Radiological Impact due to the Tailings Dams in the Vicinity of the Proposed Spitzland Development




Assessing Radiological Impact on People & the Environment

Date: 14 May 2018

Prepared by: Dawid de Villiers, Ph.D. (Pr.Sci.Nat, Pr.Phys.)

Radiation Protection Specialist (NORM)

Document No: SR-REP-04/2018

SciRad Consulting (Pty) Ltd

Reg. No: 2012/210743/07

P.O. Box 843, Hartbeespoort, 0216, Tel: +27 12 253 1507, Cell: +27 82 339 0254, Email: dawid@sciradconsulting.com

DISCLAIMER

Although SciRAD Consulting (Pty) Ltd exercises due care and diligence in rendering services and preparing documents, SciRAD Consulting (Pty) Ltd accepts no responsibility and liability for any and all losses, expenses, costs, damages, demands and claims arising out of or in connection with illness or injuries to or the death of any person and/or damage to the property of any person, in any way sustained or allegedly sustained in connection with or by reason of the services rendered by SciRAD Consulting (Pty) Ltd or the use of the information contained in this document.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Living Africa (Pty) Ltd intends on developing a piece of land in Johannesburg for residential purposes. The proposed Spitzland Housing development is located south-west of the Roodepoort Central Business District and Main Reef Road. The land is surrounded by tailings dams (see Figure 1) which may be re-mined. This re-mining may have a radiological impact on the proposed development.

This report provides the assessment of the radiological impact of the surrounding tailings dams on the proposed Spitzland development using the information from the Air Quality Impact Assessment (Petzer, 2018) and elemental analysis results (Necsa, 2015) from one of the tailings dams.

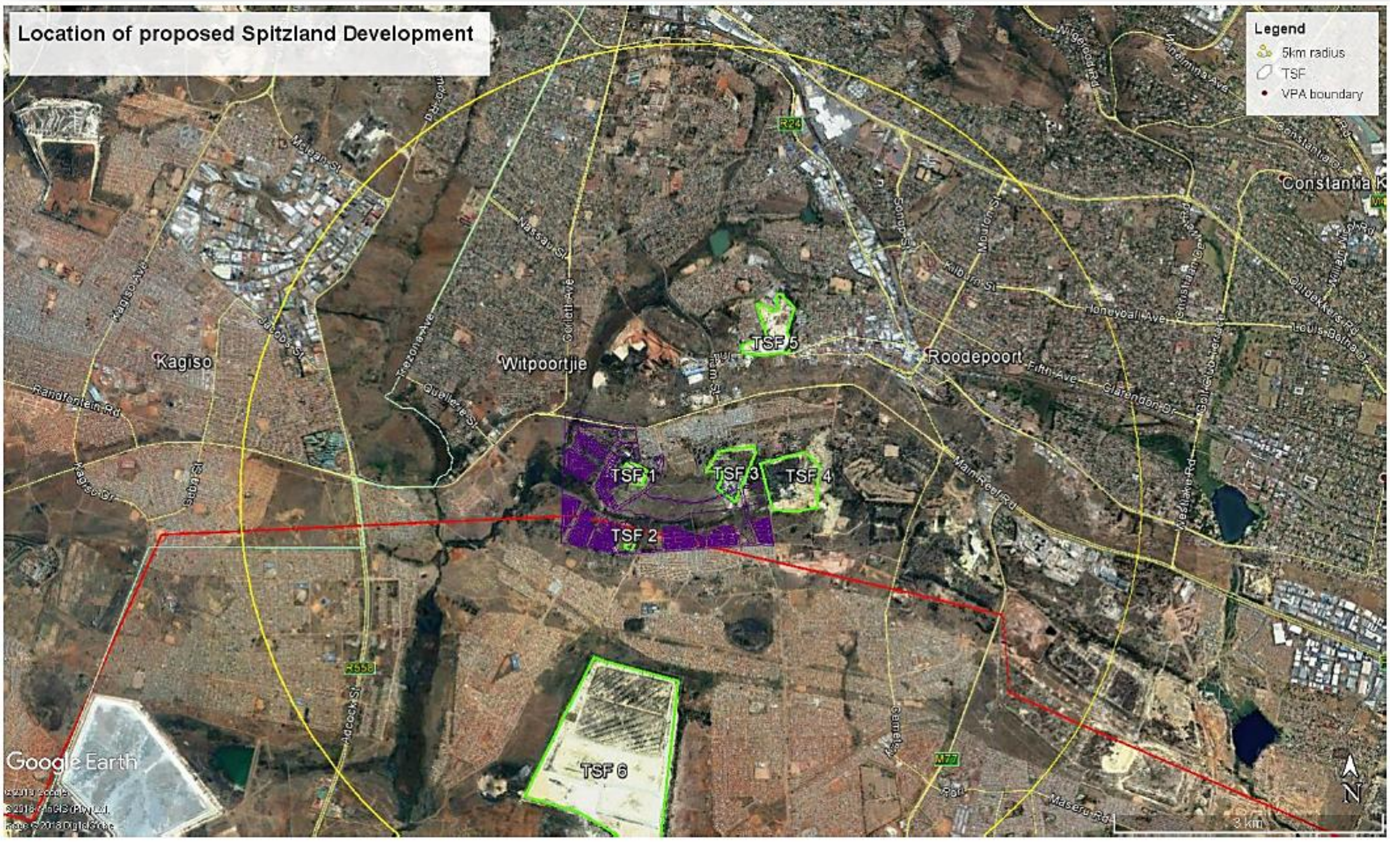

Figure 1: Location of the proposed Spitzland development, also illustrating the surrounding tailings dams (Petzer, 2018).

2.0 REGULATORY CRITERIA

Regulation R388 (DME, 2006) of the National Nuclear Regulator Act, No. 47 of 1999 (DME, 1999), defines a public dose constraint/limit of 250 µSv/a (DME, 2006) per action, and a total allowed public dose limit of 1 mSv/a (i.e. 1 000 µSv/a) from all actions involving radiation. This criterion will be used to assess whether the re-mining of the tailings dams has an acceptable dose to the public at the proposed Spitzland development. Note that this dose limit does not include the radon dose, which according to the ICRP may range from 3 mSv/a – 10 mSv/a (ICRP, 1993).

3.0 RADIOLOGICAL IMPACT ASSESSMENT

In the following section, mathematical models in conjunction with air dispersion results are used to determine the radiological impact (i.e. radiation dose) to the proposed Spitzland development when dust and radon, originating from the tailings dams, are inhaled or deposited on the ground.

3.1 RADIOLOGICAL DATA

The radionuclides giving rise to the radiological impacts associated with the tailings dams are those resulting from the uranium-238, uranium-235 and thorium-232 decay series. Elemental analyses results of the uranium and thorium concentrations (attached as Appendix A (Necsa, 2015)) in three of the tailings dams will be used as the radiation source term (the average values will be used for the remaining tailings dams). In the absence of other radionuclide information, it will be assumed that the measured uranium and thorium concentrations are in secular equilibrium with its daughter products, meaning the daughter products have the same concentrations. The concentration values were converted to activity concentrations by using the following conversion factors:

- 1 ppm Uranium-238 = 0.01235 Bq/g and
- 1 ppm Thorium-232 = 0.00406 Bq/g (IAEA, 2003).

Table 1: Radionuclide concentrations of the sediments from the tailings dams

Tailings Dam	Activity Concentrations (Bq/g)		
	Uranium-238 and daughters	Uranium-235 and daughters	Thorium-232 and daughters
TSF 1	0.027	1.9e-4	0.013
TSF 2	0.027	2.2e-4	0.013
TSF 3	0.021	1.5e-4	0.012
TSF 4,5,6	0.025	1.9e-4	0.013

3.2 ATMOSPHERIC PATHWAY

Meteorological and mechanical processes (e.g. wind speed, wind direction and dispersion) cause radon and dust to be transported from the exhalation and fugitive dust sources to the receptors. Details on environmental transfer via the atmospheric pathway are dealt with in the Air Quality Impact Assessment (Petzer, 2018) and will not be repeated here.

The atmospheric pathway is the focus of this assessment and will consider external exposure due to the deposition of dust, inhalation of dust and the inhalation of radon and it short-lived daughters.

3.3 EXPOSURE SCENARIO

An exposure scenario describes the radiation exposure conditions developed for the receptors of the possible impacts (in this case only humans). Although all age groups will be present at the proposed Spitzland development, the chosen exposure scenario assumes only adults as the doses from the inhalation of radon and long lived radioactive dust for the adult age group represent the worst case.

The people may be exposed to radon and dust emissions from the fugitive dust sources related to the re-mining of the tailings dams. The dust may also deposit in the area. Three scenarios for the re-mining was investigated in the Air Quality Assessment and will also be used in this report (Petzer, 2018):

- Scenario 1: Active re-mining at TSF 1, 2 and 3 with no vegetation and no mitigation. TSF 4 to 6 remain dormant with existing vegetation cover.
- Scenario 2: Post re-mining at TSF 1, 2 and 3. TSF 4 to 6 remain dormant with existing vegetation cover.
- Scenario 3: TSF 1 to 6 remain dormant with existing vegetation cover.

Since no occupation details are available, it is assumed that an adult member of the public spend 1 710 h/a outdoors and 7 050 h/a indoors. Where applicable, staying indoors will provide a shielding factor of 60 % (NNR, 2013) of the outdoor external exposure.

3.4 DOSES FROM DEPOSITED DUST

External exposure occurs when soil is contaminated through the deposition of airborne radioactivity (in the form of dust). In the case of deposited material, the activity is initially present as a thin cover layer. The external exposure is in this case calculated from the surface activity concentration of the soil by using published dose conversion factors for mostly gamma rays. Exposure from alpha and beta radiation can be disregarded as their contribution is insignificant.

For the proposed Spitzland development a dust fallout rate from all tailings dust sources was determined through dispersion modelling (Petzer, 2018). The modelled deposited dust concentrations were converted to deposited dust activity concentrations by multiplying the gravimetric concentrations of the source with the applicable radionuclide concentrations (Table 1). An accumulation period of 1 year for environmental outdoor conditions is assumed for the deposited dust where-after the source is assumed to have reached an equilibrium state. External doses are determined from the deposition sources, assumed to be an infinitely large surface source is expressed by:

$$D_{ext} = \left(\sum_j C_{dust}^{j} . DCF_j\right) . (T_o + SF . T_i) . 1000000 \qquad \text{Eq. 1}$$

where

D_{ext}	=	Dose from external exposure	[μSv/a]
C_{dust}	=	Activity concentration of radionuclide *j* in deposited dust	[Bq/m^2]
DCF_j	=	Dose conversion factor for radionuclide *j* in dust	[Sv/h per Bq/m^2]

T_O	=	Annual outdoor exposure period	[h/a]
T_i	=	Annual indoor exposure period	[h/a]
SF	=	Indoor shielding factor (taken as 0.6)	[-]

Dose coefficients for external exposure were taken from (Eckerman & Ryman, 1993) and are presented in Appendix B.

3.5 DUST INHALATION DOSES

Dust from the tailings dams can be inhaled and as a result people are exposed to the radioactivity within the dust. For the proposed Spitzland development the inhalable dust fraction (PM_{10}) from all tailings dust sources was determined through dispersion modelling (Petzer, 2018). The modelled airborne dust concentrations were converted to airborne dust activity concentrations by multiplying the gravimetric concentrations of the source with the applicable radionuclide concentrations (Table 1). Indoor dust concentrations are assumed to be equal to the outdoor concentrations, but with a shielding factor. The average breathing rate for adults is assumed to be 0.92 m^3/h for a 24 hour per day exposure period (which includes eight hours of sleep) (NNR, 2013). The mathematical model that is used to calculate the dust inhalation dose is expressed by:

$$D_{inh,dust} = (\textstyle\sum_j C_{dust}^{j} . DCF_j).(T_o + SF.T_i).BR \qquad \text{Eq. 2}$$

where

$D_{inh,dust}$	=	Inhalation dose from radioactive airborne dust	[μSv/a]
C_{dust}	=	Activity concentration of radionuclide *j* in airborne dust	[μBq/m^3]
DCF_j	=	Dose conversion factor for radionuclide *j* in dust	[Sv/Bq]
T_o	=	Annual outdoor exposure period	[h/a]
T_i	=	Annual indoor exposure period	[h/a]
SF	=	Indoor shielding factor (taken as 0.6)	-
BR	=	Breathing rate	[m^3/h]

The dose conversion factors (with units of Sv/Bq) for inhalation were taken from the NNR Regulatory Guidance document RG-002 (NNR, 2013), tabulated in Appendix B.

3.6 RADON INHALATION DOSES

Radon fluxes from the tailings dams can be measured experimentally, but such data are presently unavailable. The radon flux will therefore be calculated from the assumed radium-226 concentrations (Table 1), published values for the emanation (0.25), diffusion coefficient (4.2 x 10^{-6} m^2/s) (NNR, 2013) and bulk density (1217 kg/m^3) for gold mine tailings according to the following mathematical expression (IAEA, 2013):

$$F = C_{Ra-226}.1000.\rho.E.\sqrt{\lambda.D}, \qquad \text{Eq. 3}$$

where

F	=	Radon flux at the surface of the tailings dam	[Bq/m^2.s]
$C_{Ra\text{-}226}$	=	Concentration of Ra-226 in the tailings material	[Bq/g]
P	=	Bulk density of tailings	[kg/m^3]
E	=	Emanation coefficient of tailings (assumed to be 0.25)	[-]
Λ	=	Decay constant of Rn-222 (2.06 x 10^{-6} s^{-1})	[1/s]
D	=	Diffusion coefficient of tailings	[m^2/s]

For each tailings dam the radon concentrations were determined through dispersion modelling based on a unit release of 0.001 g/s/m^2 of gas. These radon concentrations were corrected by multiplying with the applicable calculated radon flux.

Thereafter the doses from the exposure to inhaled radon daughters were calculated from the corrected indoor and outdoor radon gas concentrations, by multiplication with appropriate conversion factors and exposure periods. The indoor and outdoor concentrations were taken as equivalent, as per modelled outdoor results, although different equilibrium factors with the radon progeny for indoor and outdoor gases are used as per ICRP Publication 65 (ICRP, 1993) and the UNSCEAR report (UNSCEAR, 1993). The conversion factors for radon are age-independent and will be used as such. The mathematical model that is used to calculate the radon inhalation dose is expressed by (UNSCEAR, 1993):

$$D_{Radon} = 1000.(C_{Radon\ i}.EF_i.T_i + C_{Radon\ o}.EF_o.T_o).DCF_{Radon}.CC_{Radon} \quad \text{Eq. 4}$$

where

D_{Radon}	=	Dose from radon exposure	[μSv/a]
$C_{Radon\ i}$	=	Indoor radon concentration	[Bq/m^3]
EF_i	=	Indoor equilibrium factor (taken as 0.4)	[-]
T_i	=	Indoor exposure period	[h/a]
$C_{Radon\ o}$	=	Outdoor radon concentration	[Bq/m^3]
F_o	=	Outdoor equilibrium factor (taken as 0.8)	[-]
T_o	=	Outdoor exposure period	[h/a]
CC_{Rn}	=	Ratio of PAEC and EEC for radon (5.6 x 10^{-6})	[mJ/m^3 per Bq/m^3]
DCF	=	Dose conversion factor for radon exposure (taken as 1.1)	[mSv/h per mJ/m^3]

4.0 RESULTS & DISCUSSION

In this section the assessment results for the exposure scenario according to the three scenarios (Section 3.3) are presented.

4.1 Doses from Deposited Dust

The radiation doses to adults due to deposited dust are depicted in Figures 2 to 4 for Scenario 1 to 3 respectively. All assessed external doses are insignificant (that is below 1 µSv/a) at the proposed Spitzland development and of no concern.

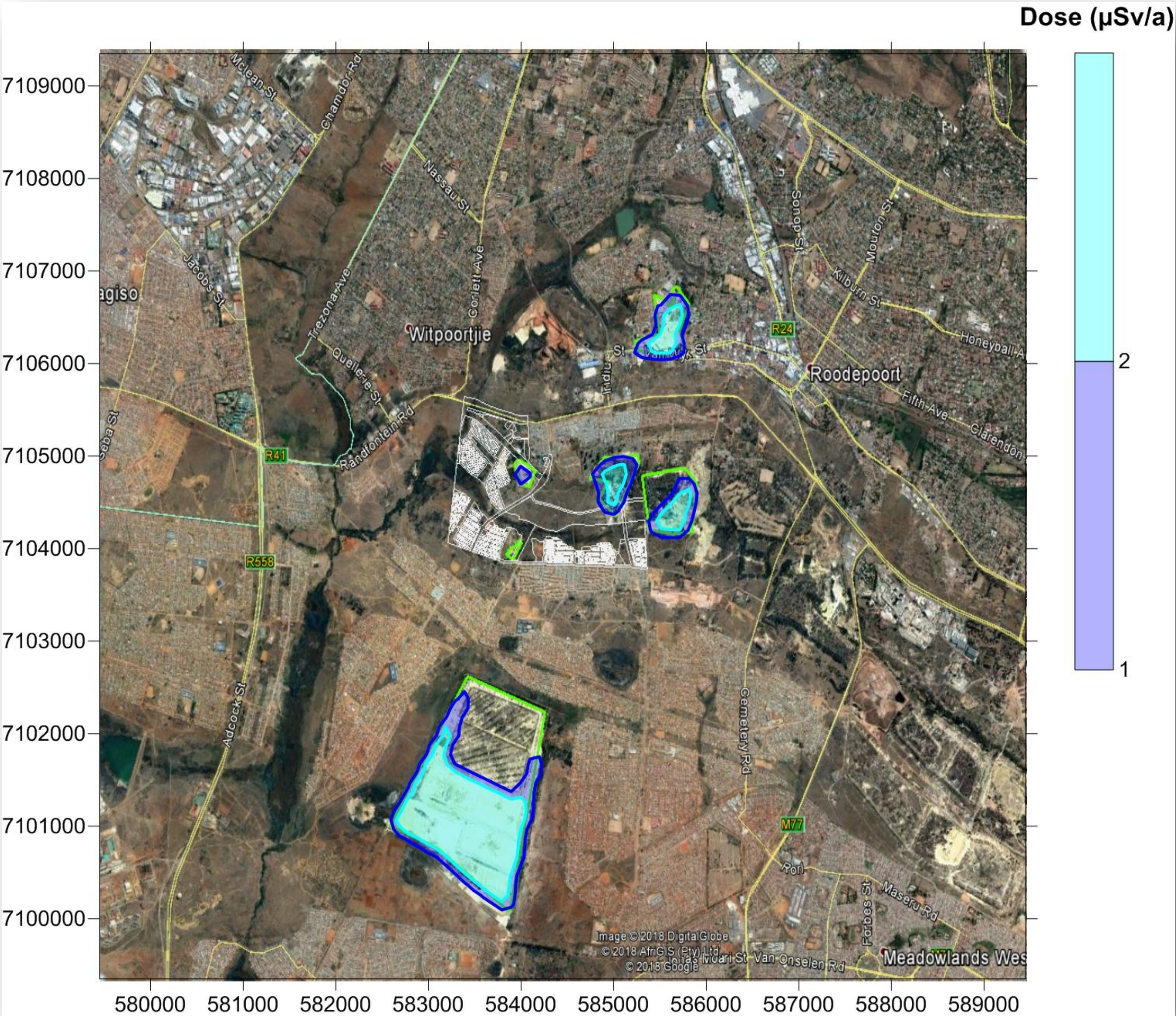

Figure 2: Calculated doses (µSv/a) for External Exposure to deposited dust – Scenario 1.

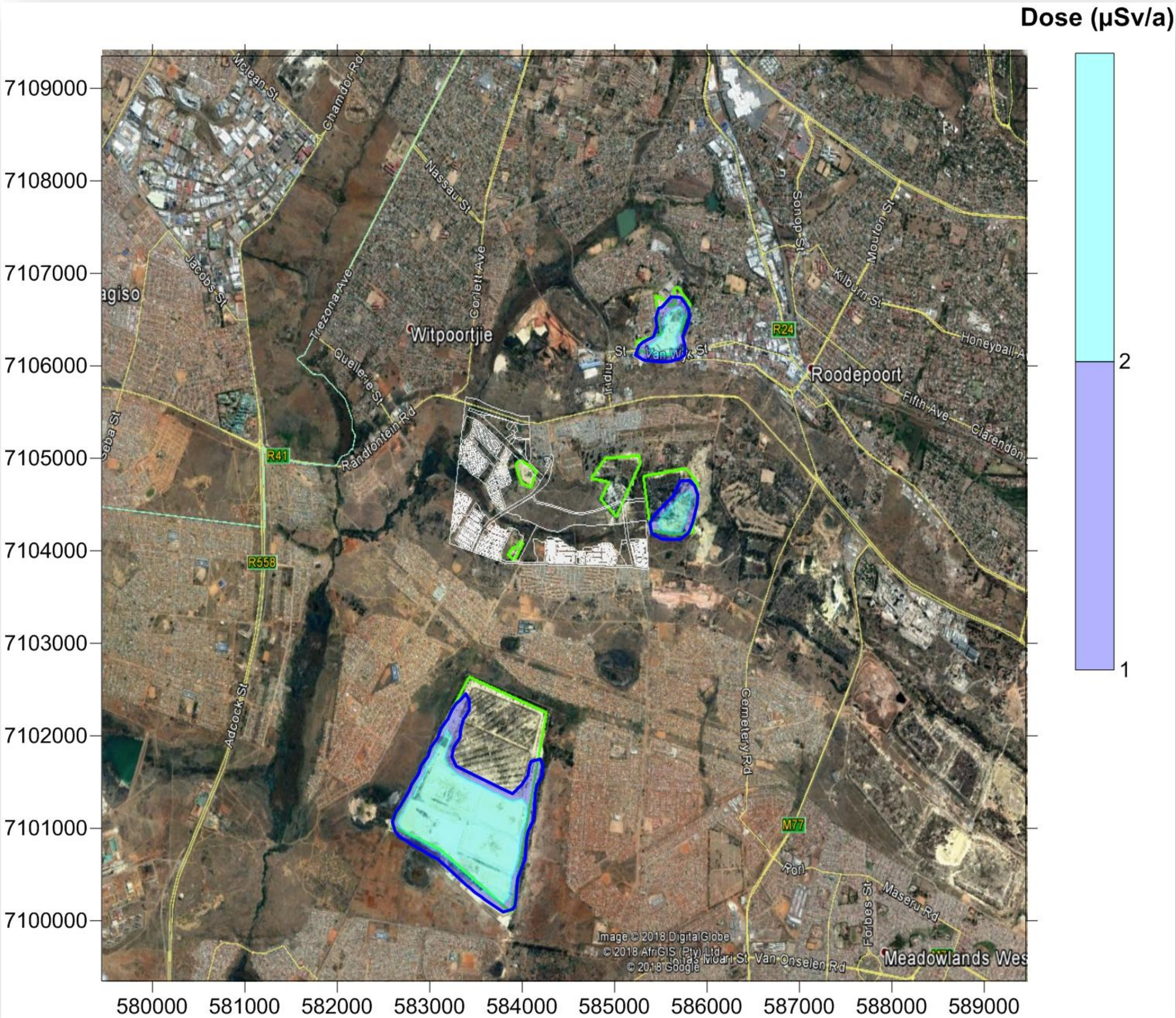

Figure 3: Calculated doses (µSv/a) for External Exposure to deposited dust – Scenario 2.

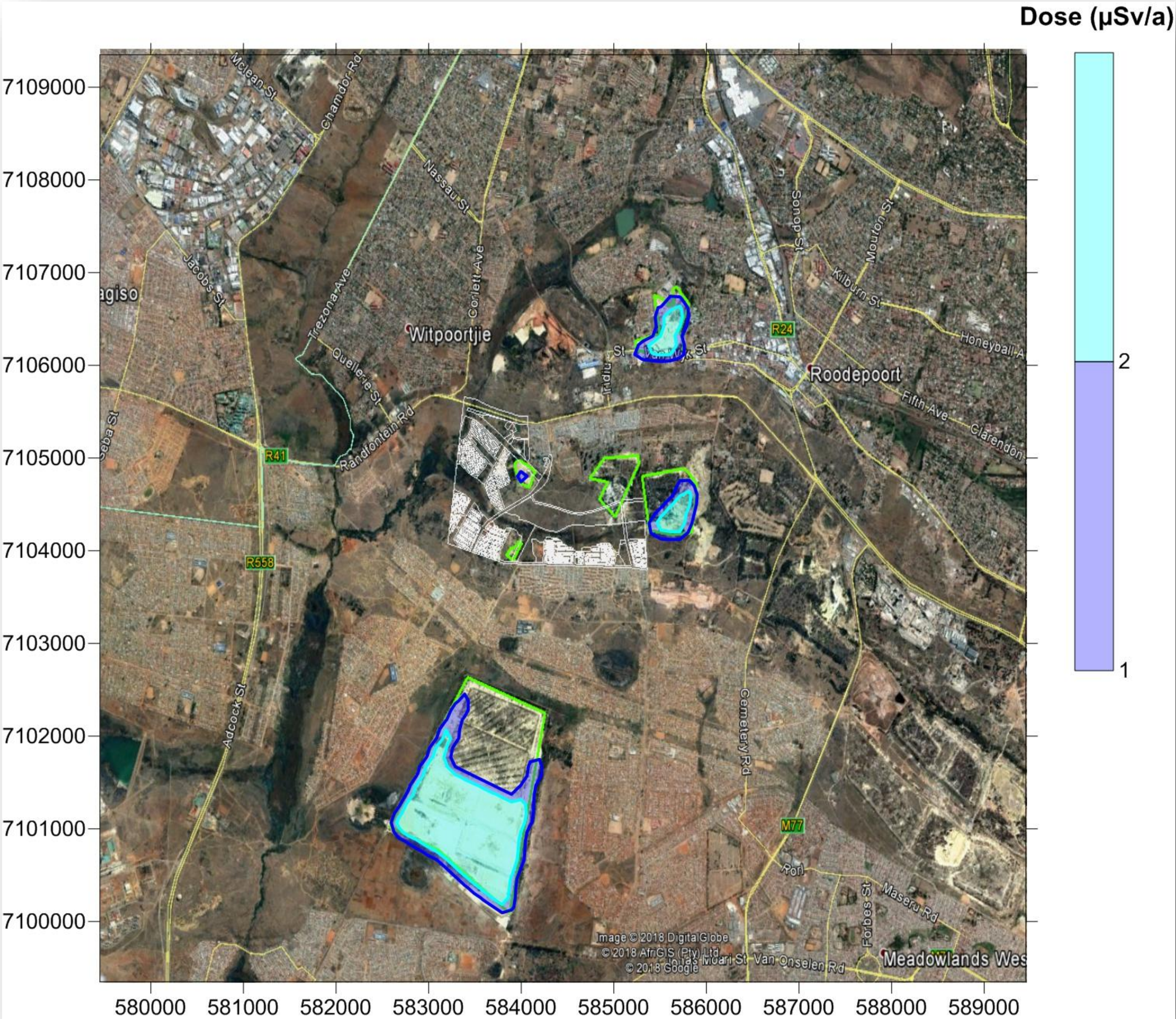

Figure 4: Calculated doses (µSv/a) for External Exposure to deposited dust – Scenario 3.

4.2 DUST INHALATION DOSES

The radiation doses to adults due to the inhalation of dust are depicted in Figures 5 to 7 for Scenario 1 to 3 respectively. All assessed dust inhalation doses are insignificant (that is below 1 µSv/a) at the proposed Spitzland development and of no concern.

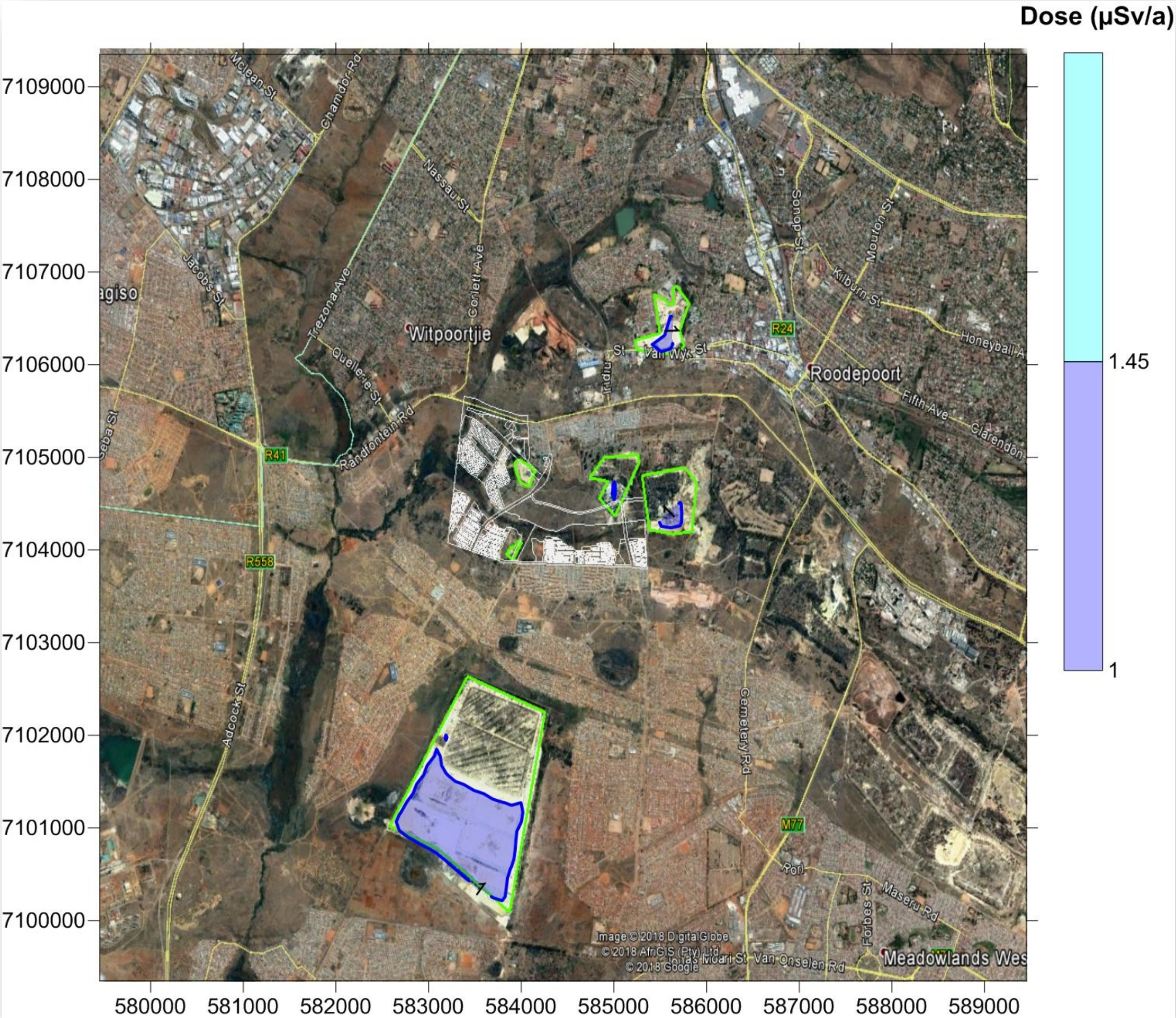

Figure 5: Calculated doses (µSv/a) for Dust Inhalation – Scenario 1.

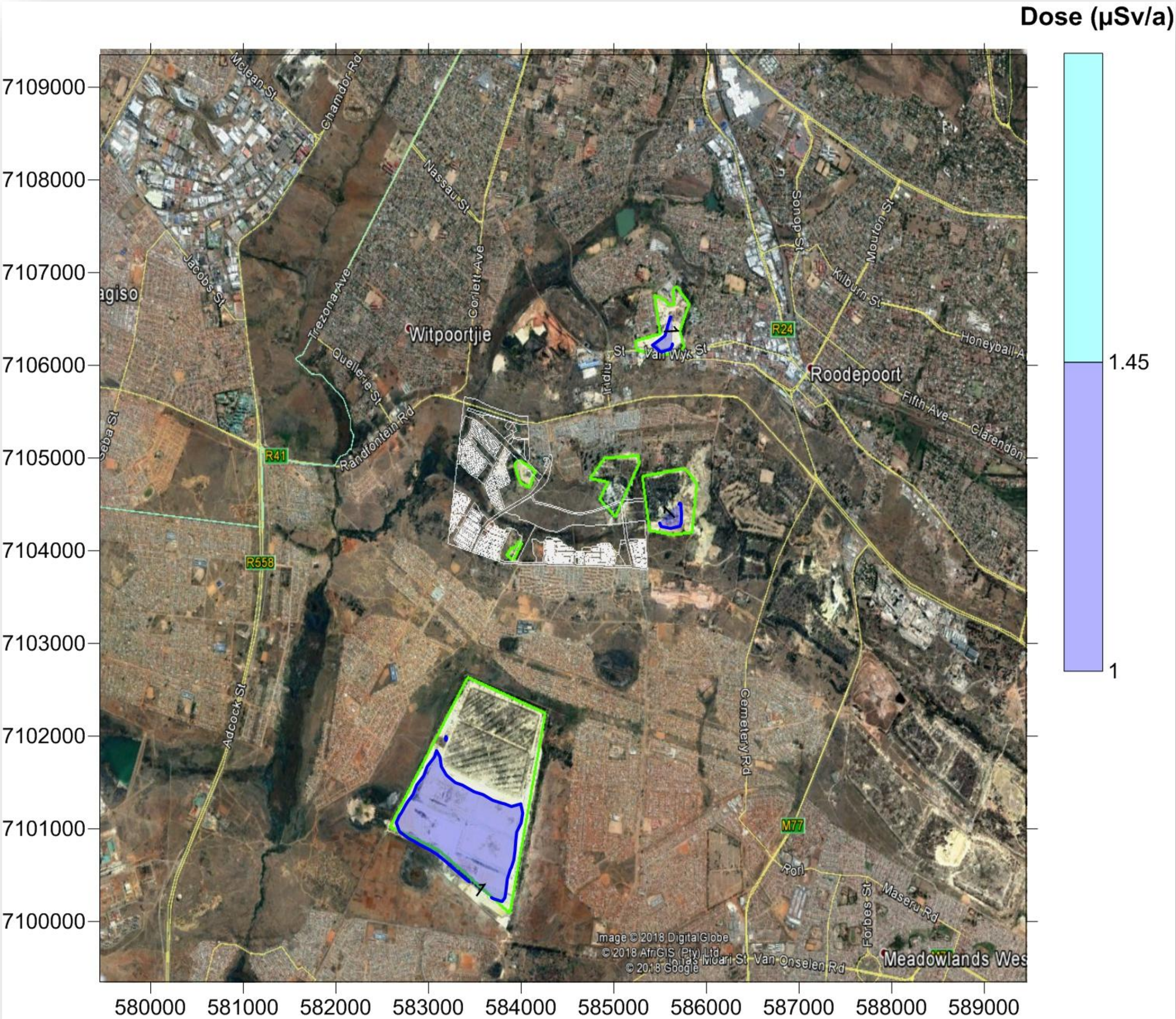

Figure 6: Calculated doses (µSv/a) for Dust Inhalation – Scenario 2.

Figure 7: Calculated doses (µSv/a) for Dust Inhalation – Scenario 3.

4.3 RADON INHALATION DOSES

The radiation doses to adults due to the inhalation of radon are depicted in Figures 8 and 9 for Scenario 1 & 3 and Scenario 2 respectively. The action level of 10 mSv/a is reached directly on the tailings dams, with most of the proposed Spitzland development in areas where the doses are less than 3 mSv/a. Only a small portion of the development (to the East) has estimated radon doses that range from 3 – 10 mSv/a. For now, these doses are still within the ICRP guidelines, but the NNR will publish their own guidelines soon which may restrict development in such high radon dose areas.

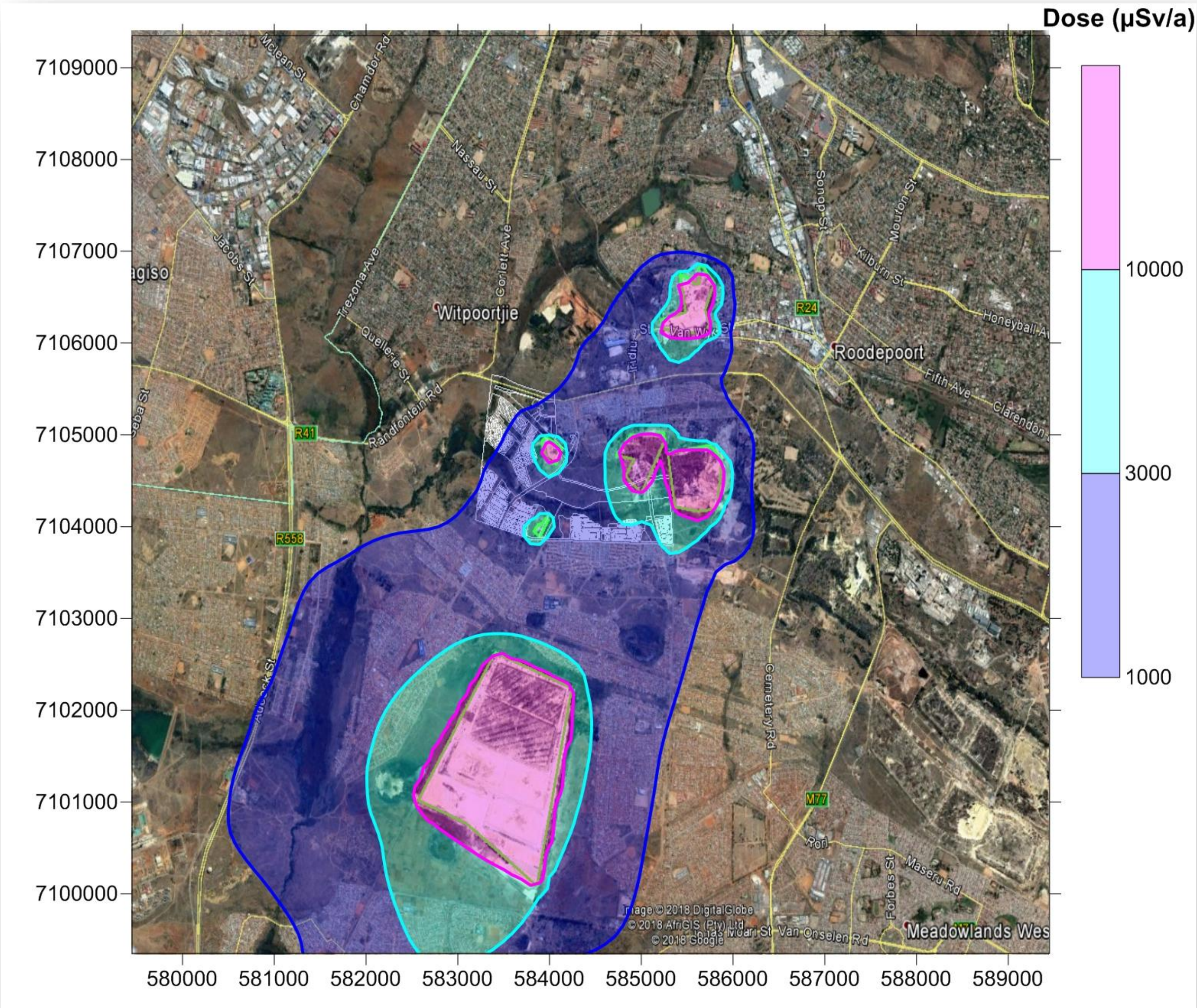

Figure 8: Calculated doses (µSv/a) for Radon Inhalation – Scenario 1 and 3.

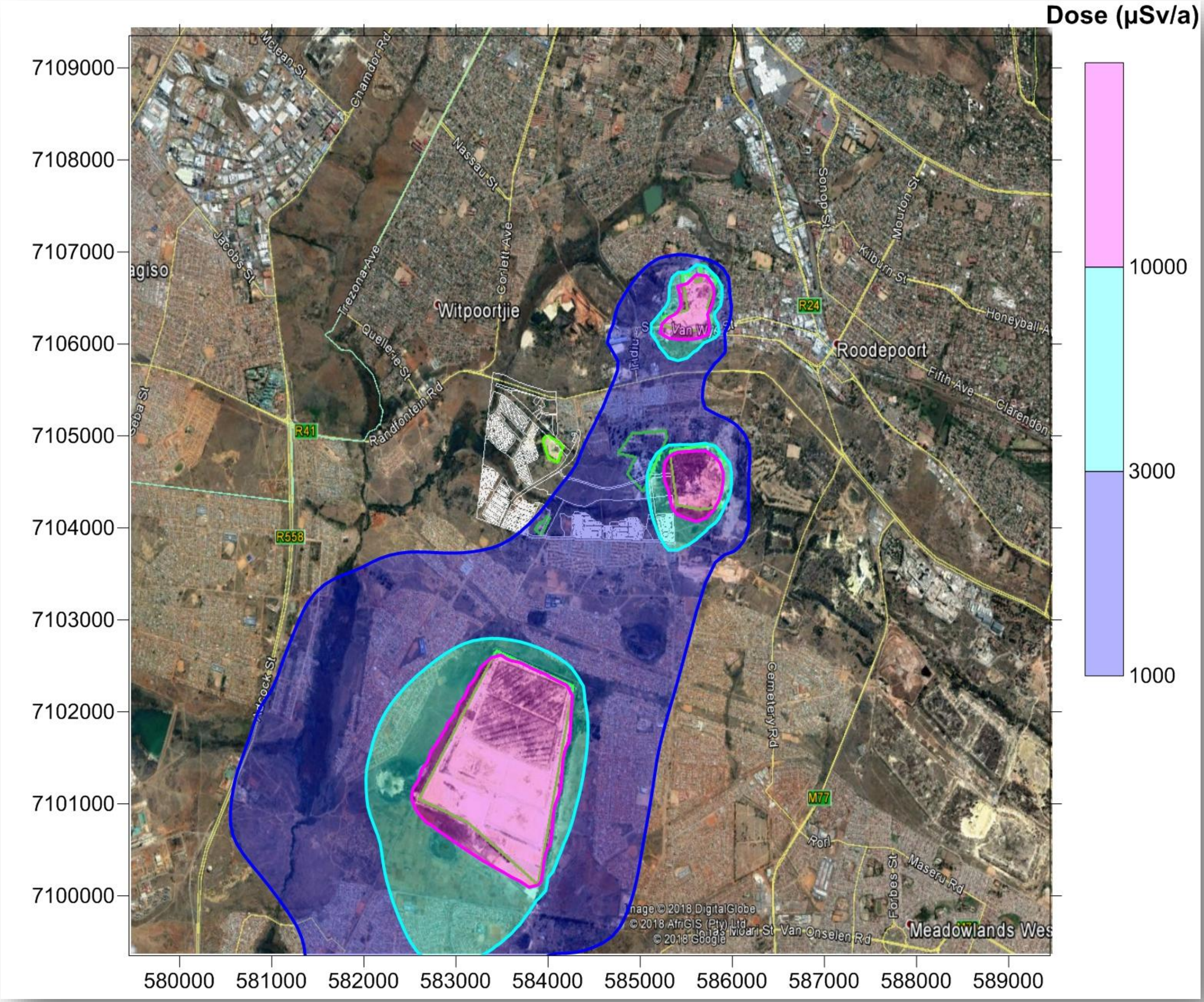

Figure 9: Calculated doses (µSv/a) for Radon Inhalation – Scenario 2.

5.0 CONCLUSION

The radiological impact, in terms of external and inhalation (dust and radon) doses, due to tailings dams in the vicinity of the proposed Spitzland development were assessed. External and dust inhalation doses were found to be insignificant (that is below 1 µSv/a) and therefore of no concern.

Radon doses were high at the tailings dams, but most of the proposed Spitzland development lies in areas where the doses are less than 3 mSv/a. Only a small portion of the development (to the East) has estimated radon doses that range from 3 – 10 mSv/a. For now, these doses are still within the ICRP guidelines, but the NNR will publish their own guidelines soon which may restrict development in such high radon dose areas.

6.0 REFERENCES

DME, 1999. *National Nuclear Regulator Act, No. 47 of 1999.,* Government Gazette No. 20760: Cape Town, 23 December.

DME, 2006. *National Safety Standards and Regulatory Practices,* Regulation 388, Revision 0, Government Gazette No. 28755, Vol. 490: Department of Minerals and Energy, Pretoria, 28 April.

Eckerman, K. & Ryman, C., 1993. *External Exposure to Radionuclides in Air, Water and Soil,* Federal Guidance Report No. 12: Environmental Protection Agency, United States of America.

IAEA, 2003. *Guidelines for radioelement mapping using gamma ray spectrometry data,* IAEA-TECDOC-1363: International Atomic Energy Agency, Vienna.

IAEA, 2013. *Measurement and Calculation of Radon Releases from NORM Residues,* Technical Report Series No. 474: International Atomic Energy Agency.

ICRP, 1993. *Protection Agains Radon-222 at Home and at Work,* ICRP Publication 65, Annals of the ICRP, Volume 23, No.2: International Commission on Radiological Protection.

Necsa, 2015. *Elemental Analysis of Solids, Report PS2015-2576/1,* Pelindaba Analytical Laboratories, Necsa: 12 November.

NNR, 2013. *Safety Assessment of Radiation Hazards to Members of the Public form NORM Activities,* RG-002: National Nuclear Regulator, Pretoria.

Petzer, G., 2018. *Air Quality Impact Assessment for the Proposed Spitzland Development near Roodepoort, Gauteng,* Report No: 17EIM13_Rev.1.1: Airshed Planning Professionals (Pty) Ltd, April.

UNSCEAR, 1993. *Sources and Effects of Ionising Radiation,* Report: United Nations Scientific Commitee on the Effects of Atomic Radiation.

Wortmann, H., 2007. *Sedimentation and Desiccation of Gold Mine Tailings,* M.Sc. Thesis: University of Pretoria, unpublished.

7.0 APPENDIX A: ELEMENTAL ANALYSIS OF TAILINGS MATERIAL

PO Box 582
Pretoria
0001

Pelindaba Analytical Labs

Test Report

Elias Motsoaledi Street Extension (Church Street West)
R104 Pelindaba

Laboratory Reference Number:	PS2015-2576/1
Quotation Reference Number:	PQ2015-0330 (Ver 2)
Client Order Number:	COD

Client:	**Contact:**	Dr D de Villiers
	Company:	SciRad Consulting (Pty) Ltd
	Address:	PO Box 843 Schoemansville Hartbeespoort
	Telephone:	012 253 1507
	Fax:	
Dates:	**Received:**	2015-10-19
	Analysed:	2015-11-12
	Reported:	2015-11-12
Remarks:		

Analysts & Authorisers

Analyst(s):

PP Pieterse (Phillip)	Technical Signatory
S Sibiya (Simanga)	Technician

Checked by:

WG van Niekerk (Wouter)	Technical Signatory

Sample ID: PS2015-2576X001 **Sample Name:** SR-LA-T1

Determination	Result	Units	Method Used	Uncertainty
Potassium (K)	372	mg/kg	AA Analysis - Full Report - K	
Sodium (Na)	391	mg/kg	AA Analysis - Full Report - Na	
Antimony (Sb)	0.8	mg/kg	ICP-MS Analysis - FULL Report	
Arsenic (As)	178	mg/kg	ICP-MS Analysis - FULL Report	
Barium (Ba)	30.2	mg/kg	ICP-MS Analysis - FULL Report	
Beryllium (Be)	0.1	mg/kg	ICP-MS Analysis - FULL Report	
Bismuth (Bi)	0.4	mg/kg	ICP-MS Analysis - FULL Report	
Boron (B)	2.5	mg/kg	ICP-MS Analysis - FULL Report	
Cadmium (Cd)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Chromium (Cr)	124	mg/kg	ICP-MS Analysis - FULL Report	
Cobalt (Co)	0.5	mg/kg	ICP-MS Analysis - FULL Report	
Copper (Cu)	5.5	mg/kg	ICP-MS Analysis - FULL Report	
Gold (Au)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Indium (In)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Iridium (Ir)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Lanthanum (La)	17.2	mg/kg	ICP-MS Analysis - FULL Report	
Lead (Pb)	82.0	mg/kg	ICP-MS Analysis - FULL Report	
Lithium (Li)	1.0	mg/kg	ICP-MS Analysis - FULL Report	
Manganese (Mn)	188	mg/kg	ICP-MS Analysis - FULL Report	
Mercury (Hg)	0.2	mg/kg	ICP-MS Analysis - FULL Report	
Molybdenum (Mo)	0.9	mg/kg	ICP-MS Analysis - FULL Report	
Nickel (Ni)	5.8	mg/kg	ICP-MS Analysis - FULL Report	
Palladium (Pd)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Phosphorus (P)	87.6	mg/kg	ICP-MS Analysis - FULL Report	
Platinum (Pt)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	

Sample ID: PS2015-2576X001 **Sample Name:** SR-LA-T1

Determination	Result	Units	Method Used	Uncertainty
Rhodium (Rh)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Ruthenium (Ru)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Selenium (Se)	0.1	mg/kg	ICP-MS Analysis - FULL Report	
Silver (Ag)	0.1	mg/kg	ICP-MS Analysis - FULL Report	
Strontium (Sr)	6.0	mg/kg	ICP-MS Analysis - FULL Report	
Tellurium (Te)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Thallium (Tl)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Thorium (Th)	2.9	mg/kg	ICP-MS Analysis - FULL Report	
Tin (Sn)	0.5	mg/kg	ICP-MS Analysis - FULL Report	
Titanium (Ti)	159	mg/kg	ICP-MS Analysis - FULL Report	
Uranium (U)	1.7	mg/kg	ICP-MS Analysis - FULL Report	
Vanadium (V)	19.6	mg/kg	ICP-MS Analysis - FULL Report	
Zinc (Zn)	4.2	mg/kg	ICP-MS Analysis - FULL Report	
Zirconium (Zr)	9.1	mg/kg	ICP-MS Analysis - FULL Report	
Aluminium (Al)	18680	mg/kg	ICP-OES Analysis - FULL Report	
Calcium (Ca)	630	mg/kg	ICP-OES Analysis - FULL Report	
Iron (Fe)	22368	mg/kg	ICP-OES Analysis - FULL Report	
Magnesium (Mg)	2350	mg/kg	ICP-OES Analysis - FULL Report	
Silicon (Si)	1611	mg/kg	ICP-OES Analysis - FULL Report	
Sulphur (S)	7832	mg/kg	ICP-OES Analysis - FULL Report	

Sample ID: PS2015-2576X002 **Sample Name:** SR-LA-T2

Determination	Result	Units	Method Used	Uncertainty
Potassium (K)	98	mg/kg	AA Analysis - Full Report - K	
Sodium (Na)	140	mg/kg	AA Analysis - Full Report - Na	
Antimony (Sb)	0.7	mg/kg	ICP-MS Analysis - FULL Report	

Sample ID: PS2015-2576X002 **Sample Name:** SR-LA-T2

Determination	Result	Units	Method Used	Uncertainty
Arsenic (As)	62.4	mg/kg	ICP-MS Analysis - FULL Report	
Barium (Ba)	24.6	mg/kg	ICP-MS Analysis - FULL Report	
Beryllium (Be)	0.3	mg/kg	ICP-MS Analysis - FULL Report	
Bismuth (Bi)	0.6	mg/kg	ICP-MS Analysis - FULL Report	
Boron (B)	1.4	mg/kg	ICP-MS Analysis - FULL Report	
Cadmium (Cd)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Chromium (Cr)	88.5	mg/kg	ICP-MS Analysis - FULL Report	
Cobalt (Co)	5.1	mg/kg	ICP-MS Analysis - FULL Report	
Copper (Cu)	9.1	mg/kg	ICP-MS Analysis - FULL Report	
Gold (Au)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Indium (In)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Iridium (Ir)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Lanthanum (La)	18.9	mg/kg	ICP-MS Analysis - FULL Report	
Lead (Pb)	64.7	mg/kg	ICP-MS Analysis - FULL Report	
Lithium (Li)	3.6	mg/kg	ICP-MS Analysis - FULL Report	
Manganese (Mn)	130	mg/kg	ICP-MS Analysis - FULL Report	
Mercury (Hg)	0.7	mg/kg	ICP-MS Analysis - FULL Report	
Molybdenum (Mo)	1.5	mg/kg	ICP-MS Analysis - FULL Report	
Nickel (Ni)	17.6	mg/kg	ICP-MS Analysis - FULL Report	
Palladium (Pd)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Phosphorus (P)	233	mg/kg	ICP-MS Analysis - FULL Report	
Platinum (Pt)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Rhodium (Rh)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Ruthenium (Ru)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Selenium (Se)	0.2	mg/kg	ICP-MS Analysis - FULL Report	

Sample ID: PS2015-2576X002 **Sample Name:** SR-LA-T2

Determination	Result	Units	Method Used	Uncertainty
Silver (Ag)	0.1	mg/kg	ICP-MS Analysis - FULL Report	
Strontium (Sr)	12.5	mg/kg	ICP-MS Analysis - FULL Report	
Tellurium (Te)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Thallium (Tl)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Thorium (Th)	3.2	mg/kg	ICP-MS Analysis - FULL Report	
Tin (Sn)	0.5	mg/kg	ICP-MS Analysis - FULL Report	
Titanium (Ti)	266	mg/kg	ICP-MS Analysis - FULL Report	
Uranium (U)	2.2	mg/kg	ICP-MS Analysis - FULL Report	
Vanadium (V)	15.4	mg/kg	ICP-MS Analysis - FULL Report	
Zinc (Zn)	17.6	mg/kg	ICP-MS Analysis - FULL Report	
Zirconium (Zr)	17.2	mg/kg	ICP-MS Analysis - FULL Report	
Aluminium (Al)	10176	mg/kg	ICP-OES Analysis - FULL Report	
Calcium (Ca)	2516	mg/kg	ICP-OES Analysis - FULL Report	
Iron (Fe)	14459	mg/kg	ICP-OES Analysis - FULL Report	
Magnesium (Mg)	1613	mg/kg	ICP-OES Analysis - FULL Report	
Silicon (Si)	1888	mg/kg	ICP-OES Analysis - FULL Report	
Sulphur (S)	2680	mg/kg	ICP-OES Analysis - FULL Report	

Sample ID: PS2015-2576X003 **Sample Name:** SR-LA-T3

Determination	Result	Units	Method Used	Uncertainty
Potassium (K)	49	mg/kg	AA Analysis - Full Report - K	
Sodium (Na)	87	mg/kg	AA Analysis - Full Report - Na	
Antimony (Sb)	0.6	mg/kg	ICP-MS Analysis - FULL Report	
Arsenic (As)	75.1	mg/kg	ICP-MS Analysis - FULL Report	
Barium (Ba)	10.1	mg/kg	ICP-MS Analysis - FULL Report	
Beryllium (Be)	0.5	mg/kg	ICP-MS Analysis - FULL Report	

Sample ID: PS2015-2576X003 **Sample Name:** SR-LA-T3

Determination	Result	Units	Method Used	Uncertainty
Bismuth (Bi)	0.8	mg/kg	ICP-MS Analysis - FULL Report	
Boron (B)	0.6	mg/kg	ICP-MS Analysis - FULL Report	
Cadmium (Cd)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Chromium (Cr)	113	mg/kg	ICP-MS Analysis - FULL Report	
Cobalt (Co)	9.4	mg/kg	ICP-MS Analysis - FULL Report	
Copper (Cu)	11.4	mg/kg	ICP-MS Analysis - FULL Report	
Gold (Au)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Indium (In)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Iridium (Ir)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Lanthanum (La)	18.8	mg/kg	ICP-MS Analysis - FULL Report	
Lead (Pb)	39.8	mg/kg	ICP-MS Analysis - FULL Report	
Lithium (Li)	5.6	mg/kg	ICP-MS Analysis - FULL Report	
Manganese (Mn)	170	mg/kg	ICP-MS Analysis - FULL Report	
Mercury (Hg)	1.3	mg/kg	ICP-MS Analysis - FULL Report	
Molybdenum (Mo)	2.1	mg/kg	ICP-MS Analysis - FULL Report	
Nickel (Ni)	31.7	mg/kg	ICP-MS Analysis - FULL Report	
Palladium (Pd)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Phosphorus (P)	187	mg/kg	ICP-MS Analysis - FULL Report	
Platinum (Pt)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Rhodium (Rh)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Ruthenium (Ru)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Selenium (Se)	0.3	mg/kg	ICP-MS Analysis - FULL Report	
Silver (Ag)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Strontium (Sr)	15.4	mg/kg	ICP-MS Analysis - FULL Report	
Tellurium (Te)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	

Test Report

Sample ID: PS2015-2576X003 **Sample Name:** SR-LA-T3

Determination	Result	Units	Method Used	Uncertainty
Thallium (Tl)	<0.1	mg/kg	ICP-MS Analysis - FULL Report	
Thorium (Th)	3.3	mg/kg	ICP-MS Analysis - FULL Report	
Tin (Sn)	1.0	mg/kg	ICP-MS Analysis - FULL Report	
Titanium (Ti)	385	mg/kg	ICP-MS Analysis - FULL Report	
Uranium (U)	2.4	mg/kg	ICP-MS Analysis - FULL Report	
Vanadium (V)	16.4	mg/kg	ICP-MS Analysis - FULL Report	
Zinc (Zn)	30.2	mg/kg	ICP-MS Analysis - FULL Report	
Zirconium (Zr)	20.5	mg/kg	ICP-MS Analysis - FULL Report	
Aluminium (Al)	10874	mg/kg	ICP-OES Analysis - FULL Report	
Calcium (Ca)	564	mg/kg	ICP-OES Analysis - FULL Report	
Iron (Fe)	17895	mg/kg	ICP-OES Analysis - FULL Report	
Magnesium (Mg)	3444	mg/kg	ICP-OES Analysis - FULL Report	
Silicon (Si)	1287	mg/kg	ICP-OES Analysis - FULL Report	
Sulphur (S)	844	mg/kg	ICP-OES Analysis - FULL Report	

End of Report

8.0 APPENDIX B: DOSE CONVERSION FACTORS

Age-independent dose conversion factors for external exposure:

Radionuclide	Nuclide-specific External DCF (Sv/h per Bq/g)
U-238+	3.6E-07
U-234	1.2E-11
Th-230	3.7E-11
Ra-226+	3.5E-07
Pb-210+	1.9E-10
Po-210	1.6E-12
U-235+	2.3E-08
Pa-231	5.9E-09
Ac-227+	5.1E-08
Ra-223	1.9E-08
Th-232	1.6E-11
Ra-228+	1.8E-07
Th-228	2.4E-10
Ra-224+	7.7E-07

Inhalation dose conversion factors for all age groups:

Radio nuclide	Adult Nuclide-specific (Sv/Bq)	15 Year Nuclide-specific (Sv/Bq)	10 Year Nuclide-specific (Sv/Bq)	5 Year Nuclide-specific (Sv/Bq)	1 Year Nuclide-specific (Sv/Bq)
U-238+	8.0E-06	8.7E-06	1.0E-05	1.6E-05	2.5E-05
U-234	9.4E-06	1.0E-05	1.2E-05	1.9E-05	2.9E-05
Th-230	1.4E-05	1.5E-05	1.6E-05	2.4E-05	3.5E-05
Ra-226+	9.5E-06	1.0E-05	1.2E-05	1.9E-05	2.9E-05
Pb-210+	5.7E-06	6.0E-06	7.3E-06	1.1E-05	1.8E-05
Po-210	4.3E-06	5.1E-06	5.9E-06	8.6E-06	1.4E-05
U-235+	8.5E-06	9.2E-06	1.1E-05	1.7E-05	2.6E-05
Pa-231	3.4E-05	3.6E-05	3.9E-05	5.2E-05	6.9E-05
Ac-227+	8.2E-05	8.9E-05	1.0E-04	1.5E-04	2.3E-04
Ra-223	8.7E-06	1.1E-05	1.1E-05	1.5E-05	2.4E-05
Th-232	2.5E-05	2.5E-05	2.6E-05	3.7E-05	5.0E-05
Ra-228+	1.6E-05	1.6E-05	2.0E-05	3.2E-05	4.8E-05
Th-228	4.0E-05	4.7E-05	5.5E-05	8.2E-05	1.3E-04
Ra-224+	3.6E-06	4.5E-06	4.7E-06	6.3E-06	9.8E-06