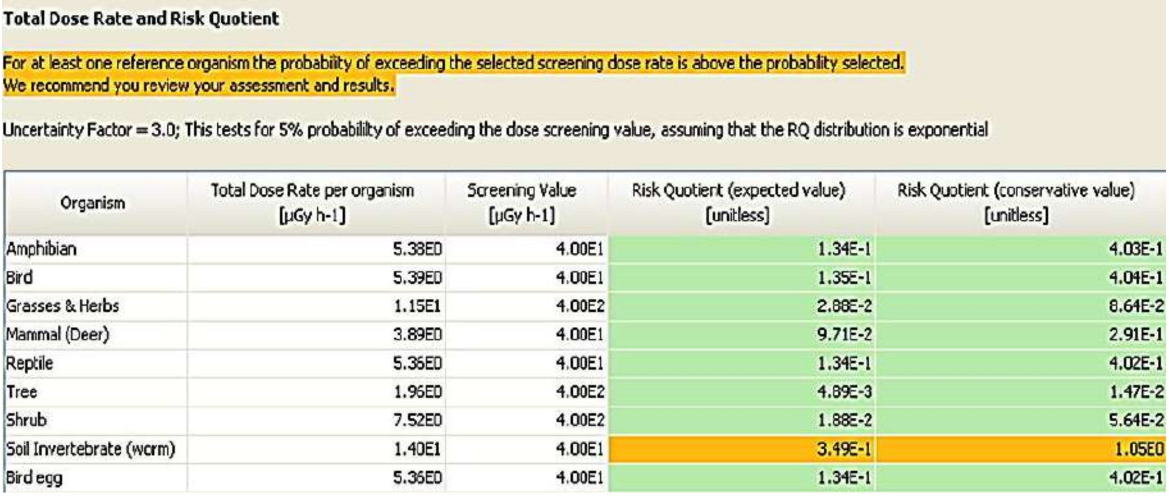
Table 3-18: Habitation factors for the radioactive land area (U-stockpile area with no cover)

Habitat	Amphibian	Bird	Grasses and Herbs	Mammal (game)	Reptile	Tree	Shrub	Soil Invertebrate (worm)	Bird egg
On-soil	1	0.2	1	0.5	1	1	1	0	1
In-soil	0	0	0	0	0	0	0	1	0

The dose rates as a function of different radionuclide concentrations are listed in Table 3-19. Red indicates a potentially unacceptable risk.

Ra-226 contributes most to the dose to the different organisms. Based on these results a TSF cover of suitable thickness and with radioactivity concentrations less than 1 Bq/g will be required to provide adequate radio-ecological protection.

Table 3-19: Dose rates to different organisms as a function of soil activity **1Bq/g**



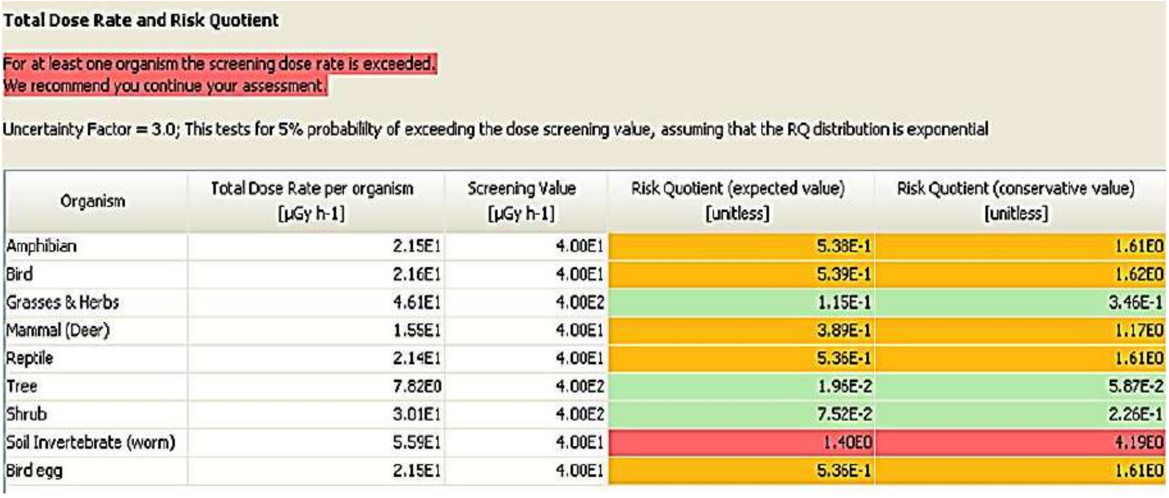
Total Dose Rate and Risk Quotient

For at least one reference organism the probabiity of exceeding the selected screening dose rate is above the probablity selected.
We recommend you review your assessment and results.

Uncertainty Factor = 3.0; This tests for 5% probability of exceeding the dose screening value, assuming that the RQ distribution is exponential

Organism	Total Dose Rate per organism [µGy h-1]	Screening Value [µGy h-1]	Risk Quotient (expected value) [unitless]	Risk Quotient (conservative value) [unitless]
Amphibian	5.38E0	4.00E1	1.34E-1	4.03E-1
Bird	5.39E0	4.00E1	1.35E-1	4.04E-1
Grasses & Herbs	1.15E1	4.00E2	2.88E-2	8.64E-2
Mammal (Deer)	3.89E0	4.00E1	9.71E-2	2.91E-1
Reptile	5.36E0	4.00E1	1.34E-1	4.02E-1
Tree	1.96E0	4.00E2	4.89E-3	1.47E-2
Shrub	7.52E0	4.00E2	1.88E-2	5.64E-2
Soil Invertebrate (worm)	1.40E1	4.00E1	3.49E-1	1.05E0
Bird egg	5.36E0	4.00E1	1.34E-1	4.02E-1

4 Bq/g



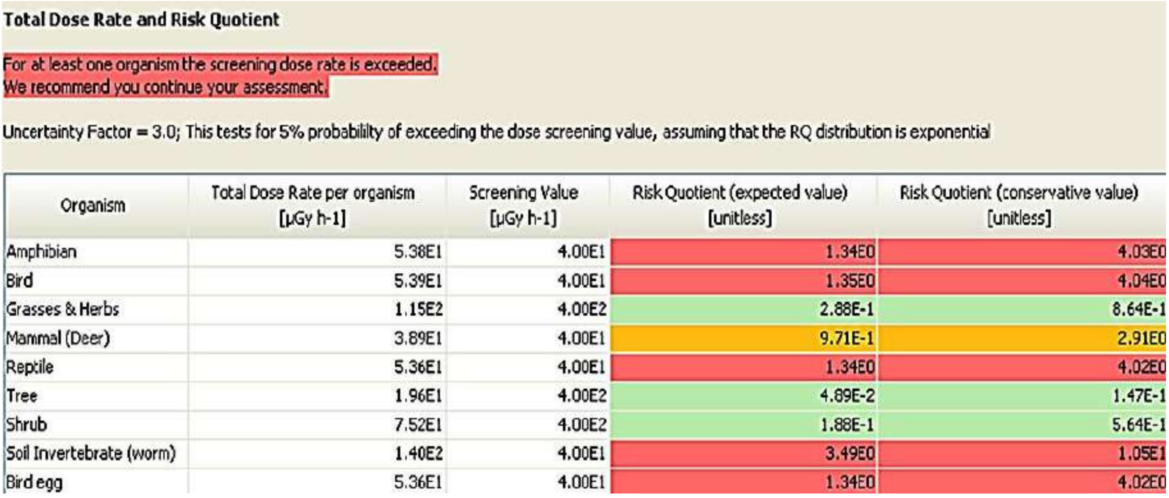
Total Dose Rate and Risk Quotient

For at least one organism the screening dose rate is exceeded.
We recommend you continue your assessment.

Uncertainty Factor = 3.0; This tests for 5% probability of exceeding the dose screening value, assuming that the RQ distribution is exponential

Organism	Total Dose Rate per organism [µGy h-1]	Screening Value [µGy h-1]	Risk Quotient (expected value) [unitless]	Risk Quotient (conservative value) [unitless]
Amphibian	2.15E1	4.00E1	5.38E-1	1.61E0
Bird	2.16E1	4.00E1	5.39E-1	1.62E0
Grasses & Herbs	4.61E1	4.00E2	1.15E-1	3.46E-1
Mammal (Deer)	1.55E1	4.00E1	3.89E-1	1.17E0
Reptile	2.14E1	4.00E1	5.36E-1	1.61E0
Tree	7.82E0	4.00E2	1.96E-2	5.87E-2
Shrub	3.01E1	4.00E2	7.52E-2	2.26E-1
Soil Invertebrate (worm)	5.59E1	4.00E1	1.40E0	4.19E0
Bird egg	2.15E1	4.00E1	5.36E-1	1.61E0

10 Bq/g



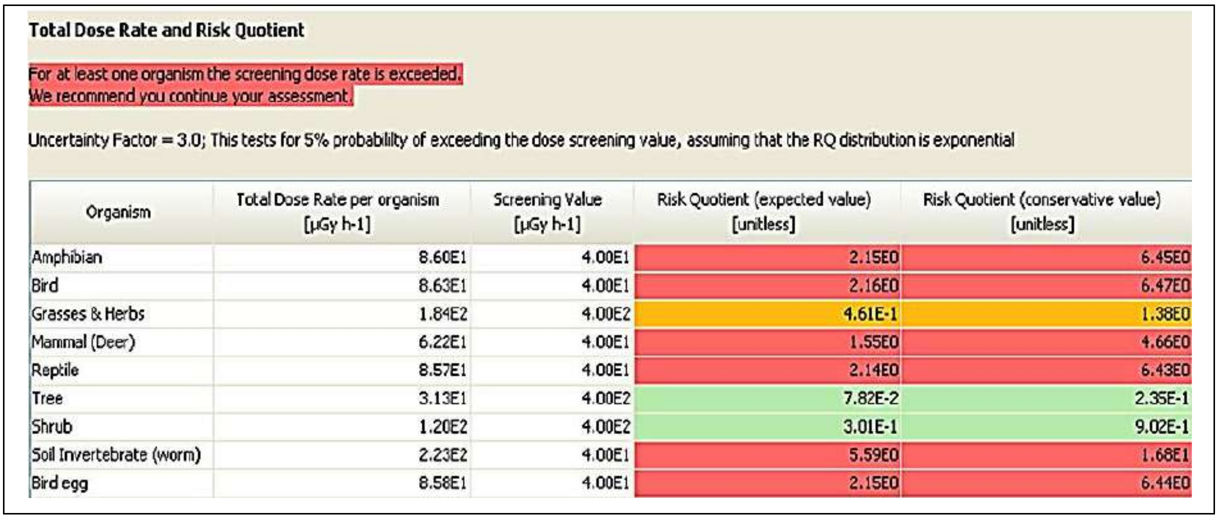
Total Dose Rate and Risk Quotient

For at least one organism the screening dose rate is exceeded.
We recommend you continue your assessment.

Uncertainty Factor = 3.0; This tests for 5% probability of exceeding the dose screening value, assuming that the RQ distribution is exponential

Organism	Total Dose Rate per organism [µGy h-1]	Screening Value [µGy h-1]	Risk Quotient (expected value) [unitless]	Risk Quotient (conservative value) [unitless]
Amphibian	5.38E1	4.00E1	1.34E0	4.03E0
Bird	5.39E1	4.00E1	1.35E0	4.04E0
Grasses & Herbs	1.15E2	4.00E2	2.88E-1	8.64E-1
Mammal (Deer)	3.89E1	4.00E1	9.71E-1	2.91E0
Reptile	5.36E1	4.00E1	1.34E0	4.02E0
Tree	1.96E1	4.00E2	4.89E-2	1.47E-1
Shrub	7.52E1	4.00E2	1.88E-1	5.64E-1
Soil Invertebrate (worm)	1.40E2	4.00E1	3.49E0	1.05E1
Bird egg	5.36E1	4.00E1	1.34E0	4.02E0

16 Bq/g



Total Dose Rate and Risk Quotient

For at least one organism the screening dose rate is exceeded.
We recommend you continue your assessment.

Uncertainty Factor = 3.0; This tests for 5% probability of exceeding the dose screening value, assuming that the RQ distribution is exponential

Organism	Total Dose Rate per organism [µGy h-1]	Screening Value [µGy h-1]	Risk Quotient (expected value) [unitless]	Risk Quotient (conservative value) [unitless]
Amphibian	8.60E1	4.00E1	2.15E0	6.45E0
Bird	8.63E1	4.00E1	2.16E0	6.47E0
Grasses & Herbs	1.84E2	4.00E2	4.61E-1	1.38E0
Mammal (Deer)	6.22E1	4.00E1	1.55E0	4.66E0
Reptile	8.57E1	4.00E1	2.14E0	6.43E0
Tree	3.13E1	4.00E2	7.82E-2	2.35E-1
Shrub	1.20E2	4.00E2	3.01E-1	9.02E-1
Soil Invertebrate (worm)	2.23E2	4.00E1	5.59E0	1.68E1
Bird egg	8.58E1	4.00E1	2.15E0	6.44E0

SECTION 4

Environmental Impact Rating, Conclusions and Radiological Monitoring Programmes

4-1 ENVIRONMENTAL IMPACT RATING

No significant radiological impacts are expected during site preparation and construction. Removal of top soil and waste rock during the early phases of the KUP, will pose low or no radiological hazards to the public. The highest radiological impact will occur when the actual uranium ore is mined and processed.

The following model was used for determination of the *significance* of radiological impacts aligned with other impacts assessed in an EIA:

Significance = (magnitude + duration + scale) x probability

The maximum potential value for significance of an impact is 100 points. Impacts are rated as high, medium or low significance on the following basis:

- High significance; public dose likely to exceed the national public dose limit of 1 mSv/y: 71 ï 100 points
- Medium significance: public dose exceeds the dose constraint value of 0.25 mSv/y but is less than 1 mSv/y: 46 ï 70 points
- Low significance; the regulatory dose constraint for the public is met; i.e. dose is less than 0.25 mSv/y: 0 ï 45 points

The radiological significance rating results are presented in Table 4-1. Two values for each significance rating are indicated. The values without brackets indicate the rating when no mitigation during KUP operation and/or poor rehabilitation is carried out at mine closure. The values inside brackets indicate successful mitigation and closure.

The probability values equal to ñ5ò for the operational, decommissioning and post-closure phases, are based on the fact that the radiological hazard is a permanent aspect of uranium ore and it is only the probability of exposure that can be controlled. The radiological half-lives of the NORM radionuclides are long; e.g. Ra-226 has a half-live of 1.6 thousand years and for U-238 it is even longer, 4.7 billion years.

A scenario that can potentially result in a ñhighò significance rating is where material with elevated radioactivity becomes accessible to members of the public. Mitigation against this scenario is site rehabilitation that will require authorisation to release the site from regulatory control, ensuring a safe closure condition of the site. A safety assessment that investigates all potential exposure scenarios and their mitigation after closure will have to be approved by the NNR at mine closure.

closure

Table 4-1: Radiological significance rating

Rating element	Site preparation / construction	Mining operations	Decommissioning, rehabilitation and closure	Post-closure
Magnitude (M)				
10 ï Very high (or unknown)				
8 ï High				8
6 ï Moderate		6	6	
4 ï Low				[4]
2 ï Minor	2 [2]	[2]	[2]	
Scale (S)				
5 ï International				
4 ï National				
3 ï Regional		3	3	3
2 ï Local	2 [2]	[2]	[2]	[2]
1 ï Site				
0 ï None				
Duration (D)				
5 ï Permanent				5 [5]
4 ï Long-term (ceases at the end of operation)				
3 ï Medium-term (6-12 years)		3 [3]		
2 ï Short-term (0-5 years)	2 [2]		2 [2]	
1 ï Immediate				
Probability (P)				
5 ï Definite (or unknown)		5 [5]	5 [5]	5 [5]
4 ï High probability				
3 ï Medium probability				
2 ï Low probability				
1 ï Improbable	1 [1]			
0 ï None				
Environmental significance	6 [6]	60 [35]	55 [30]	80 [55]
	Low [Low]	Medium [Low]	Medium [Low]	High [Medium]

4-2 CONCLUSIONS

The estimated additional radiation dose a member of the public from airborne exposure pathways is less than the regulatory dose limit of 1 mSv/yr and the dose constraint value of 0.25 mSv/yr. The safety assessment is based on conservative assumptions. These assumptions represent conditions that will exist at the end of KUP operations when maximum exposure conditions are expected.

Environmental monitoring and effluent control programmes, which include radiological aspects should result in lower exposures and radiation dose to the public than predicted in this safety assessment.

A quantitative radiological risk assessment for liquid exposure pathways is not included in this safety assessment. Any radioactive contamination of water resources can cause extremely negative public perceptions for the mine, even if the radiation dose contribution may meet regulatory criteria. A zero-release approach of mine water is defined in the KUP EIA. The mine designs presented in the EIA and the associated environmental monitoring programmes indicate a low probability for exposure pathways associated with surface water and groundwater. Radioactivity is only one aspect of potential water impacts. The prevention of non-radiological impacts will in most cases also prevent radiological impacts. Environmental monitoring programmes will be of cardinal importance to provide early warning against potential water impacts.

The extremely large volume of tailings wastes makes it unlikely to isolate the TSF completely from the environment over a prolonged period. Poor practices in the placement and management of TSFs in the history of uranium mining have contributed significantly to the negative legacy of uranium mining. The company has expressed its commitment to international best practice [44]. The engineering design is especially important in respect of TSF remediation and its cover design following closure.

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ATTACHMENT 1
BACKGROUND EXTERNAL RADIATION

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Ryst Kuil	1	6382063	673560	5.67	5.6	0.07	5.1	0.5	0.1	0.08
Ryst Kuil	2	6382133	673587	8.27	8.23	0.04	6.13	2.1	0.12	0.08
Ryst Kuil	3	6382169	673609	6.97	6.9	0.07	5.4	1.5	0.08	0.07
Ryst Kuil	4	6382258	673611	5.73	5.7	0.03	4.87	0.83	0.09	0.07
Ryst Kuil	5	6382273	673557	7.07	7.03	0.04	5.87	1.16	0.08	0.07
Ryst Kuil	6	6382326	673451	6	5.93	0.07	4.23	1.7	0.07	0.07
Ryst Kuil	7	6382275	673466	7.13	6.93	0.2	5.57	1.36	0.07	0.07
Ryst Kuil	8	6382292	673399	6.87	6.73	0.14	4.7	2.03	0.09	0.08
Ryst Kuil	9	6382269	673373	7.3	7.23	0.07	5.53	1.7	0.08	0.07
Ryst Kuil	10	6382236	673401	7	6.97	0.03	5.13	1.84	0.08	0.08
Ryst Kuil	11	6382258	673508	7.4	7.3	0.1	5.3	2	0.09	0.08
Ryst Kuil	12	6382209	673523	6.5	6.43	0.07	5.33	1.1	0.07	0.06
Ryst Kuil	13	6382156	673512	6.6	6.57	0.03	4.73	1.84	0.08	0.07

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Ryst Kuil	14	6382132	673503	6.33	6.17	0.16	5.3	0.87	0.08	0.07
Vlakplaas	1	6391346	685661	5.8	5.73	0.07	4.73	1	0.06	0.06
Vlakplaas	2	6390966	685886	6.37	6.33	0.04	5.23	1.1	0.07	0.08
Haanekuil	1	6392231	692540	6.77	6.6	0.17	4.37	2.23	0.04	0.07
Haanekuil	2	6392208	692401	5.23	5.17	0.06	4.17	1	0.06	0.07
Haanekuil	3	6390566	693254	5.57	5.47	0.1	4.23	1.24	0.05	0.06
Haanekuil	4	6390350	691980	5.73	5.67	0.06	4.4	1.27	0.06	0.06
Haanekuil	5	6391068	691776	6.07	6.03	0.04	4.9	1.13	0.08	0.09
Haanekuil	6	6392491	693047	6.97	6.93	0.04	4.87	2.06	0.06	0.09
Haanekuil	7	6389250	696066	5.2	5.07	0.13	4.63	0.44	0.05	0.07
Haanekuil	8	6387402	695404	5.2	5.13	0.07	4.53	0.6	0.04	0.05
Haanekuil	9	6386780	695612	5.57	5.57	0	5.2	0.37	0.06	0.07
Haanekuil	10	6386200	695343	5.23	5.17	0.06	4.43	0.74	0.05	0.06

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Kareepoort	1	6407125	654133	8.03	8.03	0	5.33	2.7	0.08	0.08
Kareepoort	2	6406991	654077	5.67	5.57	0.1	4.6	0.97	0.07	0.06
Kareepoort	3	6407498	654107	5.13	5.03	0.1	4.23	0.8	0.05	0.05
Vaalvlei	1	6408164	647169	5.97	5.83	0.14	5.1	0.73	0.09	0.09
Vaalvlei	2	6407595	646327	5.67	5.5	0.17	4.37	1.13	0.08	0.06
Vaalvlei	3	6407676	646265	4.83	4.77	0.06	3.53	1.24	0.05	0.05
Bokvlei	1	6410620	654500	4.6	4.37	0.23	3.77	0.6	0.05	0.04
Bokvlei	2	6410512	654251	5.2	5	0.2	3.6	1.4	0.04	0.04
Bokvlei	3	6410404	654037	5.47	5.4	0.07	3.73	1.67	0.06	0.05
Bokvlei	4	6409955	652977	4.97	4.87	0.1	3.8	1.07	0.07	0.05
Bokvlei	5	6409518	651769	6.33	6.17	0.16	4.03	2.14	0.06	0.04
Bokvlei	6	6409177	650753	6.77	6.57	0.2	4.23	2.34	0.07	0.06
Ryst Kuil	1	6382043	673833	6	5.73	0.27	5.93	-0.2	0.5	0.5

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Ryst Kuil	2	6382224	673945	6.53	6.5	0.03	4.93	1.57	0.6	0.5
Ryst Kuil	3	6382474	674350	7.03	6.91	0.12	5.97	0.94	0.9	0.08
Ryst Kuil	4	6382602	674687	7.47	7.37	0.1	5.97	1.4	0.1	0.8
Ryst Kuil	5	6382879	675451	5.8	5.67	0.13	5.87	-0.2	0.8	0.07
Ryst Kuil	6	6382825	675496	7.63	7.53	0.1	5.5	2.03	0.08	0.08
Klipstawel	1	6374865	669483	6.57	6.43	0.14	5.23	1.2	0.06	0.06
Klipstawel	2	6374915	669279	7.4	7.27	0.13	5.9	1.37	0.06	0.06
Klipstawel	3	637492	669085	7.23	7.07	0.16	5.77	1.3	0.06	0.06
Kantkraal	1	6376901	661974	7.43	7.37	0.06	5.83	1.54	0.6	0.5
Kantkraal	2	6377031	661933	7.27	7.2	0.07	5.2	2	0.07	0.07
Kantkraal	3	6377126	661965	7.5	7.3	0.2	7.23	0.07	0.09	0.08
Kantkraal	4	6377199	661859	7.23	7.1	0.13	5.67	1.43	0.08	0.08
Kat Doorn Kuil	1	6379723	665774	7.4	7.37	0.03	6.07	1.3	0.06	0.5

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Kat Doorn Kuil	2	6379687	665825	7.93	7.9	0.03	5.4	2.5	0.06	0.6
Kat Doorn Kuil	3	6381905	670105	7.23	7.17	0.06	5.5	1.67	0.08	0.7
Kat Doorn Kuil	4	6381426	670851	7.47	7.4	0.07	5.23	2.17	0.09	0.09
Kat Doorn Kuil	5	6381379	670879	5.83	5.8	0.03	5.33	0.47	0.06	0.06
Ryst Kuil controlled area	1	6378145	663372	5.3	5.13	0.17	ï	5.13	7.27	0.4
Ryst Kuil controlled area	2	6377269	664860	5.53	5.47	0.06	ï	5.47	7.03	0.4
Ryst Kuil controlled area	3	6378477	665337	4.93	4.77	0.16	ï	4.77	6	0.11
Ryst Kuil controlled area	4	6378900	670909	4.7	4.7	0	ï	4.7	6.8	0.07
Ryst Kuil controlled area	5	6378651	670102	5.63	5.53	0.1	ï	5.53	5.6	0.07
Ryst Kuil controlled area	6	6379335	670124	2	2	0	ï	2	6.4	0.08
Ryst Kuil controlled area	7	6379276	669962	5.1	5.1	0	ï	5.1	5.37	0.08
Kat Doorn Kuil	1	6381469	672287	4.5	4.43	0.07	ï	4.43	6.43	0.09

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Kat Doorn Kuil	2	6381474	673309	4.17	4.03	0.14	ï	4.03	6.3	0.08
Kat Doorn Kuil	3	6381218	673060	4.57	4.43	0.14	ï	4.43	5.8	0.08
Kat Doorn Kuil	4	6379935	672361	5.77	4.63	1.14	ï	4.63	7.7	0.09
Kat Doorn Kuil	5	6379539	670743	4.23	4.2	0.03	ï	4.2	6.8	0.07
Kat Doorn Kuil	6	6379346	670911	4.7	4.63	0.07	ï	4.63	7.2	0.09
Neverset	1	6395369	688906	6.27	6.27	0	4.8	1.47	0.07	0.07
Neverset	2	6394299	687314	6.23	6.17	0.06	4.6	1.57	0.07	0.06
Neverset	3	6391935	685441	4.93	4.9	0.03	4.6	0.3	0.04	0.06
Neverset	4	6394021	684322	5.8	5.7	0.1	4.4	1.3	0.05	0.07
Neverset	5	6396549	689545	4.93	4.93	0	4.47	0.46	0.06	0.06
De Pannen	1	6405275	716380	6.83	6.63	0.2	4.6	2.03	0.09	0.09
De Pannen	2	6406092	717096	5.67	5.57	0.1	4.23	1.34	0.06	0.07
De Pannen	3	6406061	716977	5.27	5.2	0.07	3.7	1.5	0.07	0.07

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
De Pannen	4	6406165	716919	5.83	5.7	0.13	5.17	0.53	0.07	0.07
De Pannen	5	6406443	717412	5.57	5.47	0.1	5.3	0.17	0.07	0.07
Klein Tafel Kop	1	6401065	713586	6.1	6.03	0.07	5.17	0.86	0.07	0.08
Klein Tafel Kop	2	6400647	713408	6.73	6.7	0.03	5.3	1.4	0.06	0.07
Ryst Kuil Controlled Area	1	6382454	673121	8.7	8.63	0.07	ï	8.63	0.14	0.1
Contaminated area (Ryst Kuil historical trial mine)										
Ryst Kuil Controlled Area	2	6382306	673111	ï	10	10	ï	10	0.27	0.27
Ryst Kuil Controlled Area	3	6382336	673106	71	70.5	0.5	ï	70.5	ï	1.05
Ryst Kuil Controlled Area	4	6382366	673013	8.5	8.37	0.13	ï	8.37	ï	0.09
Ryst Kuil Controlled Area	5	6382417	673051	673	669	4	ï	669	ï	1.39

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Ryst Kuil Controlled Area	6	6382516	672905	9.07	8.73	0.34	ï	8.73	ï	0.12
Ryst Kuil Controlled Area	7	6382474	672837	14	13.5	0.5	ï	13.5	ï	0.23
Ryst Kuil Controlled Area	8	6382577	672674	58.4	57.3	1.1	ï	57.3	ï	0.88
Ryst Kuil Controlled Area	9	6382695	672744	14.5	14.5	0	ï	14.5	ï	0.26
Ryst Kuil Controlled Area	10	6382656	672549	7.53	7.23	0.3	ï	7.23	ï	0.1
Ryst Kuil Controlled Area	11	6382813	672660	7.23	6.97	0.26	ï	6.97	ï	0.07
Ryst Kuil Controlled Area	12	6382734	672807	6.53	6.43	0.1	ï	6.43	ï	0.06
Ryst Kuil Controlled Area	13	6383121	672908	6.8	6.6	0.2	ï	6.6	ï	0.08

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Ryst Kuil Controlled Area	14	6383261	673165	7.1	6.97	0.13	ï	6.97	ï	0.07
Ryst Kuil Controlled Area	15	6383021	673185	7.17	6.97	0.2	ï	6.97	ï	0.09
Ryst Kuil Controlled Area	16	6382983	673340	8.83	8.77	0.06	ï	8.77	ï	0.08
Ryst Kuil Controlled Area	17	6383028	673401	6.8	6.8	0	ï	6.8	ï	0.09
Ryst Kuil Controlled Area	18	6383064	673495	7.43	7.37	0.06	ï	7.37	ï	0.09
Ryst Kuil Controlled Area	19	6383077	673541	7.23	7.13	0.1	ï	7.13	ï	0.09
Ryst Kuil Controlled Area	20	6383087	673534	8.07	8.03	0.04	ï	8.03	ï	0.1
Ryst Kuil Controlled Area	21	6379465	663890	7.2	7.1	0.1	ï	7.1	ï	0.09

Table A1-1: External Radiation measured with portable radiation monitors

Area	Measurement No	GPS Coordinates		Electra GM Surface Activity Alpha/Beta/gamma (counts per second)					Gamma reading; µSv/h	
		Y	X	Alpha + Beta + Gamma; cps	Beta + Gamma; cps	Alpha; cps	Gamma; cps	Beta; cps	Surface contact measurement	1 m height measurement
Ryst Kuil Controlled Area	22	6379462	663894	8.67	8.57	0.1	ï	8.57	ï	0.1
Ryst Kuil Controlled Area	23	6378145	663372	8.07	7.93	0.14	ï	7.93	ï	0.13
Ryst Kuil Controlled Area	24	6377269	664860	17.7	17.5	0.2	ï	17.5	ï	0.11

Table A1-2: Survey No.2 − External Radiation measured with TLD monitors (1m above ground level)

Location ID	Coordinates (UTM 34S)		TLD		Dose; mSv/period	TLD		Dose; mSv/period	Average mSv/period	Projected annual dose, mSv/h at 24h exposure
	X	Y								
Homestead: Bokvlei	721505	6409656	PSI-18	205412	0.28	PSI-28	402865	0.44	0.36	1.44
Homestead: Dawie Swart	721774	6405979	PSI-9	122974	0.31	PSI-39	416081	0.24	0.275	1.10
Homestead: David Pickard-Cambridge	693120	6393848	PSI-27	402458	0.37	PSI-37	413091	0.28	0.325	1.30
Homestead: Quaggasfontein	647583	6411570	PSI-24	308751	0.4	PSI-31	404901	0.38	0.39	1.58
F49	653213	6410504	PSI-34	408693	0.29	PSI-35	409646	0.29	0.29	1.18
F62	652468	6409944	PSI-56	9100106	0.25	PSI-58	9201091	0.31	0.28	1.14
F61	653258	6409310	PSI-29	404756	0.44	PSI-4	67565	0.31	0.375	1.52
F51	654208	6409895	PSI-3	35437	0.35	PSI-26	401253	0.48	0.415	1.68
Rietkuil Pit	606858	6412284	PSI-21	206586	9.25	PSI-10	124640	9.59	9.42	38.23
F71	675163	6384047	PSI-52	533596	0.5	PSI-51	432145	0.4	0.45	1.85
F70	673005	6385331	PSI-41	419854	0.35	PSI-45	424880	0.32	0.335	1.37

Table A1-2: Survey No.2 − External Radiation measured with TLD monitors (1m above ground level)

Location ID	Coordinates (UTM 34S)		TLD		Dose; mSv/period	TLD		Dose; mSv/period	Average mSv/period	Projected annual dose, mSv/h at 24h exposure
	X	Y								
F69	670695	6384519	PSI-55	3330920	0.35	PSI-2	35415	0.38	0.365	1.50
F68	670775	6383751	PSI-54	3322105	0.33	PSI-48	428483	0.32	0.325	1.33
F67	671495	6383305	PSI-23	212121	0.34	PSI-6	84777	0.34	0.34	1.40
Ngondo House	663974	6379633	PSI-16	147697	0.38	PSI-17	205390	0.34	0.36	1.48
F72	672400	6380730	PSI-12	126330	0.28	PSI-1	10247	0.49	0.385	1.71
F66	663800	6377825	PSI-44	423785	0.48	PSI-50	431515	0.34	0.41	1.83
F63	662761	6376295	PSI-11	124657	0.47	PSI-59	9201274	0.44	0.455	2.03
F64	661445	6376604	PSI-19	206369	0.38	PSI-46	426983	0.33	0.355	1.58
F65	662347	6377099	PSI-60	9408998	0.36	PSI-5	72337	0.33	0.345	1.54
F74	692448	6391843	PSI-8	122529	0.38	PSI-7	120073	0.33	0.355	1.58
F73	691306	6390249	PSI-32	407570	0.26	PSI-42	421266	0.25	0.255	1.14

Table A1-2: Survey No.2 − External Radiation measured with TLD monitors (1m above ground level)

Location ID	Coordinates (UTM 34S)		TLD		Dose; mSv/period	TLD		Dose; mSv/period	Average mSv/period	Projected annual dose, mSv/h at 24h exposure
	X	Y								
F75	695184	6392751	PSI-38	415484	0.33	PSI-57	9100609	0.32	0.325	1.45
F78	712569	6402453	PSI-14	141520	0.44	PSI-36	410938	0.32	0.38	1.69
F79	713656	6403379	PSI-22	210314	0.38	PSI-40	419733	0.34	0.36	1.60
F80	715117	6401544	PSI-47	427370	0.34	PSI-20	206554	0.36	0.35	1.56
F77	712597	6399112	PSI-49	429689	0.32	PSI-30	404777	0.45	0.385	1.71
F76	712412	6398821	PSI-33	408011	0.3	PSI-15	146976	0.3	0.3	1.34
F81	715614	6402039	PSI-53	3116484	0.31	PSI-25	309503	0.34	0.325	1.45

ATTACHMENT 2

BACKGROUND RADON MONITORING RESULTS

Table A2-1: Survey # 1, RGM monitor record results (2008)

Co-ordinates (UTM 34S)		RGM Monitors			Gamma radiation (contact)	Comments
Y	**X**				uSv/h	
6379376	663956	83640	83643	83606	0.095	Sample storage
6381910	670113	83621	83642	83586	0.091	Sheep camp
6381465	673390	83645	83630	83615	0.083	Fenced camp near old mine
6382456	672957	83613	83623	83648	0.41	Crusher on Ryst Kuil contaminated mining area
6382459	672897	83644	83617	83609	0.56	At radioactive waste dumps
6384809	678740	83639	83633	83684	0.064	Old water pumping area
6383416	676321	83594	83637	83589	0.08	ï
Inside Cameron decline shaft		83629	83675	83603	0.15	Decline right wall (walking in)
		83625	83653	83618	0.15	Decline left wall (walking in)
6382831	672676	83683	83608	83636	0.074	In proximity of Ryst Kuil historical mining area
6382657	672560	83590	83595	83670	0.082	
6379719	665770	83604	83622	83658	0.093	Exit from farm
6419344	649719	83679	83634	83593		Beaufort West office
6402271	648629	83652	83605	83596	0.083	Olive Grove Guest Farm

Table A2-2: Survey # 1, Radon results - RGM exposure time 1920 hours (2008)				
RGM monitor	Bq.h.m-3	Standard deviation	Bq/m^3	εSv/yr
83606	1.30E+04	1.60E+04	6.8	216.7
83607	2.30E+04	9.00E+03	12.0	383.3
83608	9.00E+03	1.80E+04	4.7	150.0
83611	3.70E+04	9.00E+03	19.3	616.7
83612	3.60E+04	1.80E+04	18.8	600.0
83614	6.00E+03	1.70E+04	3.1	100.0
83616	5.00E+03	8.00E+03	2.6	83.3
83621	8.00E+03	9.00E+03	4.2	133.3
83622	2.00E+04	9.00E+03	10.4	333.3
83624	1.80E+04	1.80E+04	9.4	300.0
83626	6.00E+03	1.50E+04	3.1	100.0
83627	1.10E+04	1.60E+04	5.7	183.3
83628	1.80E+04	8.00E+03	9.4	300.0
83631	2.00E+04	1.70E+04	10.4	333.3
83632	6.00E+03	1.50E+04	3.1	100.0
83633	1.10E+04	1.80E+04	5.7	183.3
83634	6.00E+03	8.00E+03	3.1	100.0
83635	2.30E+04	1.90E+04	12.0	383.3
83636	4.00E+03	1.70E+04	2.1	66.7
83637	3.10E+04	9.00E+03	16.1	516.7
83638	9.00E+03	1.60E+04	4.7	150.0
83639	8.00E+03	1.60E+04	4.2	133.3

Table A2-2: Survey # 1, Radon results - RGM exposure time 1920 hours (2008)

RGM monitor	Bq.h.m-3	Standard deviation	Bq/m^3	ε Sv/yr
83640	2.20E+04	9.00E+03	11.5	366.7
83641	1.50E+04	1.70E+04	7.8	250.0
83642	4.60E+04	2.20E+04	24.0	766.7
83643	2.30E+04	9.00E+03	12.0	383.3
83646	7.00E+03	1.70E+04	3.6	116.7
83649	1.60E+04	1.70E+04	8.3	266.7
83651	2.20E+04	9.00E+03	11.5	366.7
83652	1.70E+04	9.00E+03	8.9	283.3
83654	7.00E+03	1.60E+04	3.6	116.7
83655	1.50E+04	1.60E+04	7.8	250.0
83656	2.20E+04	1.70E+04	11.5	366.7
83657	8.00E+03	2.00E+04	4.2	133.3
83658	1.40E+04	1.70E+04	7.3	233.3
83659	1.10E+04	1.60E+04	5.7	183.3
83660	2.80E+04	9.00E+03	14.6	466.7
83661	3.50E+04	1.00E+04	18.2	583.3
83662	3.00E+04	9.00E+03	15.6	500.0
83663	1.10E+04	1.70E+04	5.7	183.3
83664	3.20E+04	2.00E+04	16.7	533.3
83665	1.90E+04	8.00E+03	9.9	316.7
83666	7.40E+04	1.40E+04	38.5	1233.3
83668	1.10E+04	2.00E+04	5.7	183.3

Table A2-2: Survey # 1, Radon results - RGM exposure time 1920 hours (2008)

RGM monitor	Bq.h.m-3	Standard deviation	Bq/m^3	ε Sv/yr
83669	5.00E+03	1.60E+04	2.6	83.3
83670	9.00E+03	1.70E+04	4.7	150.0
83672	2.00E+04	1.80E+04	10.4	333.3
83674	3.00E+04	1.90E+04	15.6	500.0
83676	5.10E+04	1.10E+04	26.6	850.0
83677	2.00E+04	1.80E+04	10.4	333.3
83678	1.30E+04	8.00E+03	6.8	216.7
83679	1.20E+04	8.00E+03	6.3	200.0
83680	1.90E+04	8.00E+03	9.9	316.7
83682	1.00E+04	1.70E+04	5.2	166.7
83683	1.70E+04	1.60E+04	8.9	283.3
83684	5.00E+03	1.60E+04	2.6	83.3
83685	8.00E+03	1.50E+04	4.2	133.3

Table A2-3: Radon survey # 2 (2015)

Note: The locations of the homesteads and at fence line monitoring positions are shown in figures 1-8 to 1-12 and figure 3-1

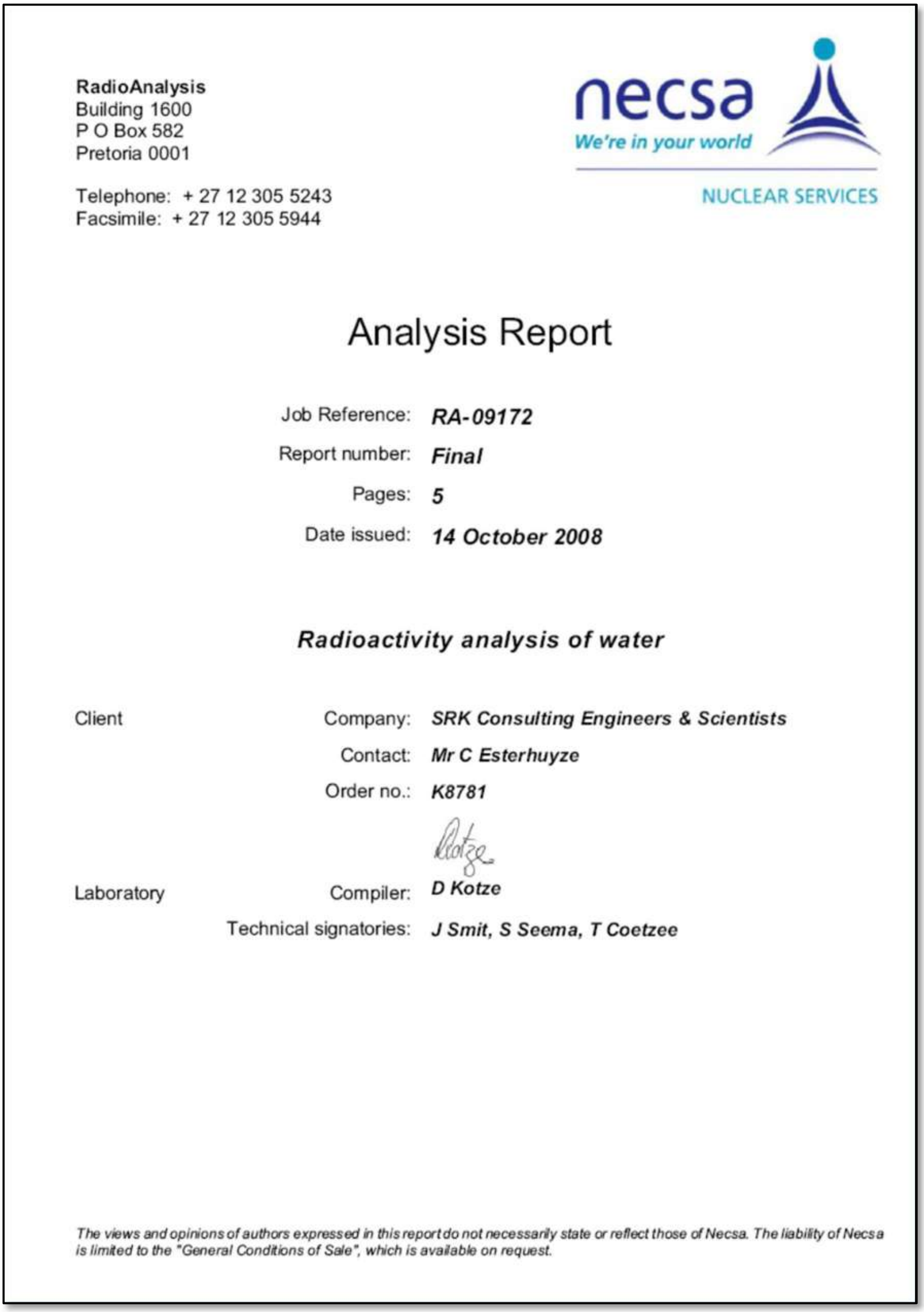
Location ID			RGM	Average, Bq.h.m^3	St Dev	RGM	Average, Bq.h.m^3	St Dev	Average, Bq.h.m^3	Bq/m^3	εSv/yr
1	PEN-RG-1-1	Homestead: Bokvlei	81400	1.74E+04	1.27E+04	81390	2.35E+04	1.32E+04	2.04E+04	10.2	327
2	PEN-RG-1-2	Homestead: Dawie Swart	81427	2.82E+04	1.36E+04	81407	2.32E+04	1.32E+04	2.57E+04	12.9	411
3	PEN-RG-1-3	Homestead: David Pickard-Cambridge	81427	1.53E+04	1.48E+04	81426	2.42E+04	1.33E+04	1.97E+04	9.9	315
4	PEN-RG-1-4	Homestead: Quaggasfontein	81381	1.98E+04	1.29E+04	81411	2.47E+04	1.33E+04	2.23E+04	11.1	356
5	PEN-RG-1-5	F49	81401	2.32E+04	1.32E+04	81435	2.46E+04	1.33E+04	2.39E+04	11.9	382
6	PEN-RG-1-6	F62	81402	1.69E+04	1.28E+04	81393	2.28E+04	1.31E+04	1.98E+04	9.9	318
7	PEN-RG-1-7	F61	81383	2.97E+04	1.37E+04	81386	2.78E+04	1.36E+04	2.87E+04	14.4	460
8	PEN-RG-1-8	F51	81404	1.69E+04	1.28E+04	81409	2.42E+04	1.33E+04	2.05E+04	10.3	328
9	PEN-RG-1-9	Rietkuil Pit	81417	1.49E+05	2.49E+04	81392	1.55E+05	2.55E+04	1.52E+05	76.0	2431
10	PEN-RG-1-10	F71	81389	2.42E+04	1.33E+04	81430	1.66E+04	1.31E+04	2.04E+04	10.2	326
11	PEN-RG-1-11	F70	81418	2.64E+04	1.35E+04	81420	1.77E+04	1.27E+04	2.21E+04	11.0	353
12	PEN-RG-1-12	F69	81388	2.31E+04	1.32E+04	81432	2.46E+04	1.33E+04	2.38E+04	11.9	381
13	PEN-RG-1-13	F68	81425	2.65E+04	1.35E+04	81413	2.06E+04	1.30E+04	2.35E+04	11.8	377
14	PEN-RG-1-14	F67	81431	1.66E+04	1.31E+04	81415	2.50E+04	1.33E+04	2.08E+04	10.4	332
15	PEN-RG-1-15	Homestead: Ngondo	81429	1.53E+04	1.48E+04	81410	1.91E+04	1.28E+04	1.72E+04	8.6	275
16	PEN-RG-1-16	F72	81391	1.62E+04	1.36E+04	81379	2.82E+04	1.36E+04	2.22E+04	11.1	355
17	PEN-RG-1-17	F66	81412	1.92E+04	1.28E+04	81414	1.84E+04	1.28E+04	1.88E+04	9.4	301
18	PEN-RG-1-18	F63	81394	3.19E+04	1.39E+04	81377	2.78E+04	1.36E+04	2.99E+04	14.9	478

Table A2-3: Radon survey # 2 (2015)

Note: The locations of the homesteads and at fence line monitoring positions are shown in figures 1-8 to 1-12 and figure 3-1

Location ID			RGM	Average, Bq.h.m^3	St Dev	RGM	Average, Bq.h.m^3	St Dev	Average, Bq.h.m^3	Bq/m^3	εSv/yr
19	PEN-RG-1-19	F64	81384	2.29E+04	1.32E+04	81433	1.74E+04	1.27E+04	2.01E+04	10.1	322
20	PEN-RG-1-20	F65	81395	1.66E+04	1.31E+04	81396	2.35E+04	1.32E+04	2.01E+04	10.0	321
21	PEN-RG-1-21	F74	81398	1.61E+04	1.36E+04	81423	2.35E+04	1.32E+04	1.98E+04	9.9	317
22	PEN-RG-1-22	F73	81380	2.85E+04	1.36E+04	81403	2.71E+04	1.35E+04	2.78E+04	13.9	445
23	PEN-RG-1-23	F75	81422	1.47E+04	1.28E+04	81387	2.24E+04	1.31E+04	1.86E+04	9.3	297
24	PEN-RG-1-24	F78	81428	1.92E+04	1.28E+04	81416	2.50E+04	1.33E+04	2.21E+04	11.0	353
25	PEN-RG-1-25	F79	81424	1.64E+04	1.32E+04	81436	2.17E+04	1.31E+04	1.91E+04	9.5	305
26	PEN-RG-1-26	F80	18434	2.49E+04	1.33E+04	81399	1.75E+04	1.27E+04	2.12E+04	10.6	339
27	PEN-RG-1-27	F77	81405	2.36E+04	1.32E+04	81378	2.28E+04	1.31E+04	2.32E+04	11.6	371
28	PEN-RG-1-28	F76	81408	1.92E+04	1.28E+04	81419	2.61E+04	1.34E+04	2.26E+04	11.3	362
29	PEN-RG-1-29	F81	81421	2.79E+04	1.36E+04	81397	2.18E+04	1.31E+04	2.49E+04	12.4	398

ATTACHMENT 3
GROUNDWATER RADIOANALYSIS RESULTS



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Analysis Report

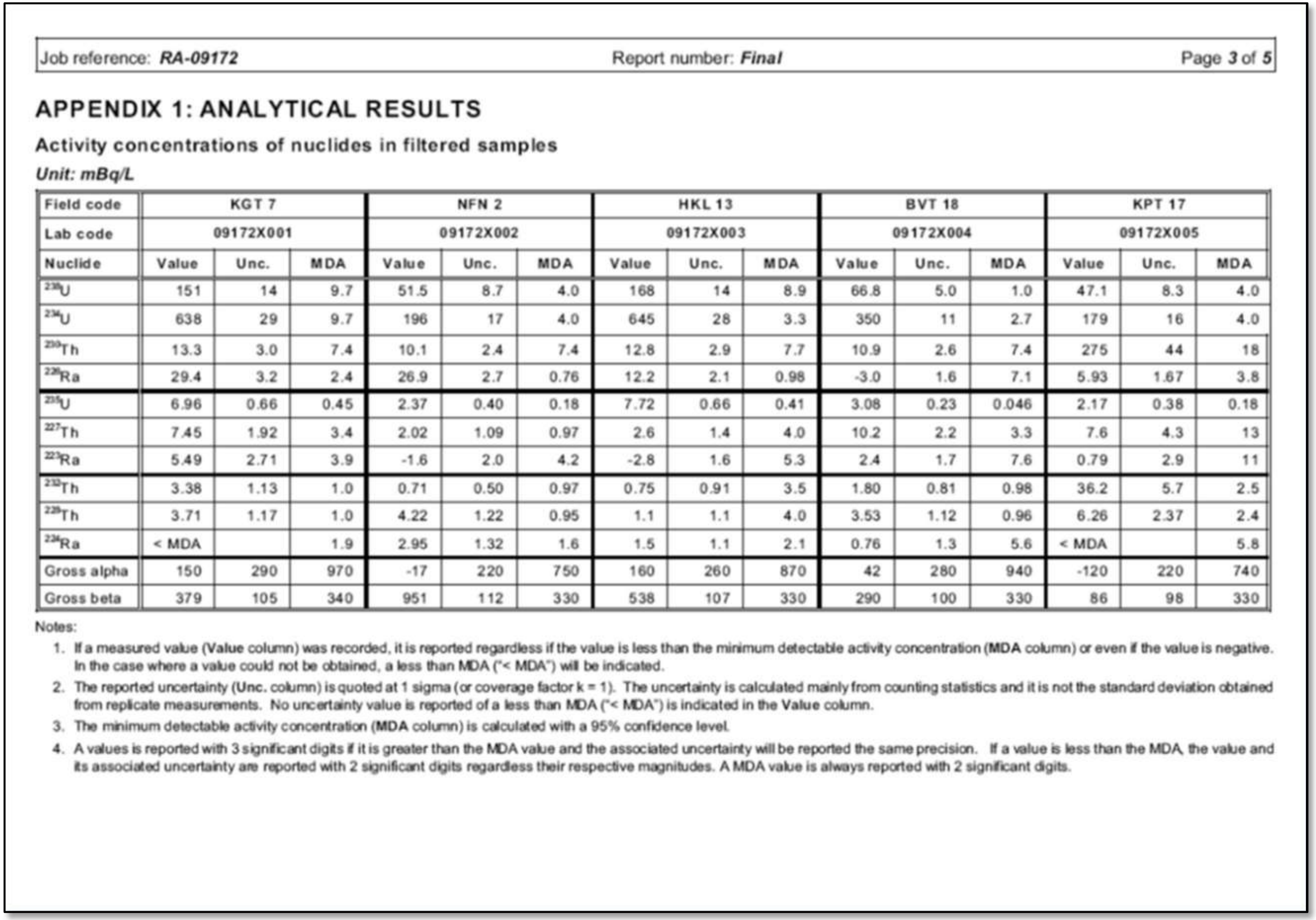
Job Reference: ***RA-09172***
Report number: ***Final***
Pages: ***5***
Date issued: ***14 October 2008***

Radioactivity analysis of water

Client
Company: ***SRK Consulting Engineers & Scientists***
Contact: ***Mr C Esterhuyze***
Order no.: ***K8781***

Kotze

Laboratory
Compiler: ***D Kotze***
Technical signatories: ***J Smit, S Seema, T Coetzee***



APPENDIX 1: ANALYTICAL RESULTS

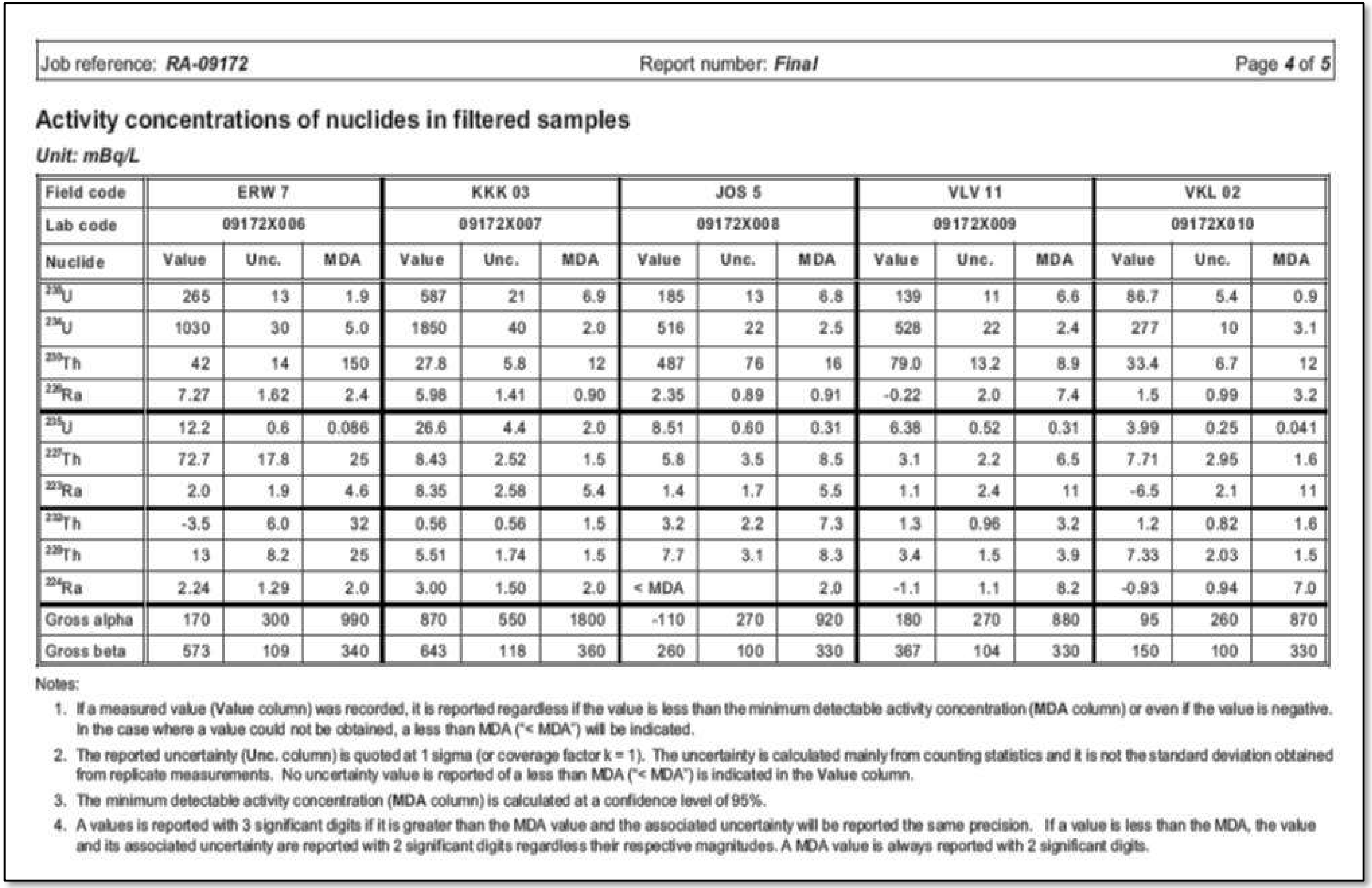
Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	KGT 7			NFN 2			HKL 13			BVT 18			KPT 17		
Lab code	09172X001			09172X002			09172X003			09172X004			09172X005		
Nuclide	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA	Value	Unc.	MDA
^{238}U	151	14	9.7	51.5	8.7	4.0	168	14	8.9	66.8	5.0	1.0	47.1	8.3	4.0
^{234}U	638	29	9.7	196	17	4.0	645	28	3.3	350	11	2.7	179	16	4.0
^{230}Th	13.3	3.0	7.4	10.1	2.4	7.4	12.8	2.9	7.7	10.9	2.6	7.4	275	44	18
^{226}Ra	29.4	3.2	2.4	26.9	2.7	0.76	12.2	2.1	0.98	-3.0	1.6	7.1	5.93	1.67	3.8
^{235}U	6.96	0.66	0.45	2.37	0.40	0.18	7.72	0.66	0.41	3.08	0.23	0.046	2.17	0.38	0.18
^{227}Th	7.45	1.92	3.4	2.02	1.09	0.97	2.6	1.4	4.0	10.2	2.2	3.3	7.6	4.3	13
^{223}Ra	5.49	2.71	3.9	-1.6	2.0	4.2	-2.8	1.6	5.3	2.4	1.7	7.6	0.79	2.9	11
^{232}Th	3.38	1.13	1.0	0.71	0.50	0.97	0.75	0.91	3.5	1.80	0.81	0.98	36.2	5.7	2.5
^{228}Th	3.71	1.17	1.0	4.22	1.22	0.95	1.1	1.1	4.0	3.53	1.12	0.96	6.26	2.37	2.4
^{224}Ra	< MDA		1.9	2.95	1.32	1.6	1.5	1.1	2.1	0.76	1.3	5.6	< MDA		5.8
Gross alpha	150	290	970	-17	220	750	160	260	870	42	280	940	-120	220	740
Gross beta	379	105	340	951	112	330	538	107	330	290	100	330	86	98	330

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-09172*** Report number: ***Final*** Page **4** of **5**

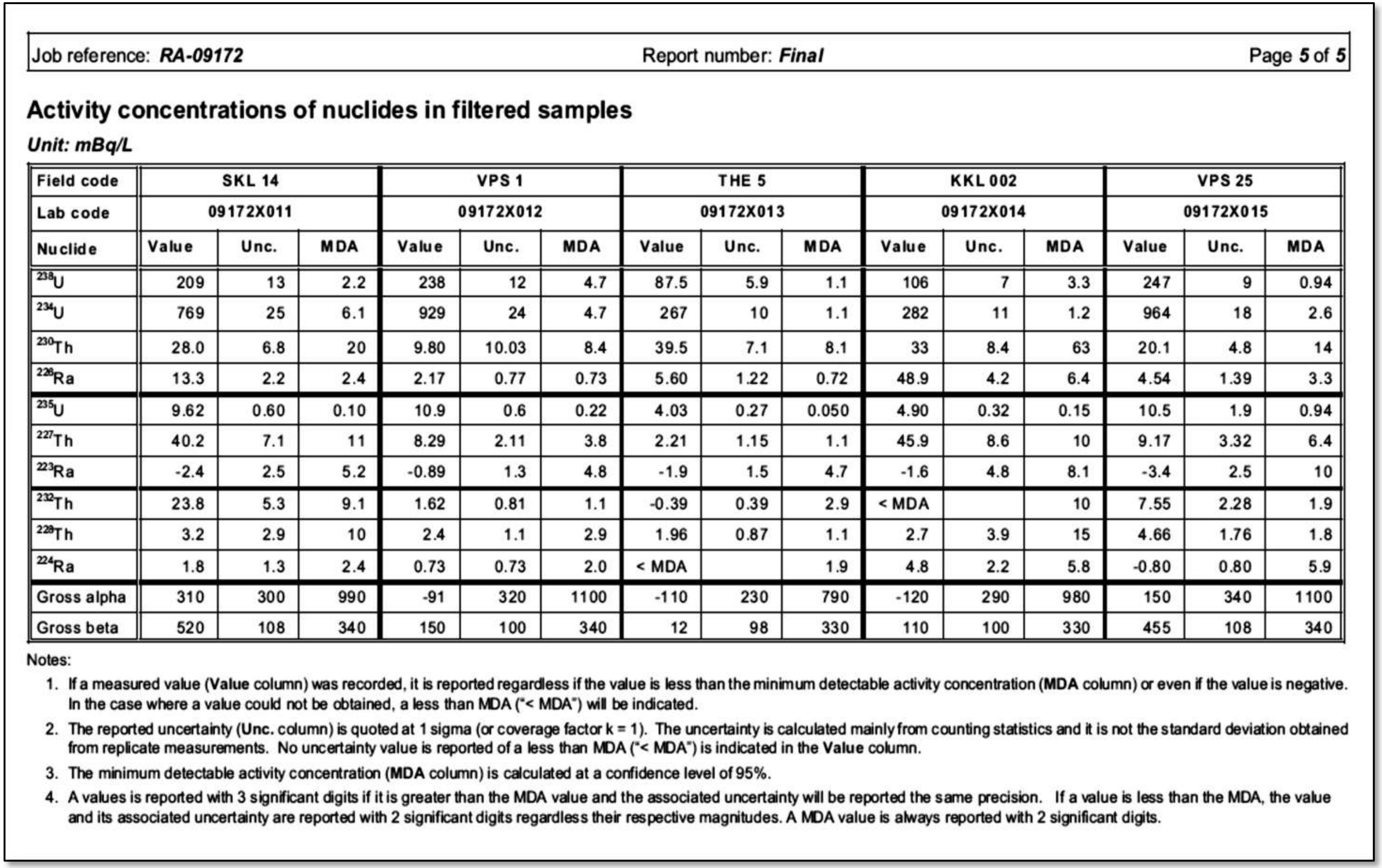
Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	**ERW 7**			**KKK 03**			**JOS 5**			**VLV 11**			**VKL 02**		
Lab code	**09172X006**			**09172X007**			**09172X008**			**09172X009**			**09172X010**		
Nuclide	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**
^{238}U	265	13	1.9	587	21	6.9	185	13	6.8	139	11	6.6	86.7	5.4	0.9
^{234}U	1030	30	5.0	1850	40	2.0	516	22	2.5	528	22	2.4	277	10	3.1
^{230}Th	42	14	150	27.8	5.8	12	487	76	16	79.0	13.2	8.9	33.4	6.7	12
^{226}Ra	7.27	1.62	2.4	5.98	1.41	0.90	2.35	0.89	0.91	-0.22	2.0	7.4	1.5	0.99	3.2
^{235}U	12.2	0.6	0.086	26.6	4.4	2.0	8.51	0.60	0.31	6.38	0.52	0.31	3.99	0.25	0.041
^{227}Th	72.7	17.8	25	8.43	2.52	1.5	5.8	3.5	8.5	3.1	2.2	6.5	7.71	2.95	1.6
^{223}Ra	2.0	1.9	4.6	8.35	2.58	5.4	1.4	1.7	5.5	1.1	2.4	11	-6.5	2.1	11
^{232}Th	-3.5	6.0	32	0.56	0.56	1.5	3.2	2.2	7.3	1.3	0.96	3.2	1.2	0.82	1.6
^{228}Th	13	8.2	25	5.51	1.74	1.5	7.7	3.1	8.3	3.4	1.5	3.9	7.33	2.03	1.5
^{224}Ra	2.24	1.29	2.0	3.00	1.50	2.0	< MDA		2.0	-1.1	1.1	8.2	-0.93	0.94	7.0
Gross alpha	170	300	990	870	550	1800	-110	270	920	180	270	880	95	260	870
Gross beta	573	109	340	643	118	360	260	100	330	367	104	330	150	100	330

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-09172*** Report number: ***Final*** Page ***5*** of ***5***

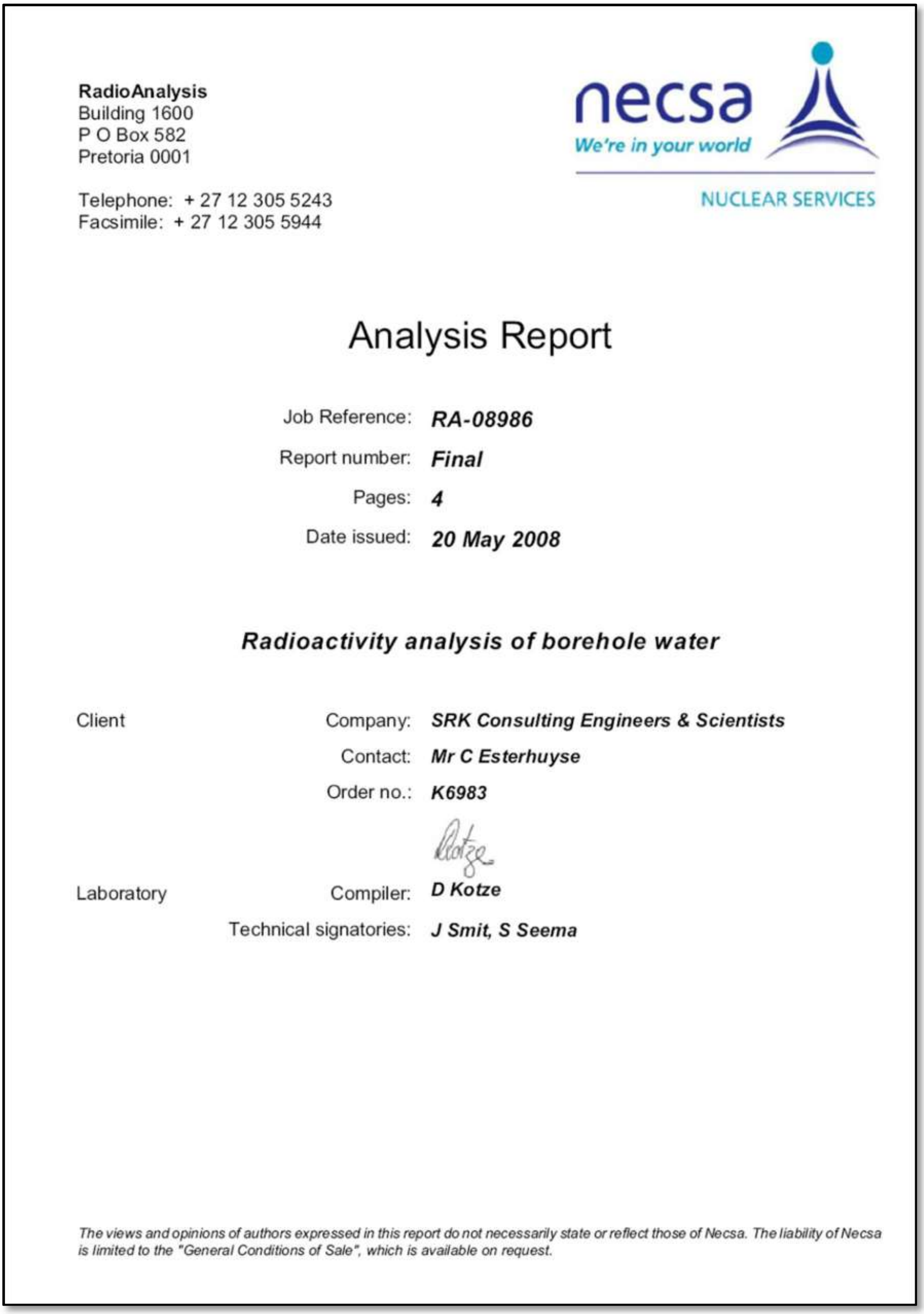
Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	**SKL 14**			**VPS 1**			**THE 5**			**KKL 002**			**VPS 25**		
Lab code	**09172X011**			**09172X012**			**09172X013**			**09172X014**			**09172X015**		
Nuclide	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**
^{238}U	209	13	2.2	238	12	4.7	87.5	5.9	1.1	106	7	3.3	247	9	0.94
^{234}U	769	25	6.1	929	24	4.7	267	10	1.1	282	11	1.2	964	18	2.6
^{230}Th	28.0	6.8	20	9.80	10.03	8.4	39.5	7.1	8.1	33	8.4	63	20.1	4.8	14
^{226}Ra	13.3	2.2	2.4	2.17	0.77	0.73	5.60	1.22	0.72	48.9	4.2	6.4	4.54	1.39	3.3
^{235}U	9.62	0.60	0.10	10.9	0.6	0.22	4.03	0.27	0.050	4.90	0.32	0.15	10.5	1.9	0.94
^{227}Th	40.2	7.1	11	8.29	2.11	3.8	2.21	1.15	1.1	45.9	8.6	10	9.17	3.32	6.4
^{223}Ra	-2.4	2.5	5.2	-0.89	1.3	4.8	-1.9	1.5	4.7	-1.6	4.8	8.1	-3.4	2.5	10
^{232}Th	23.8	5.3	9.1	1.62	0.81	1.1	-0.39	0.39	2.9	< MDA		10	7.55	2.28	1.9
^{228}Th	3.2	2.9	10	2.4	1.1	2.9	1.96	0.87	1.1	2.7	3.9	15	4.66	1.76	1.8
^{224}Ra	1.8	1.3	2.4	0.73	0.73	2.0	< MDA		1.9	4.8	2.2	5.8	-0.80	0.80	5.9
Gross alpha	310	300	990	-91	320	1100	-110	230	790	-120	290	980	150	340	1100
Gross beta	520	108	340	150	100	340	12	98	330	110	100	330	455	108	340

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.



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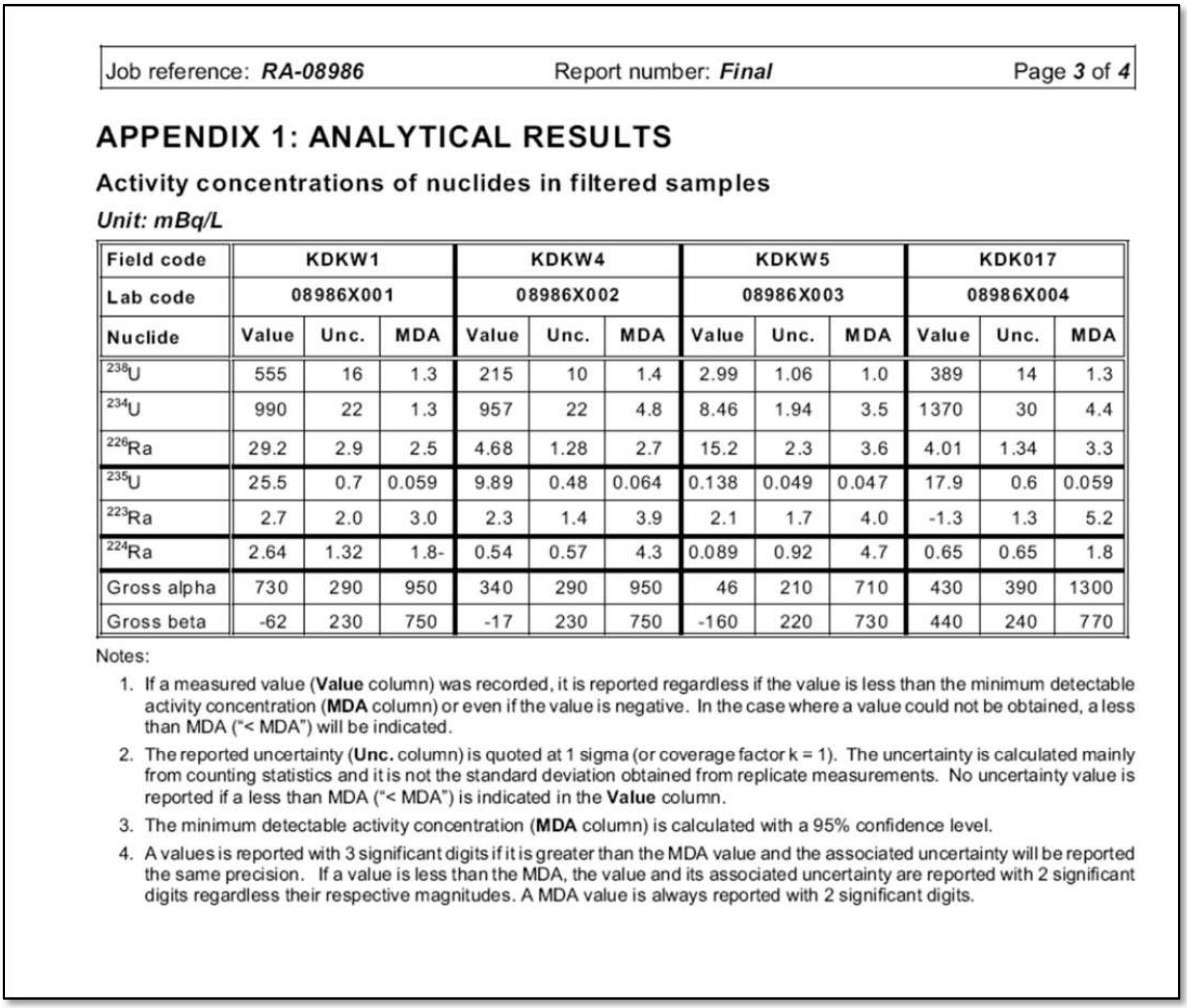
Analysis Report

Job Reference: ***RA-08986***
Report number: ***Final***
Pages: ***4***
Date issued: ***20 May 2008***

Radioactivity analysis of borehole water

Client	Company:	***SRK Consulting Engineers & Scientists***
	Contact:	***Mr C Esterhuyse***
	Order no.:	***K6983***
		Kotze
Laboratory	Compiler:	***D Kotze***
	Technical signatories:	***J Smit, S Seema***



Job reference: ***RA-08986*** Report number: ***Final*** Page **3** of **4**

APPENDIX 1: ANALYTICAL RESULTS

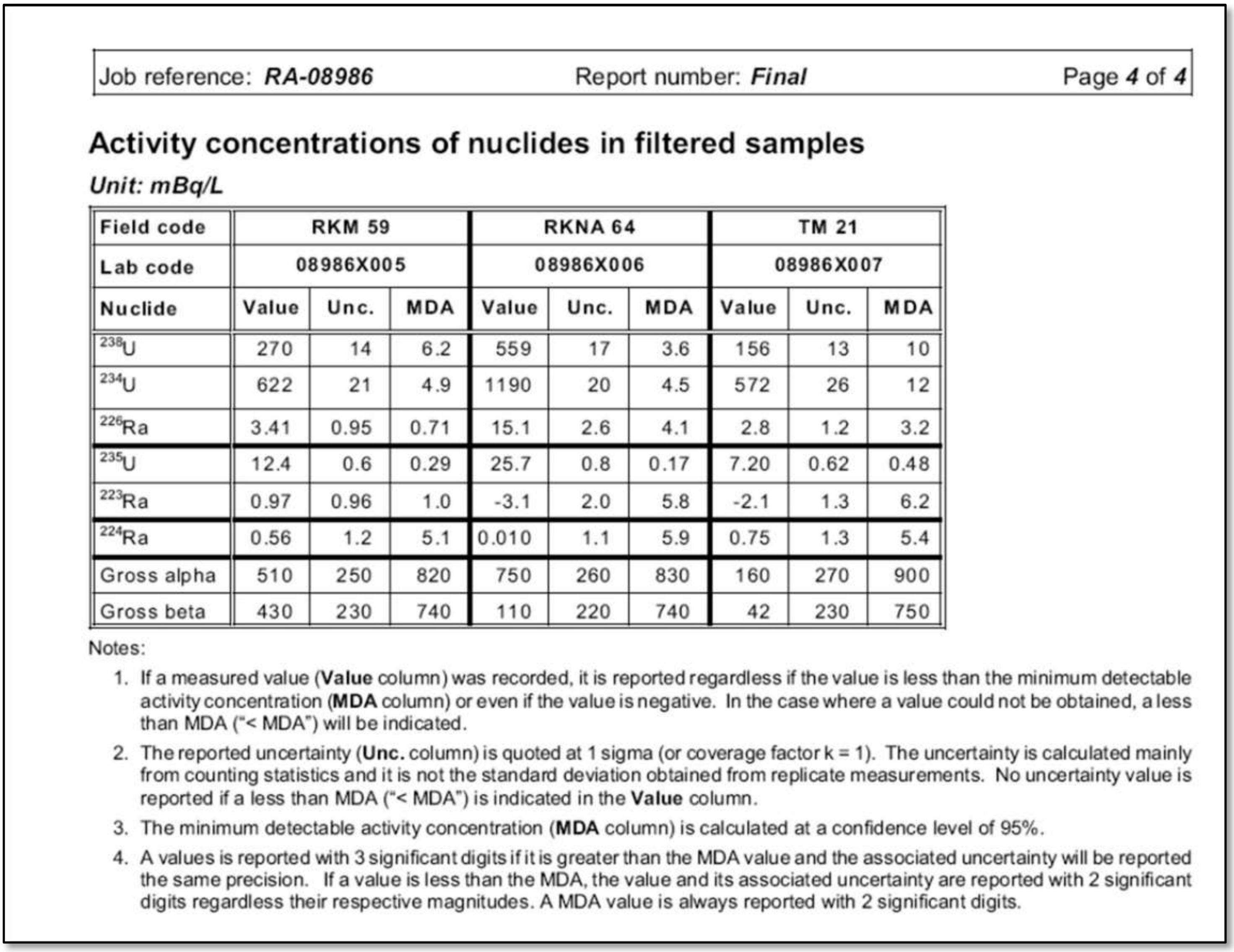
Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	**KDKW1**			**KDKW4**			**KDKW5**			**KDK017**		
Lab code	**08986X001**			**08986X002**			**08986X003**			**08986X004**		
Nuclide	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**
^{238}U	555	16	1.3	215	10	1.4	2.99	1.06	1.0	389	14	1.3
^{234}U	990	22	1.3	957	22	4.8	8.46	1.94	3.5	1370	30	4.4
^{226}Ra	29.2	2.9	2.5	4.68	1.28	2.7	15.2	2.3	3.6	4.01	1.34	3.3
^{235}U	25.5	0.7	0.059	9.89	0.48	0.064	0.138	0.049	0.047	17.9	0.6	0.059
^{223}Ra	2.7	2.0	3.0	2.3	1.4	3.9	2.1	1.7	4.0	-1.3	1.3	5.2
^{224}Ra	2.64	1.32	1.8-	0.54	0.57	4.3	0.089	0.92	4.7	0.65	0.65	1.8
Gross alpha	730	290	950	340	290	950	46	210	710	430	390	1300
Gross beta	-62	230	750	-17	230	750	-160	220	730	440	240	770

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-08986*** Report number: ***Final*** Page ***4*** of ***4***

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	**RKM 59**			**RKNA 64**			**TM 21**		
Lab code	**08986X005**			**08986X006**			**08986X007**		
Nuclide	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**
^{238}U	270	14	6.2	559	17	3.6	156	13	10
^{234}U	622	21	4.9	1190	20	4.5	572	26	12
^{226}Ra	3.41	0.95	0.71	15.1	2.6	4.1	2.8	1.2	3.2
^{235}U	12.4	0.6	0.29	25.7	0.8	0.17	7.20	0.62	0.48
^{223}Ra	0.97	0.96	1.0	-3.1	2.0	5.8	-2.1	1.3	6.2
^{224}Ra	0.56	1.2	5.1	0.010	1.1	5.9	0.75	1.3	5.4
Gross alpha	510	250	820	750	260	830	160	270	900
Gross beta	430	230	740	110	220	740	42	230	750

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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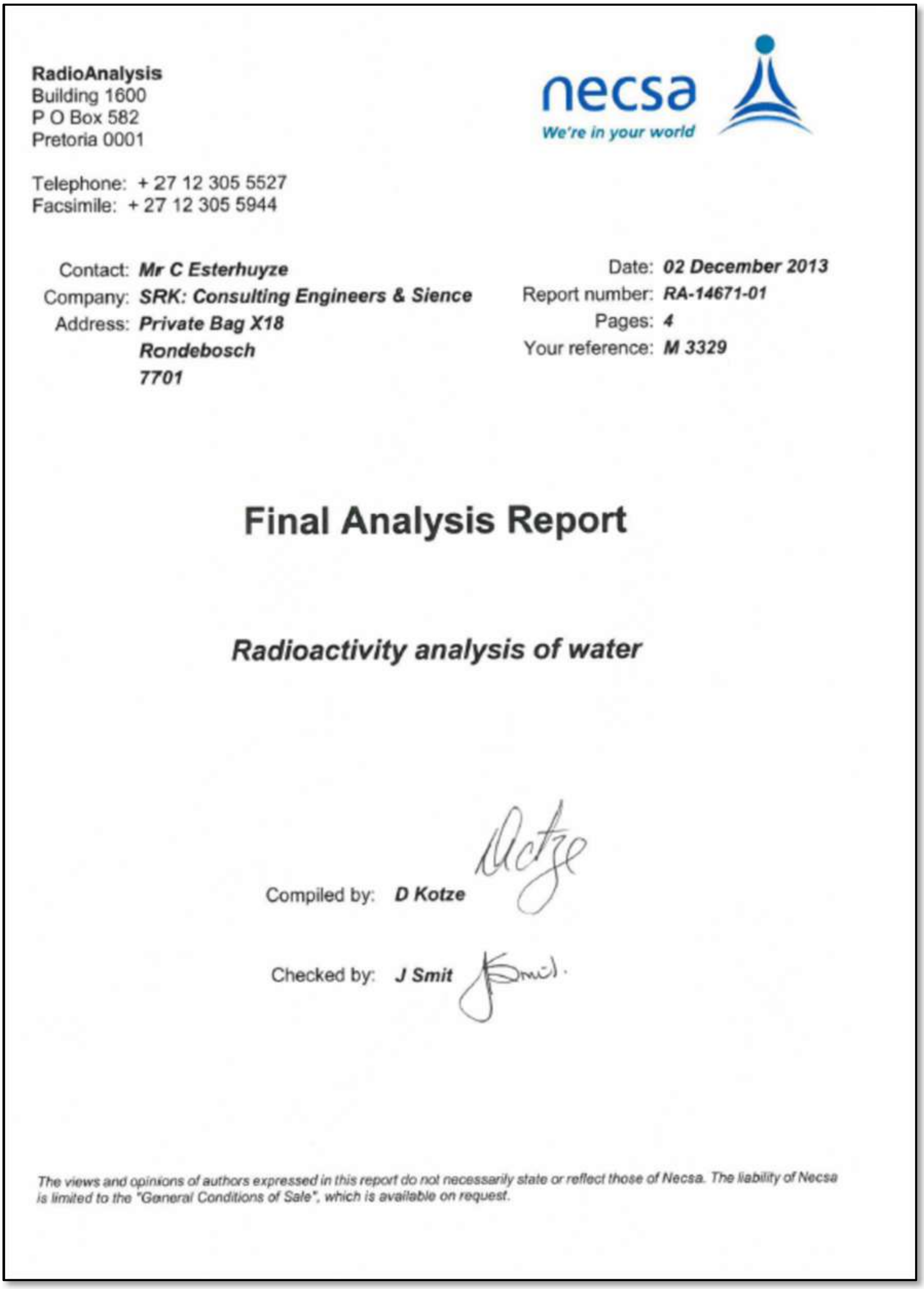
3. The minimum detectable activity concentration (**MDA** column) is calculated at a confidence level of 95%.
4. A values is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the 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.



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necsa
We're in your world

Contact: ***Mr C Esterhuyze***
Company: ***SRK: Consulting Engineers & Sience***
Address: ***Private Bag X18***
Rondebosch
7701

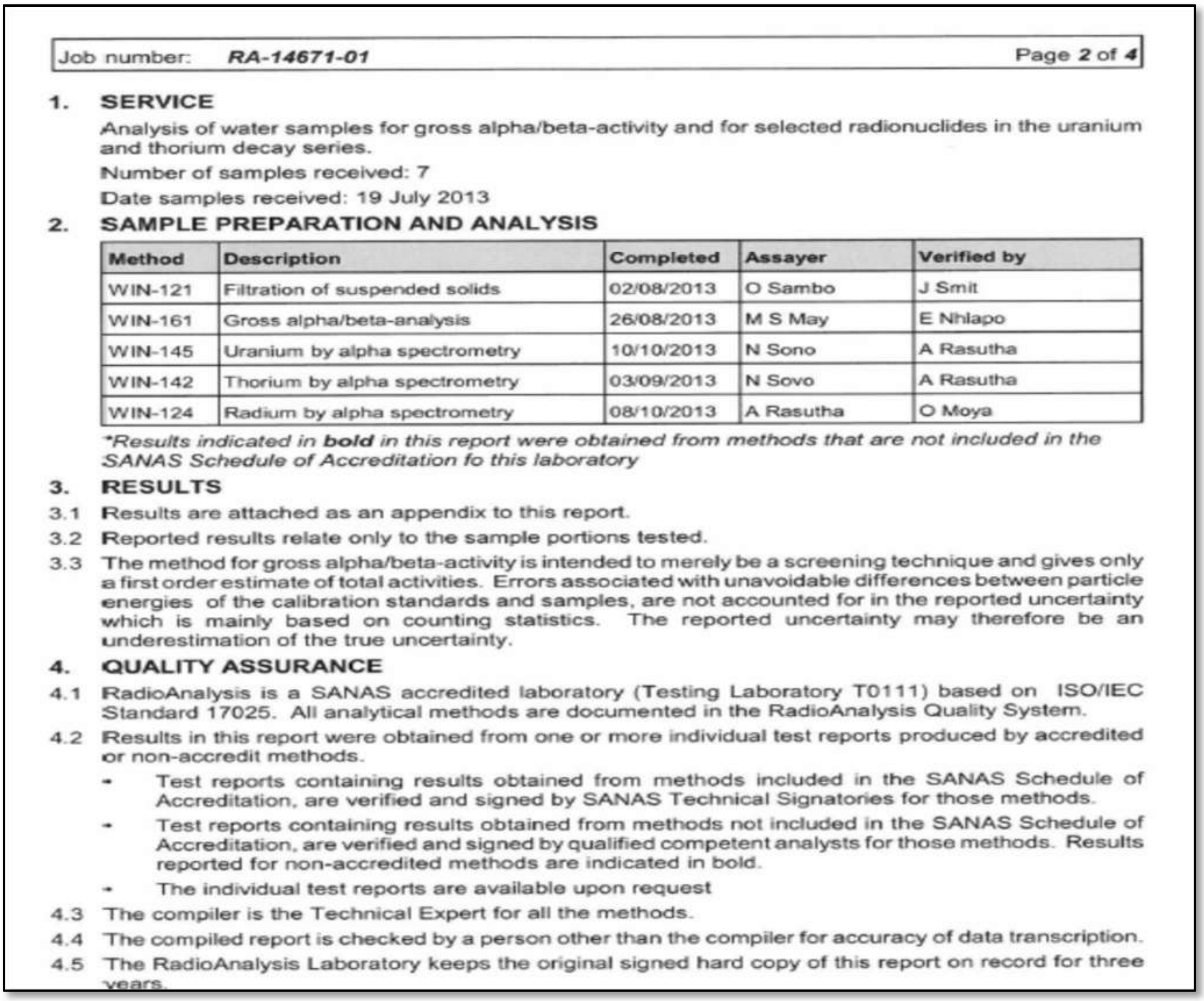
Date: ***02 December 2013***
Report number: ***RA-14671-01***
Pages: ***4***
Your reference: ***M 3329***

Final Analysis Report

Radioactivity analysis of water

Compiled by: ***D Kotze***

Checked by: ***J Smit***



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: 7

Date samples received: 19 July 2013

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-121	Filtration of suspended solids	02/08/2013	O Sambo	J Smit
WIN-161	Gross alpha/beta-analysis	26/08/2013	M S May	E Nhlapo
WIN-145	Uranium by alpha spectrometry	10/10/2013	N Sono	A Rasutha
WIN-142	Thorium by alpha spectrometry	03/09/2013	N Sovo	A Rasutha
WIN-124	Radium by alpha spectrometry	08/10/2013	A Rasutha	O Moya

***Results indicated in bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation fo 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.

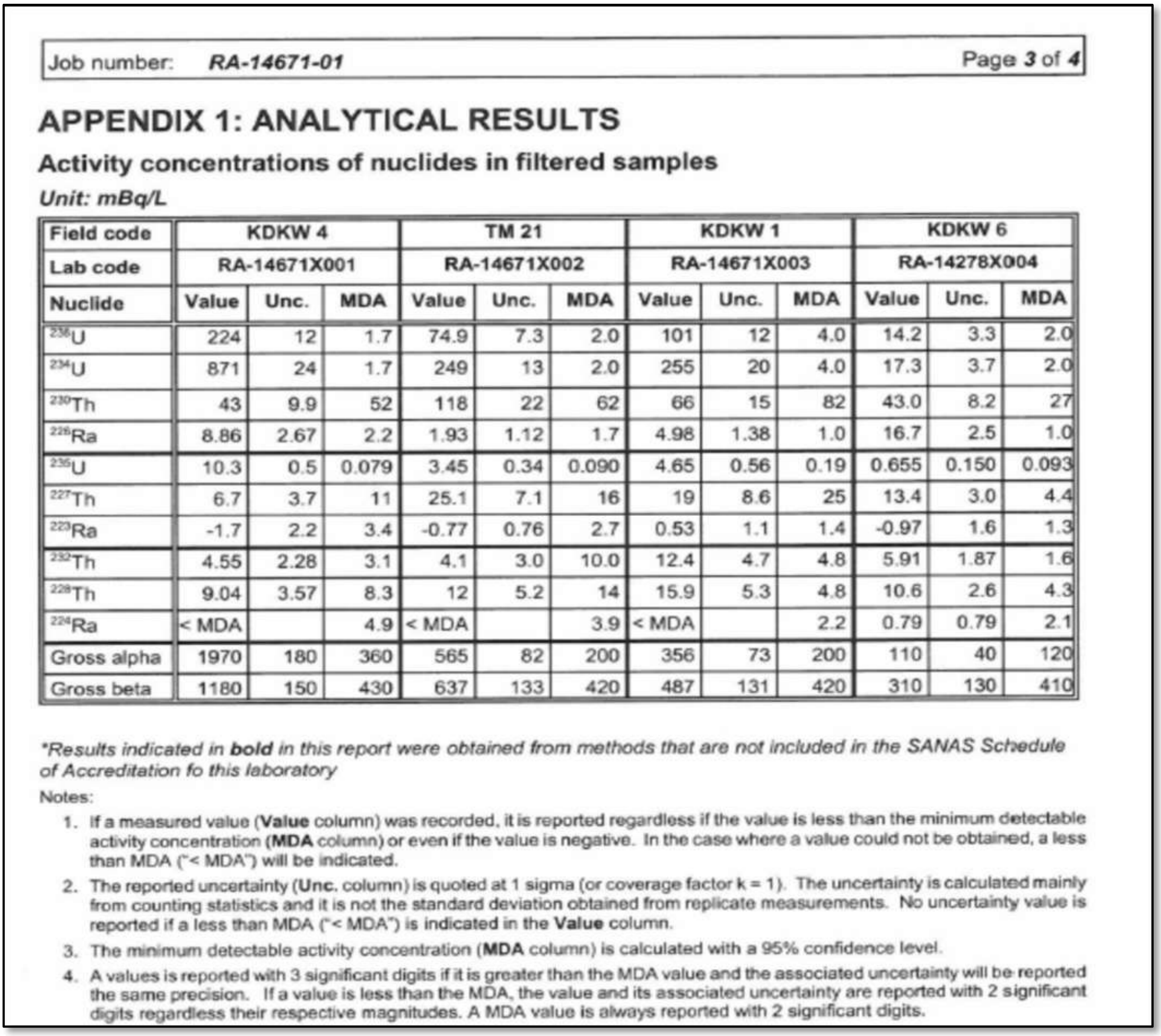
4.2 Results in this report were obtained from one or more individual test reports produced by accredited or non-accredit methods.

- 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-14671-01* Page **3** of **4**

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	**KDKW 4**			**TM 21**			**KDKW 1**			**KDKW 6**		
Lab code	**RA-14671X001**			**RA-14671X002**			**RA-14671X003**			**RA-14278X004**		
Nuclide	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**
^{238}U	224	12	1.7	74.9	7.3	2.0	101	12	4.0	14.2	3.3	2.0
^{234}U	871	24	1.7	249	13	2.0	255	20	4.0	17.3	3.7	2.0
^{230}Th	43	9.9	52	118	22	62	66	15	82	43.0	8.2	27
^{226}Ra	8.86	2.67	2.2	1.93	1.12	1.7	4.98	1.38	1.0	16.7	2.5	1.0
^{235}U	10.3	0.5	0.079	3.45	0.34	0.090	4.65	0.56	0.19	0.655	0.150	0.093
^{227}Th	6.7	3.7	11	25.1	7.1	16	19	8.6	25	13.4	3.0	4.4
^{223}Ra	-1.7	2.2	3.4	-0.77	0.76	2.7	0.53	1.1	1.4	-0.97	1.6	1.3
^{232}Th	4.55	2.28	3.1	4.1	3.0	10.0	12.4	4.7	4.8	5.91	1.87	1.6
^{228}Th	9.04	3.57	8.3	12	5.2	14	15.9	5.3	4.8	10.6	2.6	4.3
^{224}Ra	< MDA		4.9	< MDA		3.9	< MDA		2.2	0.79	0.79	2.1
Gross alpha	1970	180	360	565	82	200	356	73	200	110	40	120
Gross beta	1180	150	430	637	133	420	487	131	420	310	130	410

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation fo this laboratory*

Notes:

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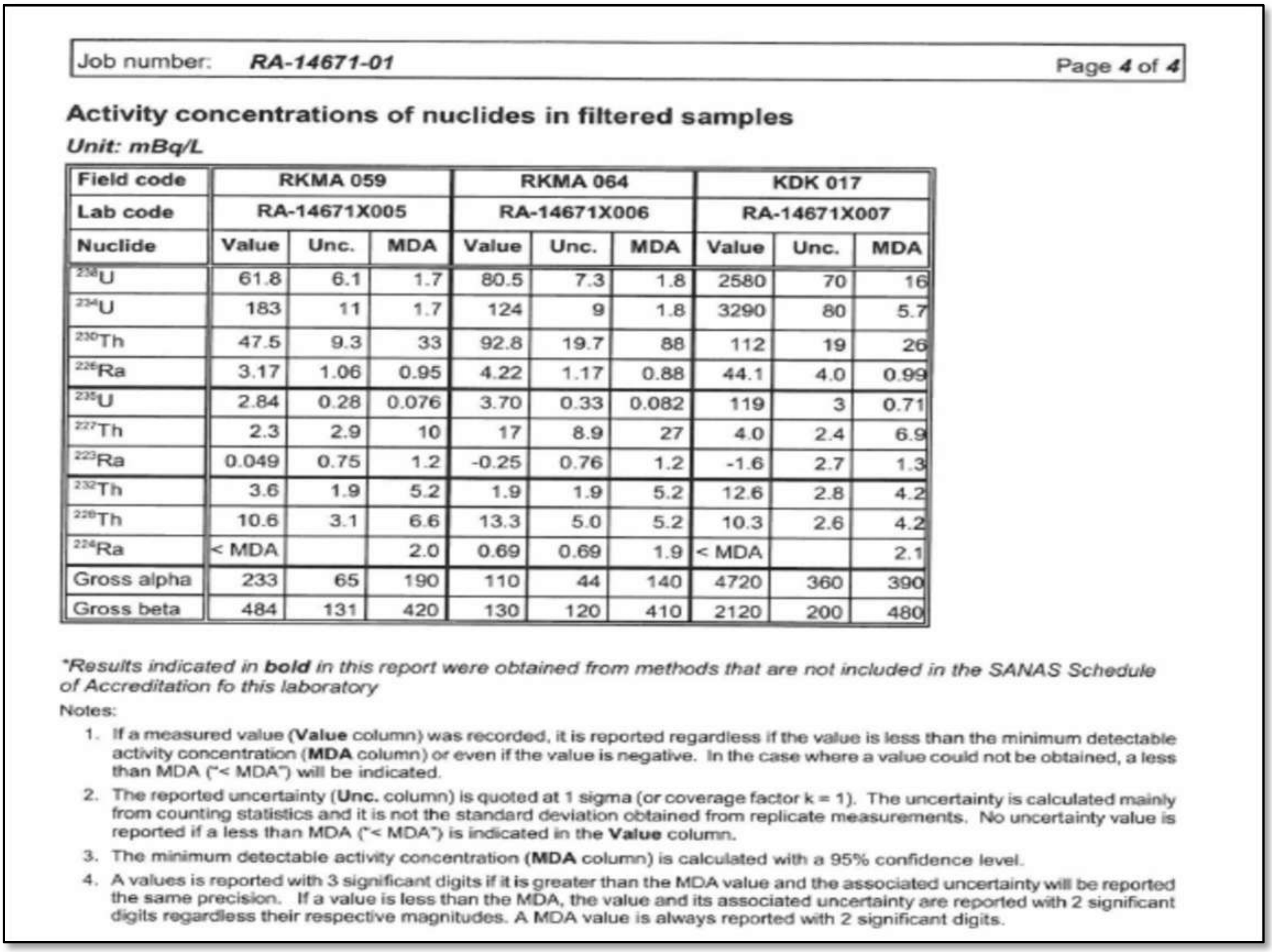

Job number: ***RA-14671-01*** Page **4** of **4**

Activity concentrations of nuclides in filtered samples

Unit: mBq/L

Field code	**RKMA 059**			**RKMA 064**			**KDK 017**		
Lab code	**RA-14671X005**			**RA-14671X006**			**RA-14671X007**		
Nuclide	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**	**Value**	**Unc.**	**MDA**
^{238}U	61.8	6.1	1.7	80.5	7.3	1.8	2580	70	16
^{234}U	183	11	1.7	124	9	1.8	3290	80	5.7
^{230}Th	47.5	9.3	33	92.8	19.7	88	112	19	26
^{226}Ra	3.17	1.06	0.95	4.22	1.17	0.88	44.1	4.0	0.99
^{235}U	2.84	0.28	0.076	3.70	0.33	0.082	119	3	0.71
^{227}Th	2.3	2.9	10	17	8.9	27	4.0	2.4	6.9
^{223}Ra	0.049	0.75	1.2	-0.25	0.76	1.2	-1.6	2.7	1.3
^{232}Th	3.6	1.9	5.2	1.9	1.9	5.2	12.6	2.8	4.2
^{228}Th	10.6	3.1	6.6	13.3	5.0	5.2	10.3	2.6	4.2
^{224}Ra	< MDA		2.0	0.69	0.69	1.9	< MDA		2.1
Gross alpha	233	65	190	110	44	140	4720	360	390
Gross beta	484	131	420	130	120	410	2120	200	480

Results indicated in **bold in this report were obtained from methods that are not included in the SANAS Schedule of Accreditation fo this laboratory*

Notes:

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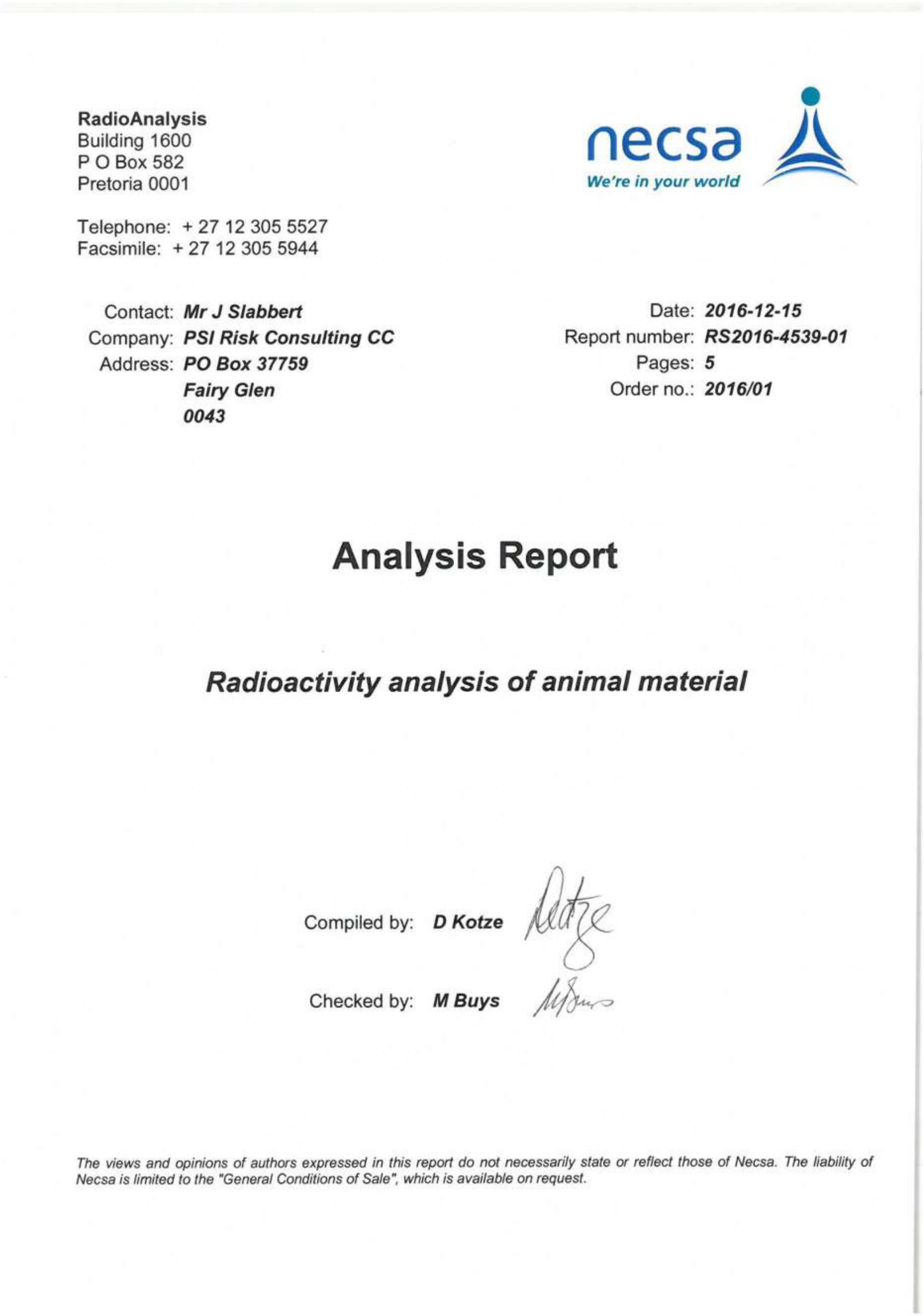
ATTACHMENT 4
RADIOANALYSIS RESULTS OF SHEEP SAMPLES



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Contact: ***Mr J Slabbert***
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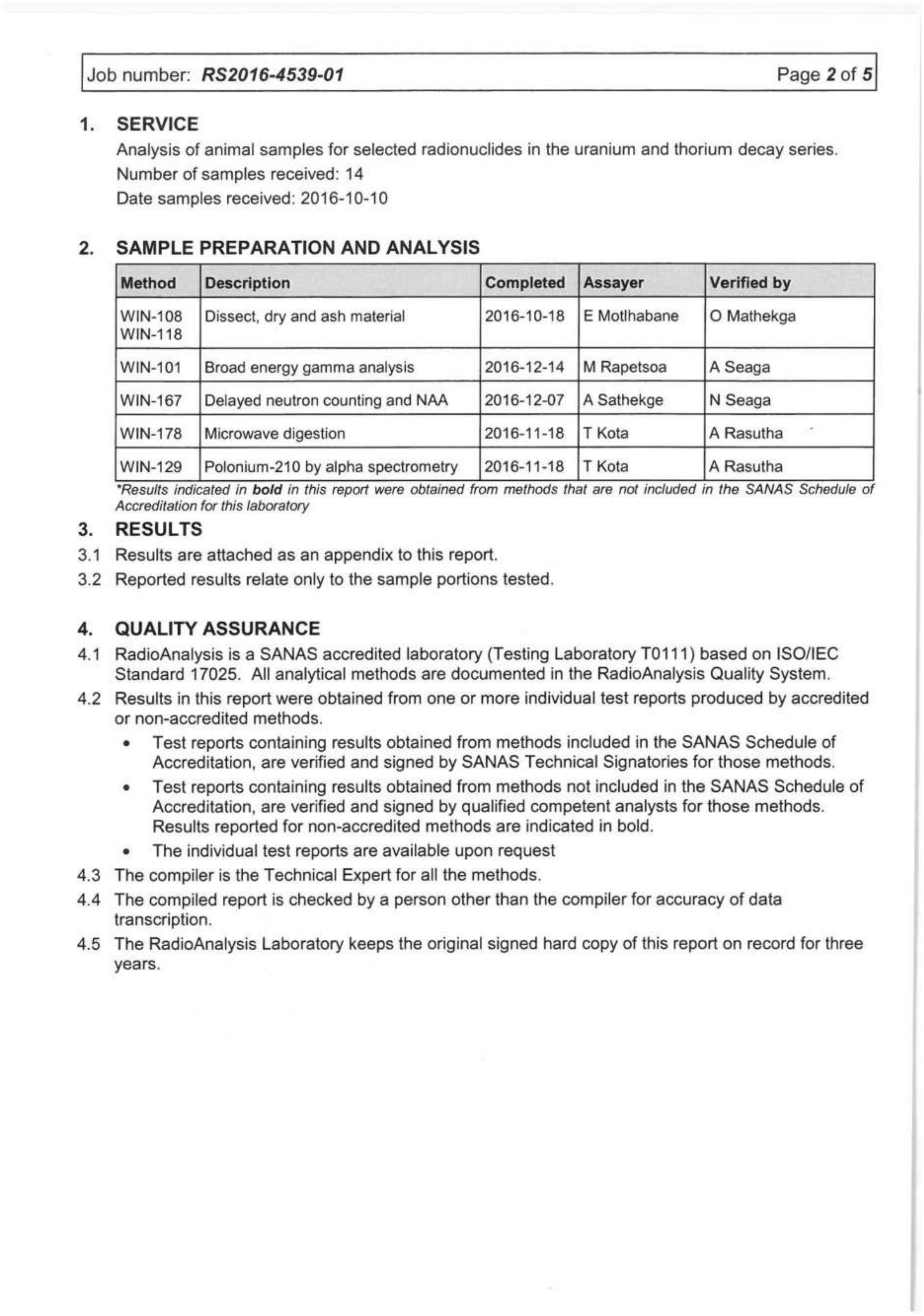
Date: ***2016-12-15***
Report number: ***RS2016-4539-01***
Pages: ***5***
Order no.: ***2016/01***

Analysis Report

Radioactivity analysis of animal material

Compiled by: ***D Kotze***

Checked by: ***M Buys***



Job number: ***RS2016-4539-01*** Page **2** of **5**

1. SERVICE

Analysis of animal samples for selected radionuclides in the uranium and thorium decay series.

Number of samples received: 14

Date samples received: 2016-10-10

2. SAMPLE PREPARATION AND ANALYSIS

Method	Description	Completed	Assayer	Verified by
WIN-108 WIN-118	Dissect, dry and ash material	2016-10-18	E Motlhabane	O Mathekga
WIN-101	Broad energy gamma analysis	2016-12-14	M Rapetsoa	A Seaga
WIN-167	Delayed neutron counting and NAA	2016-12-07	A Sathekge	N Seaga
WIN-178	Microwave digestion	2016-11-18	T Kota	A Rasutha
WIN-129	Polonium-210 by alpha spectrometry	2016-11-18	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 Reported results relate only to the sample portions tested.

4. QUALITY ASSURANCE

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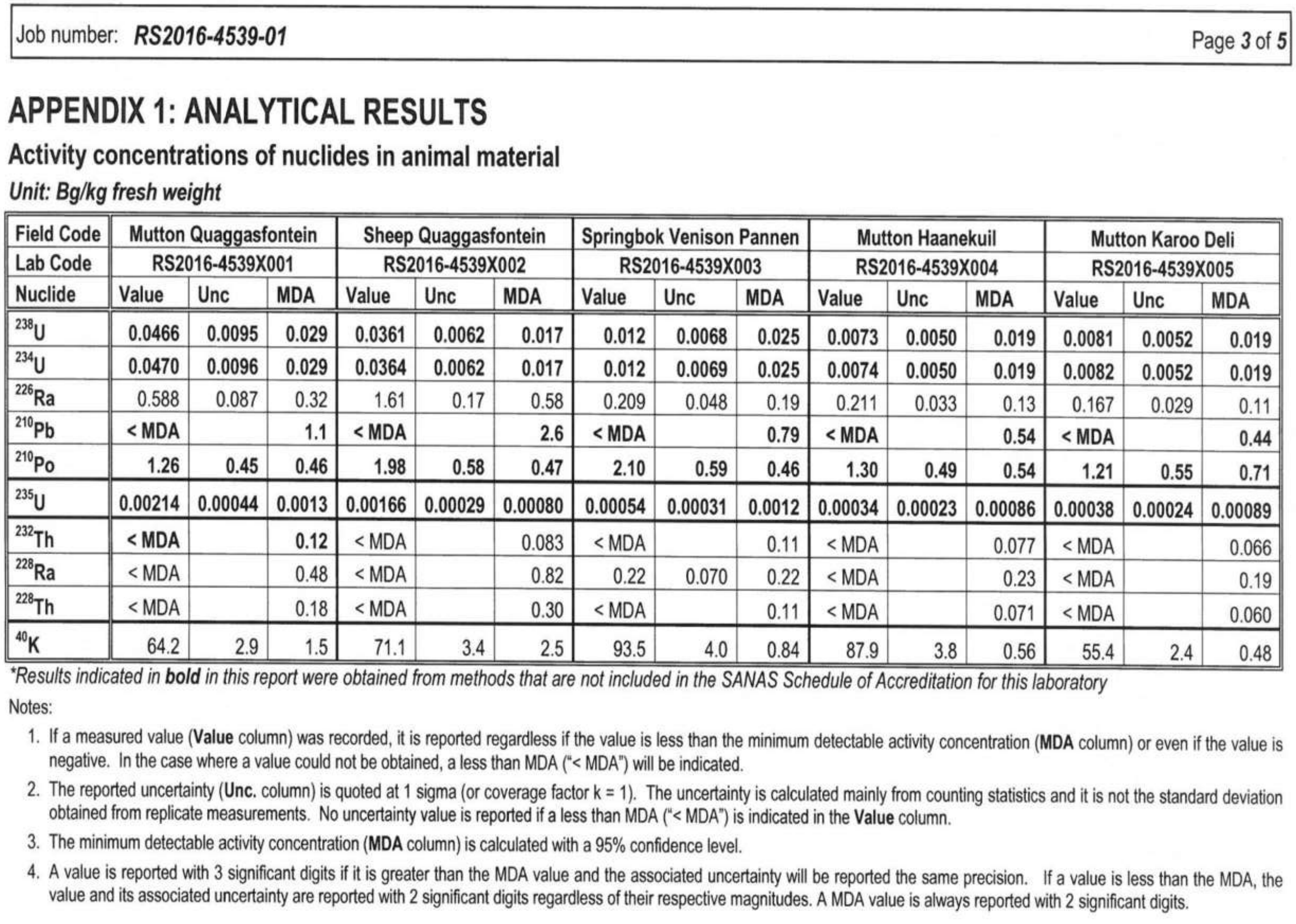

Job number: ***RS2016-4539-01*** Page **3** of **5**

APPENDIX 1: ANALYTICAL RESULTS

Activity concentrations of nuclides in animal material

Unit: Bg/kg fresh weight

Field Code	Mutton Quaggasfontein			Sheep Quaggasfontein			Springbok Venison Pannen			Mutton Haanekuil			Mutton Karoo Deli		
Lab Code	RS2016-4539X001			RS2016-4539X002			RS2016-4539X003			RS2016-4539X004			RS2016-4539X005		
Nuclide	Value	Unc	MDA	Value	Unc	MDA	Value	Unc	MDA	Value	Unc	MDA	Value	Unc	MDA
^{238}U	**0.0466**	**0.0095**	**0.029**	**0.0361**	**0.0062**	**0.017**	**0.012**	**0.0068**	**0.025**	**0.0073**	**0.0050**	**0.019**	**0.0081**	**0.0052**	**0.019**
^{234}U	**0.0470**	**0.0096**	**0.029**	**0.0364**	**0.0062**	**0.017**	**0.012**	**0.0069**	**0.025**	**0.0074**	**0.0050**	**0.019**	**0.0082**	**0.0052**	**0.019**
^{226}Ra	0.588	0.087	0.32	1.61	0.17	0.58	0.209	0.048	0.19	0.211	0.033	0.13	0.167	0.029	0.11
^{210}Pb	**< MDA**		**1.1**	**< MDA**		**2.6**	**< MDA**		**0.79**	**< MDA**		**0.54**	**< MDA**		**0.44**
^{210}Po	**1.26**	**0.45**	**0.46**	**1.98**	**0.58**	**0.47**	**2.10**	**0.59**	**0.46**	**1.30**	**0.49**	**0.54**	**1.21**	**0.55**	**0.71**
^{235}U	**0.00214**	**0.00044**	**0.0013**	**0.00166**	**0.00029**	**0.00080**	**0.00054**	**0.00031**	**0.0012**	**0.00034**	**0.00023**	**0.00086**	**0.00038**	**0.00024**	**0.00089**
^{232}Th	**< MDA**		**0.12**	< MDA		0.083	< MDA		0.11	< MDA		0.077	< MDA		0.066
^{228}Ra	< MDA		0.48	< MDA		0.82	0.22	0.070	0.22	< MDA		0.23	< MDA		0.19
^{228}Th	< MDA		0.18	< MDA		0.30	< MDA		0.11	< MDA		0.071	< MDA		0.060
^{40}K	64.2	2.9	1.5	71.1	3.4	2.5	93.5	4.0	0.84	87.9	3.8	0.56	55.4	2.4	0.48

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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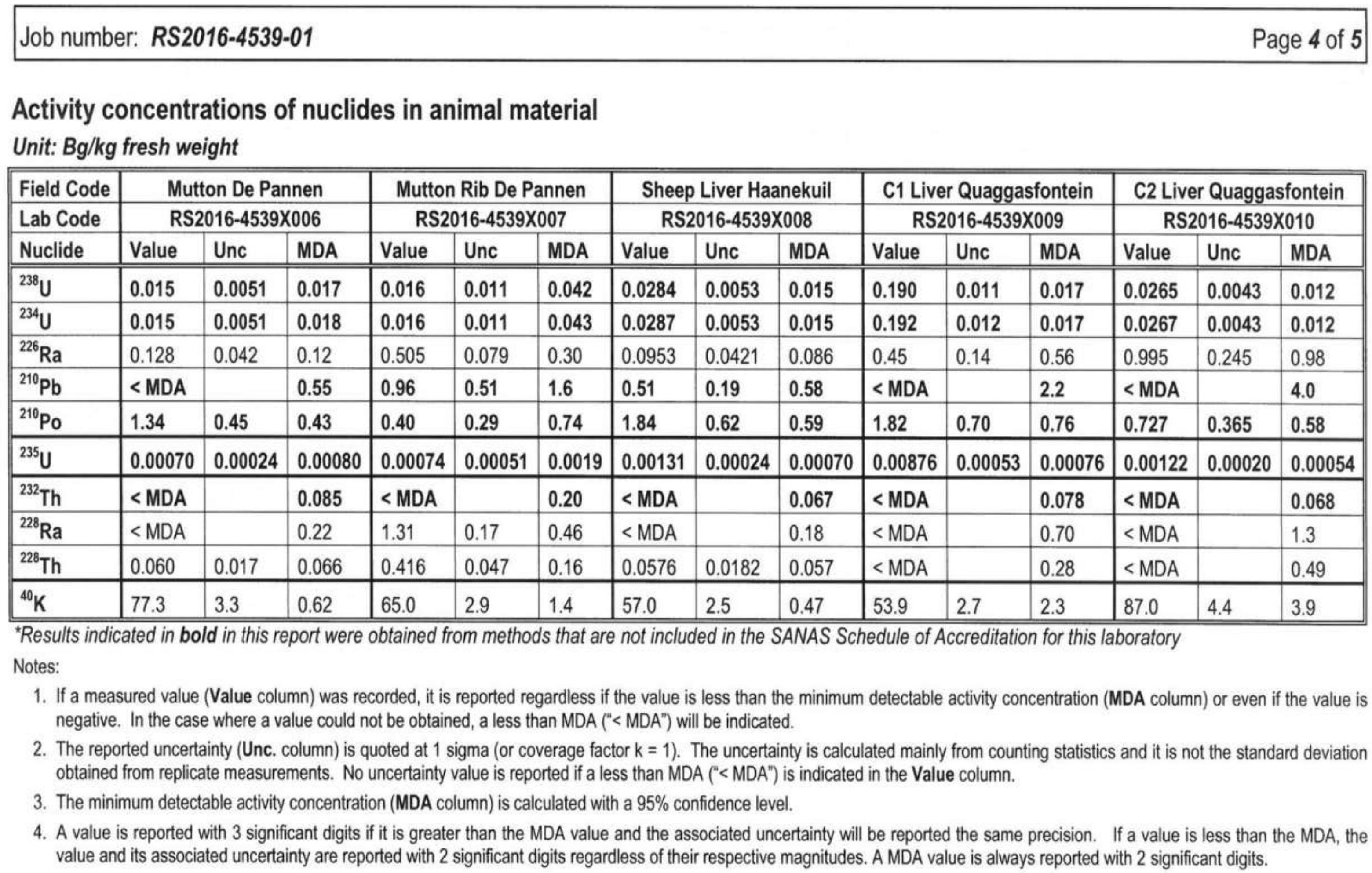
3. The minimum detectable activity concentration (**MDA** column) is calculated with a 95% confidence level.
4. A value is reported with 3 significant digits if it is greater than the MDA value and the associated uncertainty will be reported the same precision. If a value is less than the MDA, the value 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.



Job number: ***RS2016-4539-01*** Page **4** of **5**

Activity concentrations of nuclides in animal material

Unit: Bg/kg fresh weight

Field Code	**Mutton De Pannen**			**Mutton Rib De Pannen**			**Sheep Liver Haanekuil**			**C1 Liver Quaggasfontein**			**C2 Liver Quaggasfontein**		
Lab Code	**RS2016-4539X006**			**RS2016-4539X007**			**RS2016-4539X008**			**RS2016-4539X009**			**RS2016-4539X010**		
Nuclide	**Value**	**Unc**	**MDA**	**Value**	**Unc**	**MDA**	**Value**	**Unc**	**MDA**	**Value**	**Unc**	**MDA**	**Value**	**Unc**	**MDA**
^{238}U	**0.015**	**0.0051**	**0.017**	**0.016**	**0.011**	**0.042**	**0.0284**	**0.0053**	**0.015**	**0.190**	**0.011**	**0.017**	**0.0265**	**0.0043**	**0.012**
^{234}U	**0.015**	**0.0051**	**0.018**	**0.016**	**0.011**	**0.043**	**0.0287**	**0.0053**	**0.015**	**0.192**	**0.012**	**0.017**	**0.0267**	**0.0043**	**0.012**
^{226}Ra	0.128	0.042	0.12	0.505	0.079	0.30	0.0953	0.0421	0.086	0.45	0.14	0.56	0.995	0.245	0.98
^{210}Pb	**< MDA**		**0.55**	**0.96**	**0.51**	**1.6**	**0.51**	**0.19**	**0.58**	**< MDA**		**2.2**	**< MDA**		**4.0**
^{210}Po	**1.34**	**0.45**	**0.43**	**0.40**	**0.29**	**0.74**	**1.84**	**0.62**	**0.59**	**1.82**	**0.70**	**0.76**	**0.727**	**0.365**	**0.58**
^{235}U	**0.00070**	**0.00024**	**0.00080**	**0.00074**	**0.00051**	**0.0019**	**0.00131**	**0.00024**	**0.00070**	**0.00876**	**0.00053**	**0.00076**	**0.00122**	**0.00020**	**0.00054**
^{232}Th	**< MDA**		**0.085**	**< MDA**		**0.20**	**< MDA**		**0.067**	**< MDA**		**0.078**	**< MDA**		**0.068**
^{228}Ra	< MDA		0.22	1.31	0.17	0.46	< MDA		0.18	< MDA		0.70	< MDA		1.3
^{228}Th	0.060	0.017	0.066	0.416	0.047	0.16	0.0576	0.0182	0.057	< MDA		0.28	< MDA		0.49
^{40}K	77.3	3.3	0.62	65.0	2.9	1.4	57.0	2.5	0.47	53.9	2.7	2.3	87.0	4.4	3.9

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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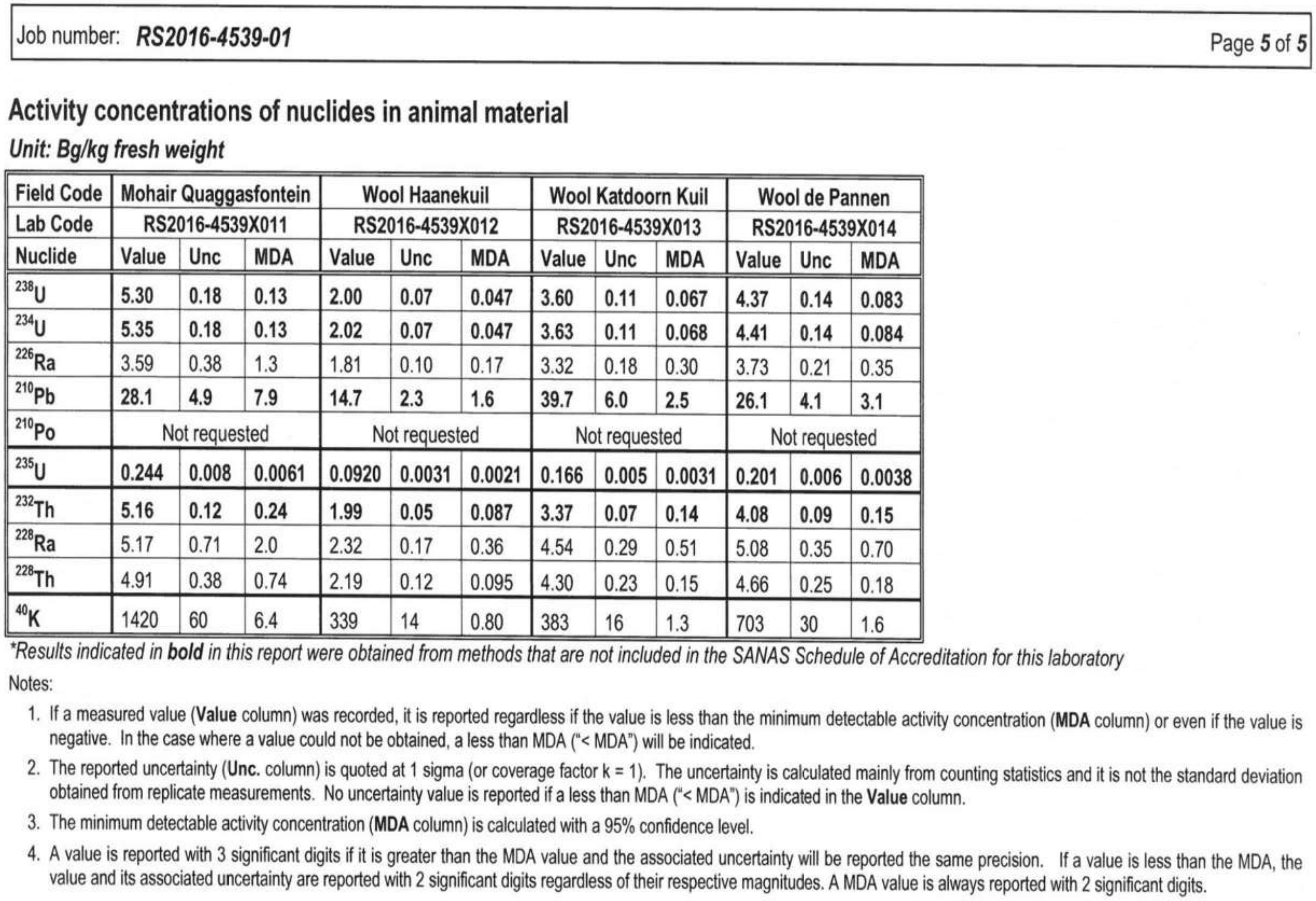
2. The reported uncertainty (**Unc.** column) is quoted at 1 sigma (or coverage factor k = 1). The uncertainty is calculated mainly from counting statistics and it is not the standard deviation obtained from replicate measurements. No uncertainty value is reported if a less than MDA ("< MDA") is indicated 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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Activity concentrations of nuclides in animal material

Unit: Bg/kg fresh weight

Field Code	Mohair Quaggasfontein			Wool Haanekuil			Wool Katdoorn Kuil			Wool de Pannen		
Lab Code	**RS2016-4539X011**			**RS2016-4539X012**			**RS2016-4539X013**			**RS2016-4539X014**		
Nuclide	**Value**	**Unc**	**MDA**	**Value**	**Unc**	**MDA**	**Value**	**Unc**	**MDA**	**Value**	**Unc**	**MDA**
^{238}U	**5.30**	**0.18**	**0.13**	**2.00**	**0.07**	**0.047**	**3.60**	**0.11**	**0.067**	**4.37**	**0.14**	**0.083**
^{234}U	**5.35**	**0.18**	**0.13**	**2.02**	**0.07**	**0.047**	**3.63**	**0.11**	**0.068**	**4.41**	**0.14**	**0.084**
^{226}Ra	3.59	0.38	1.3	1.81	0.10	0.17	3.32	0.18	0.30	3.73	0.21	0.35
^{210}Pb	**28.1**	**4.9**	**7.9**	**14.7**	**2.3**	**1.6**	**39.7**	**6.0**	**2.5**	**26.1**	**4.1**	**3.1**
^{210}Po	Not requested			Not requested			Not requested			Not requested		
^{235}U	**0.244**	**0.008**	**0.0061**	**0.0920**	**0.0031**	**0.0021**	**0.166**	**0.005**	**0.0031**	**0.201**	**0.006**	**0.0038**
^{232}Th	**5.16**	**0.12**	**0.24**	**1.99**	**0.05**	**0.087**	**3.37**	**0.07**	**0.14**	**4.08**	**0.09**	**0.15**
^{228}Ra	5.17	0.71	2.0	2.32	0.17	0.36	4.54	0.29	0.51	5.08	0.35	0.70
^{228}Th	4.91	0.38	0.74	2.19	0.12	0.095	4.30	0.23	0.15	4.66	0.25	0.18
^{40}K	1420	60	6.4	339	14	0.80	383	16	1.3	703	30	1.6

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.

ATTACHMENT 5

EXAMPLES OF RADIONUCLIDE CONCENTRATIONS CALCULATED FOR VARIOUS ENVIRONMENTAL MEDIA

U-238	Air Bq/m3	Ground; Bq/m2	VegAbove; Bq/kg	Potato; Bq/kg	VegBelow; Bq/kg	PastureGrass; Bq/kg	FeedGrain; Bq/kg	Meat; Bq/kg	Milk; Bq/L
R1 Kat Doorn Kuil	1.36E-05	2.46E+01	2.28E-02	2.51E-03	2.51E-03	4.92E-02	2.28E-02	8.36E-04	1.50E-03
R2 Kant Kraal	1.55E-05	2.82E+01	2.60E-02	2.86E-03	2.86E-03	5.62E-02	2.60E-02	9.55E-04	1.71E-03
R3 Klipstawels	1.26E-05	2.29E+01	2.11E-02	2.33E-03	2.33E-03	4.56E-02	2.11E-02	7.76E-04	1.39E-03
R4 Klipkrans	1.89E-05	3.42E+01	3.16E-02	3.49E-03	3.49E-03	6.84E-02	3.16E-02	1.16E-03	2.09E-03
R5 Eerstewater	1.58E-05	2.86E+01	2.65E-02	2.91E-03	2.91E-03	5.72E-02	2.65E-02	9.72E-04	1.74E-03
R6 Ryst Kuil	4.62E-06	8.37E+00	7.74E-03	8.52E-04	8.52E-04	1.67E-02	7.74E-03	2.84E-04	5.10E-04
R7 Lootsplaas	5.36E-07	9.71E-01	8.97E-04	9.89E-05	9.89E-05	1.94E-03	8.97E-04	3.30E-05	5.92E-05
R8 Hannekuil	6.27E-07	1.14E+00	1.05E-03	1.16E-04	1.16E-04	2.27E-03	1.05E-03	3.85E-05	6.92E-05
R9 Kareepoort	1.13E-07	2.06E-01	1.90E-04	2.09E-05	2.09E-05	4.11E-04	1.90E-04	6.98E-06	1.25E-05
R10 Quaggasfontein	3.86E-07	7.00E-01	6.46E-04	7.12E-05	7.12E-05	1.40E-03	6.46E-04	2.37E-05	4.26E-05
R11 Bokvlei	1.08E-07	1.96E-01	1.81E-04	1.99E-05	1.99E-05	3.91E-04	1.81E-04	6.64E-06	1.19E-05
R12 Beaufort West	2.04E-07	3.69E-01	3.41E-04	3.75E-05	3.75E-05	7.37E-04	3.41E-04	1.25E-05	2.25E-05
R13 Olive Grove	6.04E-07	1.09E+00	1.01E-03	1.11E-04	1.11E-04	2.18E-03	1.01E-03	3.71E-05	6.66E-05
R14 Blouboskuil	4.48E-07	8.12E-01	7.50E-04	8.26E-05	8.26E-05	1.62E-03	7.50E-04	2.76E-05	4.95E-05
R15 Oude Volks Kraal	5.42E-07	9.82E-01	9.07E-04	9.99E-05	9.99E-05	1.96E-03	9.07E-04	3.33E-05	5.98E-05
R16 Uitsig	6.57E-07	1.19E+00	1.10E-03	1.21E-04	1.21E-04	2.38E-03	1.10E-03	4.04E-05	7.25E-05
R17 Retreat	8.06E-07	1.46E+00	1.35E-03	1.49E-04	1.49E-04	2.92E-03	1.35E-03	4.96E-05	8.90E-05
R18 Hansrivier	2.76E-07	5.00E-01	4.62E-04	5.09E-05	5.09E-05	9.99E-04	4.62E-04	1.70E-05	3.05E-05
R19 Steenrotsfontein	3.60E-07	6.53E-01	6.04E-04	6.65E-05	6.65E-05	1.30E-03	6.04E-04	2.22E-05	3.98E-05
R20 Saucyskuil	2.37E-06	4.30E+00	3.97E-03	4.37E-04	4.37E-04	8.58E-03	3.97E-03	1.46E-04	2.62E-04
R21 Amosvlei	3.51E-06	6.37E+00	5.89E-03	6.48E-04	6.48E-04	1.27E-02	5.89E-03	2.16E-04	3.88E-04
R22 Vaalkraal	4.94E-06	8.96E+00	8.28E-03	9.12E-04	9.12E-04	1.79E-02	8.28E-03	3.04E-04	5.45E-04
R23 Blydskap	4.06E-07	7.35E-01	6.79E-04	7.48E-05	7.48E-05	1.47E-03	6.79E-04	2.50E-05	4.48E-05
R24 Rooidam Farmstall	2.33E-07	4.22E-01	3.89E-04	4.29E-05	4.29E-05	8.42E-04	3.89E-04	1.43E-05	2.57E-05
R25 Toomitzkuil	3.78E-06	6.84E+00	6.32E-03	6.96E-04	6.96E-04	1.37E-02	6.32E-03	2.32E-04	4.17E-04
R26 Hoekskuil	7.14E-06	1.29E+01	1.20E-02	1.32E-03	1.32E-03	2.58E-02	1.20E-02	4.39E-04	7.88E-04

U-238	Air Bq/m3	Ground; Bq/m2	VegAbove; Bq/kg	Potato; Bq/kg	VegBelow; Bq/kg	PastureGrass; Bq/kg	FeedGrain; Bq/kg	Meat; Bq/kg	Milk; Bq/L
R27 Veerekuil	2.34E-07	4.24E-01	3.92E-04	4.32E-05	4.32E-05	8.47E-04	3.92E-04	1.44E-05	2.58E-05
R28 Losboome	1.16E-07	2.10E-01	1.94E-04	2.13E-05	2.13E-05	4.19E-04	1.94E-04	7.12E-06	1.28E-05
R29 Kat Doorn Kuil	1.29E-04	2.34E+02	2.16E-01	2.38E-02	2.38E-02	4.67E-01	2.16E-01	7.94E-03	1.42E-02
R30 De Pannen	8.43E-08	1.53E-01	1.41E-04	1.55E-05	1.55E-05	3.05E-04	1.41E-04	5.18E-06	9.30E-06
R31 Nuwejaarskuil	2.61E-07	4.73E-01	4.37E-04	4.81E-05	4.81E-05	9.44E-04	4.37E-04	1.60E-05	2.88E-05
R32 De Puts	1.28E-07	2.31E-01	2.14E-04	2.36E-05	2.36E-05	4.63E-04	2.14E-04	7.87E-06	1.41E-05
R33 Oorlogspoort	7.69E-08	1.39E-01	1.29E-04	1.42E-05	1.42E-05	2.78E-04	1.29E-04	4.73E-06	8.49E-06
R34 Nuwejaarsfontein	2.38E-07	4.32E-01	3.99E-04	4.39E-05	4.39E-05	8.62E-04	3.99E-04	1.46E-05	2.63E-05
R35 Rooidraai	6.58E-08	1.19E-01	1.10E-04	1.21E-05	1.21E-05	2.38E-04	1.10E-04	4.05E-06	7.26E-06
R36 Vaalvlei	8.81E-08	1.60E-01	1.48E-04	1.63E-05	1.63E-05	3.19E-04	1.48E-04	5.42E-06	9.72E-06
R37 Upper Kiewietskuil	8.28E-08	1.50E-01	1.39E-04	1.53E-05	1.53E-05	2.99E-04	1.39E-04	5.09E-06	9.13E-06
R38 Bosduiwerivier	9.29E-07	1.68E+00	1.56E-03	1.71E-04	1.71E-04	3.36E-03	1.56E-03	5.71E-05	1.03E-04
R39 Rhenosterkop	9.17E-06	1.66E+01	1.54E-02	1.69E-03	1.69E-03	3.32E-02	1.54E-02	5.64E-04	1.01E-03
R40 Bothasdale	2.12E-06	3.85E+00	3.55E-03	3.91E-04	3.91E-04	7.68E-03	3.55E-03	1.31E-04	2.34E-04
R41 Goodhope	2.62E-06	4.75E+00	4.38E-03	4.83E-04	4.83E-04	9.47E-03	4.38E-03	1.61E-04	2.89E-04
R42 Jonkersleegte	1.66E-06	3.01E+00	2.78E-03	3.06E-04	3.06E-04	6.01E-03	2.78E-03	1.02E-04	1.83E-04
R43 Grootkraanvoelkuil	6.04E-07	1.10E+00	1.01E-03	1.11E-04	1.11E-04	2.19E-03	1.01E-03	3.72E-05	6.67E-05
R44 Helvetia	1.57E-07	2.85E-01	2.63E-04	2.90E-05	2.90E-05	5.68E-04	2.63E-04	9.66E-06	1.73E-05
R45 Eensaam	1.49E-06	2.69E+00	2.49E-03	2.74E-04	2.74E-04	5.38E-03	2.49E-03	9.14E-05	1.64E-04
R46 Hoekraal	5.59E-06	1.01E+01	9.35E-03	1.03E-03	1.03E-03	2.02E-02	9.35E-03	3.44E-04	6.17E-04
R47 Reyersvlei	1.64E-07	2.98E-01	2.75E-04	3.03E-05	3.03E-05	5.95E-04	2.75E-04	1.01E-05	1.81E-05
R48 Beyerskloof	7.69E-08	1.39E-01	1.29E-04	1.42E-05	1.42E-05	2.78E-04	1.29E-04	4.73E-06	8.49E-06
R49 Theefontein	5.30E-08	9.61E-02	8.88E-05	9.78E-06	9.78E-06	1.92E-04	8.88E-05	3.26E-06	5.85E-06
R50 Neverset	4.57E-07	8.29E-01	7.66E-04	8.44E-05	8.44E-05	1.66E-03	7.66E-04	2.81E-05	5.05E-05

Ra-226	Air Bq/m3	Ground; Bq/m2	VegAbove; Bq/kg	Potato; Bq/kg	VegBelow; Bq/kg	PastureGrass; Bq/kg	FeedGrain; Bq/kg	Meat; Bq/kg	Milk; Bq/L
R1 Kat Doorn Kuil	2.40E-06	4.14E+00	4.21E-03	4.49E-04	6.39E-04	8.95E-03	5.39E-03	2.28E-04	2.64E-04
R2 Kant Kraal	1.18E-05	2.14E+01	2.08E-02	2.23E-03	3.21E-03	4.42E-02	2.69E-02	1.13E-03	1.30E-03
R3 Klipstawels	4.12E-06	7.30E+00	7.24E-03	7.73E-04	1.11E-03	1.54E-02	9.31E-03	3.92E-04	4.53E-04
R4 Klipkrans	2.43E-06	4.05E+00	4.25E-03	4.52E-04	6.38E-04	9.04E-03	5.40E-03	2.30E-04	2.67E-04
R5 Eerstewater	1.60E-06	2.56E+00	2.79E-03	2.97E-04	4.14E-04	5.94E-03	3.52E-03	1.52E-04	1.75E-04
R6 Ryst Kuil	5.16E-07	8.30E-01	9.03E-04	9.58E-05	1.34E-04	1.92E-03	1.14E-03	4.90E-05	5.66E-05
R7 Lootsplaas	7.02E-08	1.17E-01	1.23E-04	1.31E-05	1.84E-05	2.61E-04	1.56E-04	6.66E-06	7.71E-06
R8 Hannekuil	8.01E-08	1.33E-01	1.40E-04	1.49E-05	2.10E-05	2.98E-04	1.78E-04	7.61E-06	8.80E-06
R9 Kareepoort	1.59E-08	2.67E-02	2.78E-05	2.96E-06	4.18E-06	5.91E-05	3.54E-05	1.51E-06	1.74E-06
R10 Quaggasfontein	5.07E-08	8.54E-02	8.89E-05	9.46E-06	1.34E-05	1.89E-04	1.13E-04	4.82E-06	5.57E-06
R11 Bokvlei	1.51E-08	2.55E-02	2.65E-05	2.82E-06	3.99E-06	5.64E-05	3.38E-05	1.44E-06	1.66E-06
R12 Beaufort West	3.03E-08	5.15E-02	5.32E-05	5.66E-06	8.02E-06	1.13E-04	6.77E-05	2.88E-06	3.33E-06
R14 Blouboskuil	5.27E-08	8.76E-02	9.23E-05	9.81E-06	1.38E-05	1.96E-04	1.17E-04	5.00E-06	5.79E-06
R15 Oude Volks Kraal	6.27E-08	1.04E-01	1.10E-04	1.17E-05	1.65E-05	2.34E-04	1.39E-04	5.96E-06	6.89E-06
R16 Uitsig	7.49E-08	1.24E-01	1.31E-04	1.40E-05	1.96E-05	2.79E-04	1.66E-04	7.11E-06	8.23E-06
R17 Retreat	9.09E-08	1.50E-01	1.59E-04	1.69E-05	2.38E-05	3.38E-04	2.02E-04	8.63E-06	9.98E-06
R18 Hansrivier	4.01E-08	6.79E-02	7.03E-05	7.48E-06	1.06E-05	1.49E-04	8.95E-05	3.81E-06	4.40E-06
R19 Steenrotsfontein	4.74E-08	7.99E-02	8.32E-05	8.85E-06	1.25E-05	1.77E-04	1.06E-04	4.51E-06	5.21E-06
R20 Saucyskuil	2.50E-07	4.09E-01	4.38E-04	4.65E-05	6.53E-05	9.31E-04	5.54E-04	2.37E-05	2.75E-05
R21 Amosvlei	1.43E-06	2.55E+00	2.52E-03	2.69E-04	3.86E-04	5.34E-03	3.24E-03	1.36E-04	1.58E-04
R22 Vaalkraal	2.31E-06	4.14E+00	4.07E-03	4.35E-04	6.25E-04	8.64E-03	5.25E-03	2.20E-04	2.55E-04
R23 Blydskap	5.41E-08	9.06E-02	9.49E-05	1.01E-05	1.43E-05	2.02E-04	1.21E-04	5.14E-06	5.95E-06
R24 Rooidam Farmstall	3.16E-08	5.30E-02	5.53E-05	5.89E-06	8.32E-06	1.18E-04	7.03E-05	3.00E-06	3.47E-06
R25 Toomitzkuil	4.25E-07	6.85E-01	7.43E-04	7.89E-05	1.10E-04	1.58E-03	9.37E-04	4.03E-05	4.66E-05
R26 Hoekskuil	9.06E-07	1.44E+00	1.58E-03	1.68E-04	2.34E-04	3.37E-03	1.99E-03	8.59E-05	9.94E-05

R27 Veerekuil	3.03E-08	5.06E-02	5.32E-05	5.65E-06	7.98E-06	1.13E-04	6.75E-05	2.88E-06	3.33E-06
R28 Losboome	1.53E-08	2.58E-02	2.69E-05	2.86E-06	4.04E-06	5.72E-05	3.42E-05	1.46E-06	1.69E-06
R29 Kat Doorn Kuil	1.32E-05	2.28E+01	2.31E-02	2.46E-03	3.51E-03	4.91E-02	2.96E-02	1.25E-03	1.45E-03
R30 De Pannen	1.14E-08	1.92E-02	2.00E-05	2.13E-06	3.00E-06	4.24E-05	2.54E-05	1.08E-06	1.25E-06
R31 Nuwejaarskuil	3.51E-08	5.89E-02	6.15E-05	6.54E-06	9.24E-06	1.31E-04	7.82E-05	3.33E-06	3.86E-06
R32 De Puts	3.60E-08	5.38E-02	6.28E-05	6.64E-06	9.11E-06	1.34E-04	7.81E-05	3.41E-06	3.95E-06
R33 Oorlogspoort	1.10E-08	1.86E-02	1.93E-05	2.06E-06	2.91E-06	4.11E-05	2.46E-05	1.05E-06	1.21E-06
R34 Nuwejaarsfontein	3.22E-08	5.40E-02	5.64E-05	6.00E-06	8.48E-06	1.20E-04	7.17E-05	3.06E-06	3.54E-06
R35 Rooidraai	9.57E-09	1.62E-02	1.68E-05	1.79E-06	2.53E-06	3.57E-05	2.14E-05	9.10E-07	1.05E-06
R36 Vaalvlei	1.25E-08	2.12E-02	2.20E-05	2.34E-06	3.31E-06	4.67E-05	2.80E-05	1.19E-06	1.38E-06
R37 Upper Kiewietskuil	1.19E-08	2.01E-02	2.09E-05	2.22E-06	3.14E-06	4.43E-05	2.66E-05	1.13E-06	1.31E-06
R38 Bosduiwerivier	1.38E-07	2.33E-01	2.42E-04	2.58E-05	3.64E-05	5.14E-04	3.08E-04	1.31E-05	1.52E-05
R39 Rhenosterkop	1.38E-06	2.32E+00	2.41E-03	2.57E-04	3.63E-04	5.13E-03	3.07E-03	1.31E-04	1.51E-04
R40 Bothasdale	5.74E-07	1.01E+00	1.01E-03	1.08E-04	1.54E-04	2.14E-03	1.29E-03	5.46E-05	6.32E-05
R41 Goodhope	5.70E-07	9.94E-01	1.00E-03	1.07E-04	1.52E-04	2.13E-03	1.28E-03	5.43E-05	6.28E-05
R42 Jonkersleegte	2.46E-07	4.19E-01	4.32E-04	4.60E-05	6.52E-05	9.19E-04	5.51E-04	2.34E-05	2.71E-05
R43 Grootkraanvoelkuil	7.33E-08	1.21E-01	1.28E-04	1.36E-05	1.92E-05	2.73E-04	1.63E-04	6.96E-06	8.05E-06
R44 Helvetia	2.07E-08	3.48E-02	3.64E-05	3.87E-06	5.46E-06	7.73E-05	4.62E-05	1.97E-06	2.28E-06
R45 Eensaam	2.14E-07	3.60E-01	3.75E-04	3.99E-05	5.64E-05	7.97E-04	4.77E-04	2.03E-05	2.35E-05
R46 Hoekraal	6.84E-07	1.13E+00	1.20E-03	1.27E-04	1.79E-04	2.55E-03	1.52E-03	6.50E-05	7.52E-05
R47 Reyersvlei	2.14E-08	3.59E-02	3.76E-05	3.99E-06	5.64E-06	7.98E-05	4.77E-05	2.04E-06	2.35E-06
R48 Beyerskloof	1.01E-08	1.70E-02	1.78E-05	1.89E-06	2.67E-06	3.77E-05	2.26E-05	9.62E-07	1.11E-06
R49 Theefontein	7.35E-09	1.24E-02	1.29E-05	1.37E-06	1.94E-06	2.74E-05	1.64E-05	6.98E-07	8.08E-07
R50 Neverset	5.73E-08	9.50E-02	1.00E-04	1.07E-05	1.50E-05	2.14E-04	1.27E-04	5.44E-06	6.30E-06
Olive Grove	8.09E-08	1.36E-01	1.42E-04	1.51E-05	2.13E-05	3.01E-04	1.80E-04	7.68E-06	8.89E-06

DECLARATION OF INDEPENDENCE

I, Johan Slabbert, an independent consultant, hereby confirm my independence as a specialist and declare that I do not have any interest, be it business, financial, personal, or other, in any proposed activity, application, or appeal in respect of which a public radiological impact assessment for the proposed mining activity is performed, other than fair remuneration for work performed.

JSlabbert	05/07/2017
SIGNATURE	DATE