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Radiological Public Dose Assessment for the SEIA: Proposed Mining of the Z20 Uranium Deposit – Infrastructure Corridor Across the Khan River

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Prepared by: Dawid de Villiers, PhD (Pr.Sci.Nat.)

Nuclear Liabilities Management Division
NURAD
Necsa
P.O. Box 582
Pretoria

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AUTHORIZATION

	NAME	SIGNED	DATE
PREPARED	D de Villiers	[signature]	05/11/2012
REVIEWED	GP de Beer	[signature]	05/11/2012
APPROVED	G R Liebenberg	[signature]	05/11/2012
ACCEPTED			

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LIST OF ACRONYMS AND ABBREVIATIONS

ALARA	As Low as Reasonably Achievable
BEIR	Biologic Effects of Ionising Radiation Committee
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiation Protection
I&AP	Interested and Affected Party
MDA	Minimum Detectable Activity
NECSA	South African Nuclear Energy Corporation Limited
NNR	National Nuclear Regulator
NORM	Naturally Occurring Radioactive Material
PM_{10}	Inhalable particulate matter less than 10 microns in size
SEA	Strategic Environmental Assessment
SEIA	Social and Environmental Impact Assessment
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
$Bq.g^{-1}$	Becquerel per gram
$Bq.kg^{-1}$	Becquerel per kilogram
$Bq.m^{-2}$	Becquerel per square meter
$d.kg^{-1}$	Day per kilogram
$d.L^{-1}$	Day per litre
$h.a^{-1}$	Hours per annum (year)
$L.kg^{-1}$	Litre per kilogram
$mSv.a^{-1}$	milliSievert per year
ppm	parts per million
$Sv.h^{-1}$	Sievert per hour
$Sv.Bq^{-1}$	Sievert per Becquerel
$\mu Sv.a^{-1}$	Microsievert per annum (year)

GLOSSARY

"critical group" means a group of members of the public which are reasonably homogeneous with respect to their exposure with relation to a given radiation source and given exposure pathway and are typical of persons receiving the highest effective dose or equivalent dose (as applicable) by the given exposure pathway from the given source;

"pathway" means a route by which radiation may enter the human body**;**

"radionuclide" is a unstable atom that emits energy or particles (i.e. ionising radiation) after its disintegrates;

"secular equilibrium" is the situation where a daughter radionuclide's activity concentration is the same as that of the parent radionuclide;

"source" means anything that may cause radiation exposure by emitting ionising radiation or releasing radioactive substances or materials, or in any other manner;

SUMMARY

Aurecon Namibia (Pty) Ltd and SLR Consulting Namibia (Pty) Ltd are presently conducting a Social and Environmental Impact Assessment for the proposed creation of an infrastructure corridor and the mining and processing of the Z20 uranium deposit located within the mining licence of Rössing Uranium Ltd.

This Radiological Public Dose Assessment focuses on the radiological impact to members of the public as a result of the construction and operations of the infrastructure corridor. International developments on the radiological impact to non-human species are still in its infancy and were not considered. The assessment also did not consider the occupational exposure of workers as such exposures will be controlled through the existing occupational Radiation Protection Programme at Rössing Uranium Limited.

The main focus of the assessment was the calculation of the inhalation doses from dust and doses from dust deposition for adult members of the public. This was accomplished by using the so-called source-pathway-receptor analysis method in conjunction with the gravimetric concentrations obtained from the air quality study conducted for the infrastructure corridor and the assumed radionuclide concentrations of the ore. The water pathway related to the infrastructure corridor (i.e. surface water and groundwater) was not included as it was not expected to be a radiological concern.

The outcome of this public dose assessment indicated that, for the identified critical groups as per the defined Exposure Scenarios, the doses received from the relevant sources of exposure during the proposed construction and operation of the infrastructure corridor are trivial to low i.e. resulting in doses that are lower than the dose constraint of 300 $\mu Sv.a^{-1}$, even when assumed uncertainties are added to the dose.

Mitigation options, as described by the air quality study (Liebenberg-Enslin 2012) will reduce the mentioned doses but not by an ample amount, thus the SEIA impact significance rating will not change.

No measures, except the application of ALARA principles, are therefore recommended to safeguard the critical groups from unmitigated or mitigated dust deposition or dust inhalation considering the proposed construction and operations of the infrastructure corridor.

There seems to be no significant difference between the impacts of the current baseline operations and the cumulative impacts where the infrastructure corridor operations are added to the baseline operations. Since the impact significance is low for both instances it implies that the No-Go option is not dependent on the outcome of this radiological assessment, but rather on other specialist studies and project considerations if relevant.

The SEIA impact significance relating to the construction and operations of the infrastructure corridor is therefore **Very Low (-)** for both unmitigated and mitigated operations.

1.0 INTRODUCTION

1.1 GENERAL

The present Minerals Act of Namibia (Republic of Namibia, 1992: Part VII) requires that the holder of a mineral licence shall estimate the effect of a proposed mining operation on the environment as well as the proposed steps to be taken to minimize or prevent these effects. As such Aurecon Namibia (Pty) Ltd and SLR Consulting Namibia (Pty) Ltd are presently conducting a Social and Environmental Impact Assessment (SEIA) for the proposed creation of an infrastructure corridor and the mining and processing of the Z20 uranium deposit (Aurecon 2012) located within the mining licence of Rössing Uranium Ltd.

Since the proposed mining activities will involve the handling and mining of Naturally Occurring Radioactive Material (NORM), Necsa has been contracted to perform a Radiological Public Dose Assessment as a specialist input to this SEIA. This mainly addresses the radiological impact of the construction and operation of the infrastructure corridor to members of the public that may be exposed to the various radiation sources. International developments on the radiological impact to non-human species are still in its infancy with reference animals and plants not yet specific to the desert environment. For this reason non-human species will not be considered. The assessment will also not consider the occupational exposure of workers as such exposures will be controlled through the existing occupational Radiation Protection Programme at Rössing Uranium Limited.

In this document the detail and results of the radiological public dose assessment, as related to the infrastructure corridor across the Khan River, are presented.

1.2 INTERESTED AND AFFECTED PARTY CONCERNS

The potential dispersion of radioactive dust and the resulting radiation exposure are addressed in this report. Other concerns from the public relating to radiation are listed in Table 1. The table also include comments and the sections of this document where these concerns are addressed.

Table 1: A summary of the Interested & Affected Parties concerns related to Radiation

Issue Raised	Comment & Section of Report where it is Addressed
Swakop Uranium, letter dated 30 October 2012	
Public exposure to radiation. Are baseline public exposure pathways to radioactivity to be undertaken over a full year as is best practice?	Yes, that is the focus of this report – Section 7.4
Dust from conveyor: What are the public health risks, potential damage to vegetation?	The public health risks are addressed in Sections 2.3 and 7.6.4. Potential damage to vegetation is not addressed as mentioned in Section 1.1
Dust from conveyor: Is there a way in which this dust fall-out could be cleaned up effectively?	Dust fallout needs to be measured (as recommended by the air quality assessment) and the dose assessed. This will determine if clean-up is necessary and which method can be recommended.
Dust from conveyor: Transportation of radioactive dust downstream in rain/flood events?	It is not expected to be a radiological concern - discussed in Section 2.2
Bertchen Kohrs, Earthlife Namibia, letter dated 30 October 2012	
The origin of U-238 contamination and issues with Ra-226 contamination	This will be addressed in the report for the Z20 mining and processing
Bernd Seafeldt, letter dated 31 October 2012	
“cancer and fatal cases due to ionising radiation in the region increase”	Radiation alone cannot be blamed for the increase in cancer, it is just one of many factors that can contribute – Section 2.3

2.0 APPROACH TO THE STUDY

2.1 OUTLINE OF THE TERMS OF REFERENCE

The public dose assessment will be based on the following Terms of Reference:

- Provide a brief description of the relevant legal framework with reference to national legislation, conventions and guidelines,
- Identify and quantify the radiological sources associated with the infrastructure corridor,
- Assess the cumulative public exposure radiological impacts for all relevant pathways to the potential critical group and other receptors,
- Determine whether handling of the ore using the infrastructure corridor will increase public exposure of the relevant critical groups to above 300 $\mu Sv.a^{-1}$ (refer to Section 3.1 for explanation),
- Provide input, together with Aurecon, other specialists and mine management, into the management measures going forward.

2.2 METHODOLOGY

The assessment is performed within a framework of radiation protection and waste management principles and of regulatory requirements. By nature the process of prospectively assessing radiological risks is an uncertain process since one is trying to predict future conditions, mainly through modelling exercises, using available data. For this reason a so-called source-pathway-receptor analysis was followed to formulate an exposure scenario.

In this analysis the sources of radioactivity were related to the amount of radioactivity to which members of the public are exposed through external and internal exposure. The dust and radon sources applicable to the infrastructure corridor operations together with metrological data, the gravimetric dust concentrations from the air quality study (Liebenberg-Enslin 2012) and the assumed radionuclide concentrations were used in this regard. The manner in which exposure to the radiation could take place determined the pathways that were investigated, e.g. inhalation or direct exposure. Mathematical models were then used to quantify the exposure in terms of a radiation dose and through the air dispersion modelling related to the position of critical groups. The critical groups were identified beforehand based on their location in respect of the infrastructure corridor operations. Exposure periods for the critical groups were assumed based on their expected human actions, behaviours and habits. Furthermore, the exposure scenarios consider only normal non-disruptive conditions.

The main focus of the assessment was the calculation of the inhalation doses for adult members (resulting in the most conservative doses) of the public from dust and radon and external exposure as a result of dust deposition. The water pathway (i.e. surface water and groundwater) was not included as it was not expected to be a radiological concern. The reason being the following: deposited dust may fall out onto the dry Khan River bed and a fraction thereof may be transported in the event of rain or a flood. However, the dust would not become soluble and as a result settles out in the river sediments. The dust is therefore not present in the surface water nor can it reach the ground water in this form. The same applies to contaminated material that may fall from the conveyor into the Khan River. Nevertheless, the risk for this to happen is very low (Church 2012: 7).

2.3 Radiological Risk

Exposure to radiation may damage or kill living cells depending on the dose received. The effects may therefore vary from nothing to death. In general two types of effects are observed in the human body. The first is chance effects and are those effects that only have a possibility of appearing in the body due to cell changes. Examples of chance effects are cancer and hereditary abnormalities or diseases[1]. The second are threshold effects that are only observed when one receives more than a threshold dose. Dose limits (discussed in Section 4.2) are set to ensure that the increase in the possibility i.e. risk of a chance effect is acceptable[2] and to prevent anyone from suffering any threshold effect.

The possibility of contracting a fatal cancer has been estimated by the International Commission on Radiation Protection (ICRP) by relying mainly on studies of the Japanese survivors of the atomic bombs and assessments by committees such as United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and Biologic Effects of Ionising Radiation Committee (BEIR). In its latest publication the ICRP presents these

[1]These diseases occur naturally among people and have many other causes besides radiation.
[2]In this sense radiation is no different from other hazards, it means that when the calculated risk from a radiation dose is the same as the risks one routinely takes and considers acceptable, then the radiation dose is also acceptable.

estimations as age-independent risk coefficients (ICRP 2007: 53) to express the possibility of contracting a fatal cancer and the possibility of heritable effects. These coefficients will be used in Section 7.6.4 to determine the risk from the highest calculated dose.

3.0 ASSUMPTIONS AND LIMITATIONS

Interpretation of this dose assessment is based on the following assumptions and limitations:

- The information used in this assessment was provided by other specialists or Rössing personnel. The assumption is made that this information is correct and accurate.
- At present only the average ore grade of the Z20 uranium deposit is known. In the absence of radionuclide analysis it was assumed that the state of secular equilibrium prevails in the ore. This results in very conservative activity concentrations of the various radionuclides in the ore translating to very conservative dose estimations.
- The assessment will not consider occupational exposure to workers or the radiological impact to non-human species.
- Assessment of the surface water pathway will not be performed as dust is insoluble and will settle in the river sediments instead of surface- or groundwater (refer to Section 2.2).

4.0 LEGISLATIVE CONTEXT

4.1 REGULATORY FRAMEWORK

Radiological protection standards are criteria set to ensure compliance with the basic principles of radiation safety as set out in ICRP (2007) and International Atomic Energy Agency (IAEA 1996) publications. The National Radiation Protection Authority of Namibia adopted these principles and promulgated the Radiation Protection and Waste Disposal Regulations (Republic of Namibia 2011) after the Atomic Energy and Radiation Protection Act (Act No. 5 of 2005). The aim of this regulatory framework is to ensure the protection of workers and individual members of the public and their surrounding environment. As such, dose limits and dose constraints (some fraction of the dose limit) and other appropriate criteria are defined.

4.2 Relevant Dose Limits

The individual dose limit places an upper limit to the dose from all controllable radiation sources (this excludes medical exposures and natural background sources) to which an individual may be exposed. In assessing the performance with respect to this indicator, all pathways from all the radioactive material or radiation from all practices (excluding medical exposures and natural sources) to the individual must be considered. The dose limit for members of the public is set at a 1000 µSv.a^{-1} (or 1 mSv.a^{-1}) (Republic of Namibia 2011: 53). Since the application of dose limits to a single authorised practice has some intrinsic difficulties, a source-related dose constraint is applied for a single authorised practice. A value of 300 µSv.a^{-1} is for instance recommended as a constraint for the management of waste from uranium mining (IAEA 2002: 11). This constraint will also serve as a radiological criterion for the present assessment.

5.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

The following are brief descriptions; with more detail presented in the Scoping Report (Aurecon 2012) or the air quality specialist study (Liebenberg-Enslin 2012: 1).

5.1 Project Description

Currently Rössing Uranium Mine's operational activities are focused to the north of the Khan River. These include the open pit mining, ore processing, waste rock and tailings disposal and additional activities. Rössing Uranium is now considering (Aurecon 2012) mining the Z20 ore body located to the south of the Khan River (refer to Figure 1) where Rossing's mining license area ML28 and the Namib Naukluft Park overlap. The expansion of the operations of Rössing Uranium Mine is part of the general "uranium rush" observed in the Erongo Region of Namibia with Langer Heinrich Uranium Mine nearby and more mines to follow e.g. Swakop Uranium.(Husab Mine).

In order to access the Z20 ore body consideration has been given to the need for an establishment of an infrastructure corridor, as well as infrastructure to allow for the transport of crushed ore to the existing Rössing Uranium facilities. The proposed infrastructure corridor will house an overland conveyor, road and other services e.g. power line and water supply pipeline. These will be accommodated as presented in Figure 1.

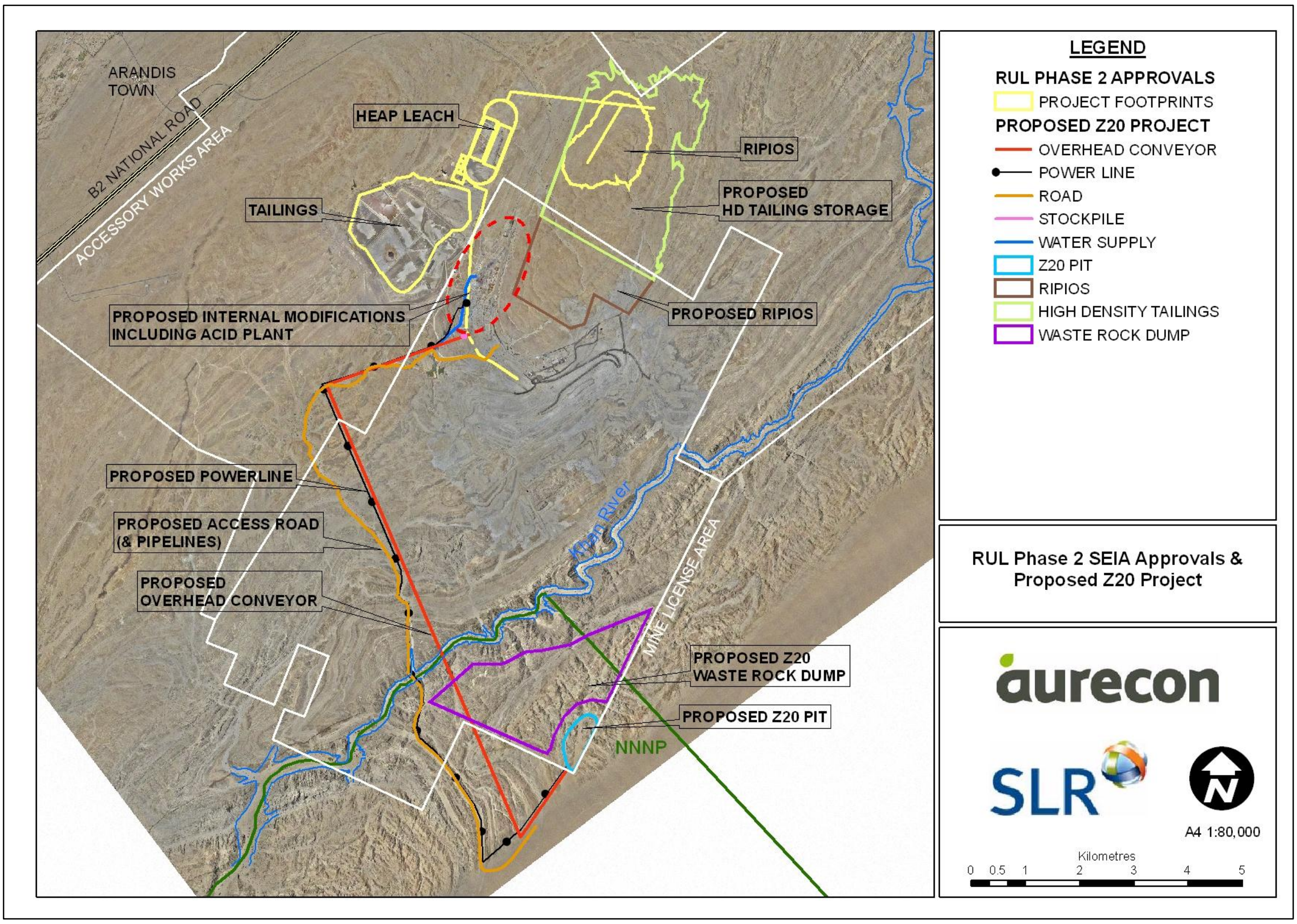

Figure 1: Rössing Uranium Mine in relation to the Z20 ore deposit and the proposed infrastructure corridor

5.2 Possible Impacts to the Environment

The activities associated with the construction and operation of the infrastructure corridor will increase dust loads around the mentioned area. An impact can therefore be expected as a result of the inhalation of the dust or from external exposure as a result of dust deposition. Since the ore contains enhanced levels of radium-226, an impact as a result of radon inhalation is also expected. The incremental doses from these actions will be derived from the atmospheric emissions from the various dust and radon sources.

No surface water impact is expected (as discussed in Section 2.2).

5.3 BACKGROUND CONDITIONS

The Rössing Uranium mine is situated in an area of elevated levels of natural radioactivity. For example, the background radon doses are normally in the low $mSv.a^{-1}$ range (De Beer et.al. 2002: 66). It is therefore expected that the total background dose is higher than the worldwide average of 2.4 $mSv.a^{-1}$ (UNSCEAR 2010: 5).

The present assessment was based on modelled dispersion results from sources associated with the infrastructure corridor operations. This represents a conservative estimate of the additional radiation doses above the background and *baseline*. No background corrections are therefore needed since the background was not included in the modelling.

6.0 DESCRIPTION OF THE ALTERNATIVES

This assessment is based on the atmospheric emissions described in the air quality specialist study. Any engineering change to the infrastructure corridor (e.g. different type of road surface) will impact on the dust generation and hence on the radiation dose. It is therefore obvious that one can generally say that the lower the dust emissions, the lower the dose to the public. Hence the only alternative that was investigated was that of mitigation of dust as described in the air quality study. The mitigation options include two side covers and a roof at the conveyor as well as enclosures at the transfer points (Liebenberg-Enslin 2012: 59). If the dose constraint is exceeded then additional mitigation options will be provided and their impact assessed.

If the proposed construction of the infrastructure corridor does not go ahead (the No-Go option) then the *status quo* in respect of exposure at Rössing Uranium will remain in terms of their contribution to the public dose. No increment in radiation dose or cancer risk will occur.

7.0 DOSE ASSESSMENT

7.1 GENERAL

This section involves the deterministic assessment of the radiological dose based on a source-pathway-receptor analysis. It includes brief overviews of each aspect of the analysis, the mathematical models needed to derive the dose and the resulting dose results.

7.2 SOURCES OF RADIOACTIVITY

7.2.1 Dust Sources

The current operations of Rössing are used as the *baseline* against which the construction and operation of the infrastructure corridor will be evaluated. The dust sources for the current operations are described in the previous public radiological assessment (De Villiers 2011: 26) and summarised as follows:

- Fugitive dust emissions from
  - materials handling operations,
  - wind erosion,
  - vehicle entrainment,
  - dozers and graders,
  - drilling and blasting,
  - loading operations and
  - fine crushing plant
- Emissions from stacks

Gravimetric concentrations for dust sources as related to the infrastructure corridor construction and operations have been calculated for the following mitigated and unmitigated source groupings and sub-groupings (Liebenberg-Enslin 2012: 39):

- Fugitive dust emissions from the Construction:
  - Clearing of the groundcover
  - Levelling and grading of the surface
  - Wind erosion from exposed areas
  - Asphalt processes
  - Vehicle and construction equipment activity

- Fugitive dust emissions from the Ore Transport:
    - Wind-blown dust from the conveyor
    - Dust generation from tipping
    - Vehicle activity on the access road

7.2.2 Radon Sources

Materials containing enhanced levels of radium-226 are sources for radon exhalation. For the *baseline* these include the materials found on the tailings dam, waste rock piles and ore stockpiles (as described in the previous public radiological assessment (De Villiers 2011: 26)).

The main source of radon for the infrastructure corridor operations is the ore transported via the conveyor.

7.3 RADIONUCLIDE CONCENTRATIONS

The radionuclides giving rise to the radiological hazards associated with the Rössing operations are the uranium-238 (^{238}U), uranium-235 (^{235}U) and thorium-232 (^{232}Th) decay series. Not all the radionuclides in these series are of importance[3] as only a selection of them contributes significantly to the total dose a person receives. This selection is:

- Long-lived alpha (α) emitters: ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Po, ^{231}Pa, ^{227}Ac, ^{223}Ra, ^{232}Th, ^{228}Th, ^{224}Ra,
- Beta (β) emitters: ^{210}Pb, ^{228}Ra and
- ^{222}Rn and ^{220}Rn (and their short-lived daughters)

The radionuclide concentrations of the above mentioned radionuclides (tabulated in Table 2) were deduced from the expected Z20 uranium ore grade of 450 ppm U_3O_8, that is 382 ppm U or 4.7 Bq/g ^{238}U and the assumption of secular equilibrium. It was further assumed that the ratio of uranium activity concentration to the thorium activity concentration is the same as the ore in the previous assessment i.e. 4.9 (De Villiers 2011: 25).

Radionuclide concentrations of the ore in the open pit, as presented in the previous assessment (De Villiers 2011: 25), were used for the *baseline*.

[3] This is due to a very small (compared to the other radionuclides) dose conversion coefficient.

Table 2: Assumed radionuclide concentrations of the Z20 Ore Deposit and *Baseline* ore

Radionuclide	Activity Concentration ($Bq.g^{-1}$)	
	Z20 Ore Deposit	Ore in the open pit, for use in the *Baseline*
^{238}U	4.7	3.6
^{234}U		
^{230}Th		
^{226}Ra		
^{210}Pb		
^{210}Po		
^{235}U	0.22	0.17
^{231}Pa		
^{227}Ac		
^{223}Ra		
^{232}Th	0.32	0.74
^{228}Ra		
^{228}Th		
^{224}Ra		

7.4 ATMOSPHERIC PATHWAY

Meteorological and mechanical processes (e.g. wind speed, wind direction and dispersion) cause dust to be transported from the fugitive sources to the receptors. Details on this environmental transfer via the atmosphere are discussed by Liebenberg-Enslin (2012) and will not be repeated here. The atmospheric pathway will mainly consider external exposure due to the deposition of dust, inhalation of dust and inhalation of radon.

7.4.1 External Exposure (direct radiation due to gamma rays) Pathway

External exposure occurs when soil is contaminated either through the deposition of airborne radioactivity (in the form of dust) or through the irrigation of soil with contaminated water. 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 coefficients.

For the infrastructure corridor operations a dust fallout rate from all fugitive dust sources was determined through dispersion modelling (Liebenberg-Enslin 2012). The modelled deposited dust concentrations were converted to deposited dust nuclide concentrations by multiplying the gravimetric concentrations with each radionuclide concentration (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 using the following mathematical model:

$$D_{ext} = 1x10^3 . Conc_{dust} . DC_{ext} . (EP_o + EP_{I.}SF) \quad \text{Eq. 1}$$

where

D_{ext}	=	Dose from external exposure	[μSv.a^{-1}]
$Conc_{dust}$	=	Dust activity concentration	[mBq.m^{-2}]
DC_{ext}	=	Dose coefficient for external exposure	[Sv.h^{-1} per Bq.m^{-2}]
EP_O	=	Annual outdoor exposure period	[h.a^{-1}]
EP_I	=	Annual indoor exposure period	[h.a^{-1}]
SF	=	Indoor shielding factor (taken as 1)	[-]

Dose coefficients for external exposure were taken from (Eckerman and Ryman 1993: 58) and are presented in Appendix A (Section 12).

7.4.2 Dust Inhalation Pathway

Dust from the infrastructure corridor operations can be inhaled and as a result people are exposed to the radioactivity within the dust. For the infrastructure corridor operations PM_{10} dust concentrations from all fugitive dust sources were determined through dispersion modelling (Liebenberg-Enslin 2012). The modelled dust concentrations were converted to airborne dust nuclide concentrations by multiplying the gravimetric concentrations with each radionuclide concentration (Table 2). The annual dose from the exposure to inhaled airborne radioactive dust is calculated from estimated outdoor dust nuclide concentrations by multiplication with appropriate dose coefficients, exposure periods, summation over all nuclides and the following assumptions: Since no indoor modelling was performed it is assumed that the indoor and outdoor dust concentrations are equal and that the indoor conditions do not provide any shielding. The average breathing rate for adults was assumed to be 0.93 m^{3}.h^{-1} for a 24 hour per day exposure period (which includes eight hours of sleep) or 1.20 $m^3.h^{-1}$ for an 8 hour per working day exposure period (ICRP 1995: 11). Dose coefficients for dust inhalation were taken from ICRP (1995: 37) and are presented in Appendix A (Section 12).

The calculation of the dust inhalation dose from each radionuclide is mathematically expressed by:

$$D_{inh,Dust} = Conc_{Dust}.DC_{inh}.(T_o + SF.T_i).BR \qquad \text{Eq. 2}$$

where

$D_{inh,Dust}$	=	Inhalation dose from radioactive airborne dust	[$\mu Sv.a^{-1}$]
$Conc_{Dust}$	=	Radionuclide activity concentration in airborne dust	[$\mu Bq.m^{-3}$]
DC_{inh}	=	Radionuclide-specific dose coefficient for dust inhalation	[$Sv.Bq^{-1}$]
T_o	=	Annual outdoor exposure period	[$h.a^{-1}$]
T_i	=	Annual indoor exposure period	[$h.a^{-1}$]
SF	=	Indoor shielding factor (taken as 1.0)	[-]
BR	=	Breathing rate for adult member of the group	[$m^3.h^{-1}$]

7.4.3 Radon Inhalation Pathway

The radon exhalation rate from the ore on the overland conveyer can be calculated by assuming a flat surface of ore material with a uniform density and ^{226}Ra concentration of 4.7 $Bq.g^{-1}$ (Table 2) by the mathematical expression (IAEA 1992):

$$F = C.\rho.E.\sqrt{\lambda.D_t} \qquad \text{Eq. 3}$$

where

F_t	=	Radon exhalation rate	[$Bq.m^{-2}.s^{-1}$]
C	=	^{226}Ra concentration	[$Bq.g^{-1}$]
ρ	=	Bulk density (assumed to be 1500 $kg.m^{-3}$)	[$kg.m^{-3}$]
E	=	Emanation coefficient of tailings (assumed to be 0.2)	[-]
λ	=	Decay constant of ^{222}Rn (2.06 x 10^{-6} s^{-1})	[s^{-1}]
D_t	=	Diffusion coefficient of tailings (assumed to be 1.0 x 10^{-6} $m^2.s^{-1}$)	[$m^2.s^{-1}$]

The total radon source term (1.5 x 10^5 $Bq.s^{-1}$) is obtained by multiplying the radon exhalation (2 $Bq.m^{-2}.s^{-1}$) by the total surface area of the conveyor (6 m x 12 550 m = 75 300 m^2 (Liebenberg-Enslin 2012: 43)).

No radon dispersion modelling was performed. However, dividing the gravimetric dust concentrations of the unmitigated and mitigated operations by the total dust emission rate (Liebenberg-Enslin 2012: 43-45) a dispersion factor per grid point is obtained. By multiplying this dispersion factor with the total radon source term, an estimated radon concentration per grid point is obtained. Since the total dust emission rate for the *baseline* was not presented by Liebenberg-Enslin (2012), the same method could not be followed for the *baseline* operations. However, the Base Case radon inhalation doses, calculated for the previous assessment (De Villiers 2011: 44), were assumed for the critical groups.

The doses from the exposure to inhaled radon daughters were calculated from modelled 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 1993: 5 and UNSCEAR 1993: 73). The conversion factors for radon are age-independent and will be used as such. The mathematical model for the calculation of radon is expressed by:

$$D_{Radon} = 1000.(C_i.F_i.T_i + C_o.F_o.T_o).CC_{Rn}.DC_{Rn} \qquad \text{Eq. 4}$$

where

D_{Radon}	= Dose from radon exposure	[μSv.a^{-1}]
C_i	= Indoor radon concentration	[Bq.m^{-3}]
F_i	= Indoor equilibrium factor (0.4)	
T_i	= Indoor exposure period	[h.a^{-1}]
C_o	= Outdoor radon concentration	[Bq.m^{-3}]
F_o	= Outdoor equilibrium factor (0.8)	
T_o	= Outdoor exposure period	[h.a^{-1}]
CC_{Rn}	= Ratio of PAEC and EEC for radon	[mJ.m^{-3} per Bq.m^{-3}]
	= (5.6×10^{-6})	
DC_{Rn}	= Dose coefficient for radon exposure	[mSv.h^{-1} per mJ.m^{-3}]
	= (1.1 for the public and 1.4 for workers)	

7.5 Critical Groups and Exposure Scenarios

7.5.1 Critical Groups

The modelling domain of the air quality assessment accounts for six discrete receptor locations where members of the public could potentially be impacted by the operations of the infrastructure corridor. These include working and living activities at the Arandis Town, and Arandis Airport; working activities at Rössing's E-Camp and Husab Mine and recreational activities at the old Khan Mine site and the Khan River. These locations are depicted in Figure 2 (Liebenberg-Enslin 2012: 3).

The critical groups that are found at these receptor locations represent the highest doses that the public will receive as a result of the infrastructure corridor construction and operations. It is assumed that the critical groups consist of adults only. For the assessed atmospheric pathway this assumption generally relates to the most conservative dose[4]. Other parameters typical of the critical groups and their expected human actions, behaviour and habits that might have an influence on the assessment are also assumed and discussed in the next section.

7.5.2 Exposure Scenarios

7.5.2.1 Exposure Scenario 1: Working and Living Activities at Towns/Sites

Under this exposure scenario, it is assumed that a community lives and works in towns or sites that are located around the infrastructure corridor. These include Arandis Town, Arandis Airport and the old Khan Mine site (this is a tourist attraction, but there are security personnel that stay at the site). Residents may be exposed to dust emissions from the fugitive sources related to the infrastructure corridor operations, which may also deposit in the area. Since no occupation details are available, a conservative dose will be estimated by dividing the maximum annual exposure time equally between indoor and outdoor conditions (i.e. 4380 $h.a^{-1}$ indoors and 4380 $h.a^{-1}$ outdoors).

[4] Doses to other age groups can be interpolated through a correction factor based on the product of the breathing rate and the sum of the dose conversion factors from all the radionuclides for the different age groups. This results in a dose that ranges from 2% to 85% of the adult dose.

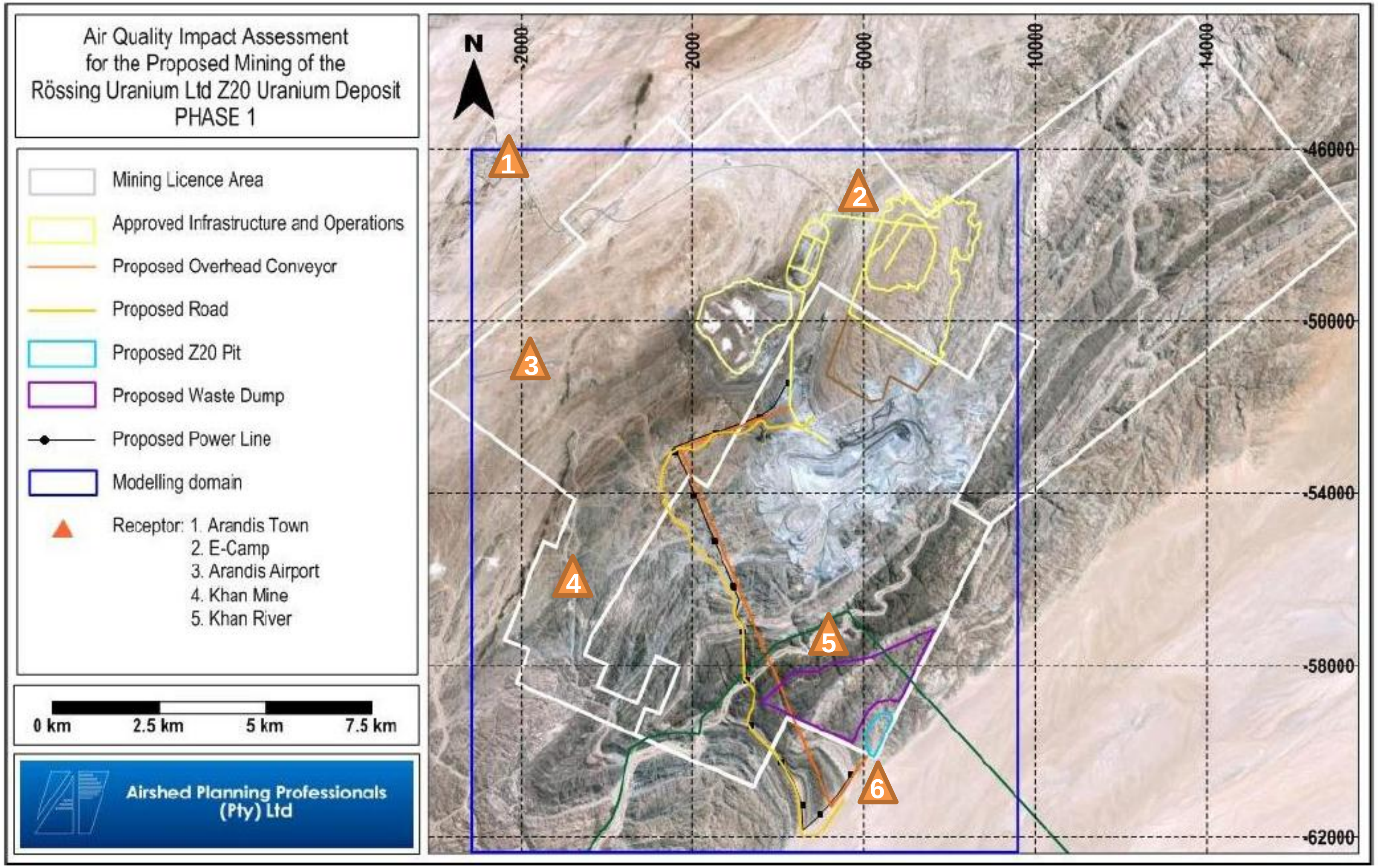

Figure 2: The modelling domain and the receptor locations included in the Radiological Assessment (Liebenberg-Enslin 2012: 3)

7.5.2.2 Exposure Scenario 2: Working Activities at Mine Sites

Exposure Scenario 2 includes workers at the office and visitor centre (E-Camp) of Rössing Mine and workers at the Husab Mine. This scenario is similar to Exposure Scenario 1, except that instead of living in the area, is it assumed that the adults work for an average of 2000 $h.a^{-1}$ outdoors at these sites.

7.5.2.3 Exposure Scenario 3: Recreational Activities at the Khan River

Exposure Scenario 3 include public that travel to the Khan River for recreational activities. This scenario is similar to Exposure Scenario 1, except that the adults are assumed to remain in the area for 4 days a year, i.e. 96 $h.a^{-1}$ outdoors.

7.6 Radiological Assessment Results

Radiation doses for the atmospheric pathway are presented below for the *baseline* and the infrastructure corridor operations.

7.6.1 External Exposure

The predicted dust fallout rates (Liebenberg-Enslin 2012: 36) and the respective calculated external exposure (due to gamma radiation) at each of the critical groups for the *baseline* operations are summarised in Table 3. Most of the doses are trivial (i.e. below 10 $\mu Sv.a^{-1}$), with the exception of the Khan Mine where the dose is a low 17 $\mu Sv.a^{-1}$.

Table 3: Predicted dust fallout and respective calculated external exposure at each of the critical groups for the *baseline* operations

Critical Group	Dust Fallout Rate ($mg.m^{-2}.day^{-1}$)	Period Outdoors ($h.a^{-1}$)	Period Indoors ($h.a^{-1}$)	Dose ($\mu Sv.a^{-1}$)
Arandis Town	13	4380	4380	1
E-Camp	75	2000	0	2
Arandis Airport	26	4380	4380	3
Khan Mine	170	4380	4380	17
Khan River	275	96	0	< 1
Husab Mine	6	2000	0	< 1

The calculated incremental external exposure at each of the critical groups for the infrastructure corridor operations are summarised in Table 4. All the doses are trivial (i.e. below 10 $\mu Sv.a^{-1}$) for both unmitigated and mitigated operations, with a maximum of 5 $\mu Sv.a^{-1}$ at the Khan Mine during unmitigated operations. Isopleth plots depicting the incremental[5] unmitigated and mitigated dust deposition doses for an adult exposed for 4380 hours outdoors and 4380 hours outdoors are presented in Figure 3 and Figure 4 respectively.

Table 4: Calculated incremental dust deposition doses at each of the critical groups for the unmitigated and mitigated infrastructure corridor operations

Critical Group	Period Outdoors ($h.a^{-1}$)	Period Indoors ($h.a^{-1}$)	Dose ($\mu Sv.a^{-1}$)	
			Unmitigated	Mitigated
Arandis Town	4380	4380	< 1	< 1
E-Camp	2000	0	< 1	< 1
Arandis Airport	4380	4380	1	< 1
Khan Mine	4380	4380	5	< 1
Khan River	96	0	< 1	< 1
Husab Mine	2000	0	1	< 1

For the construction phase similar dust fallout rates as those derived for the unmitigated operational phase are expected. (Liebenberg-Enslin 2012: 56). This implies that similar or lower doses than those mentioned in Table 4 are expected during the construction phase at the respective critical groups.

[5] Dust fallout concentrations were not available for the grid points other than the critical groups; hence a cumulative isopleth for the *baseline* could not be created. .

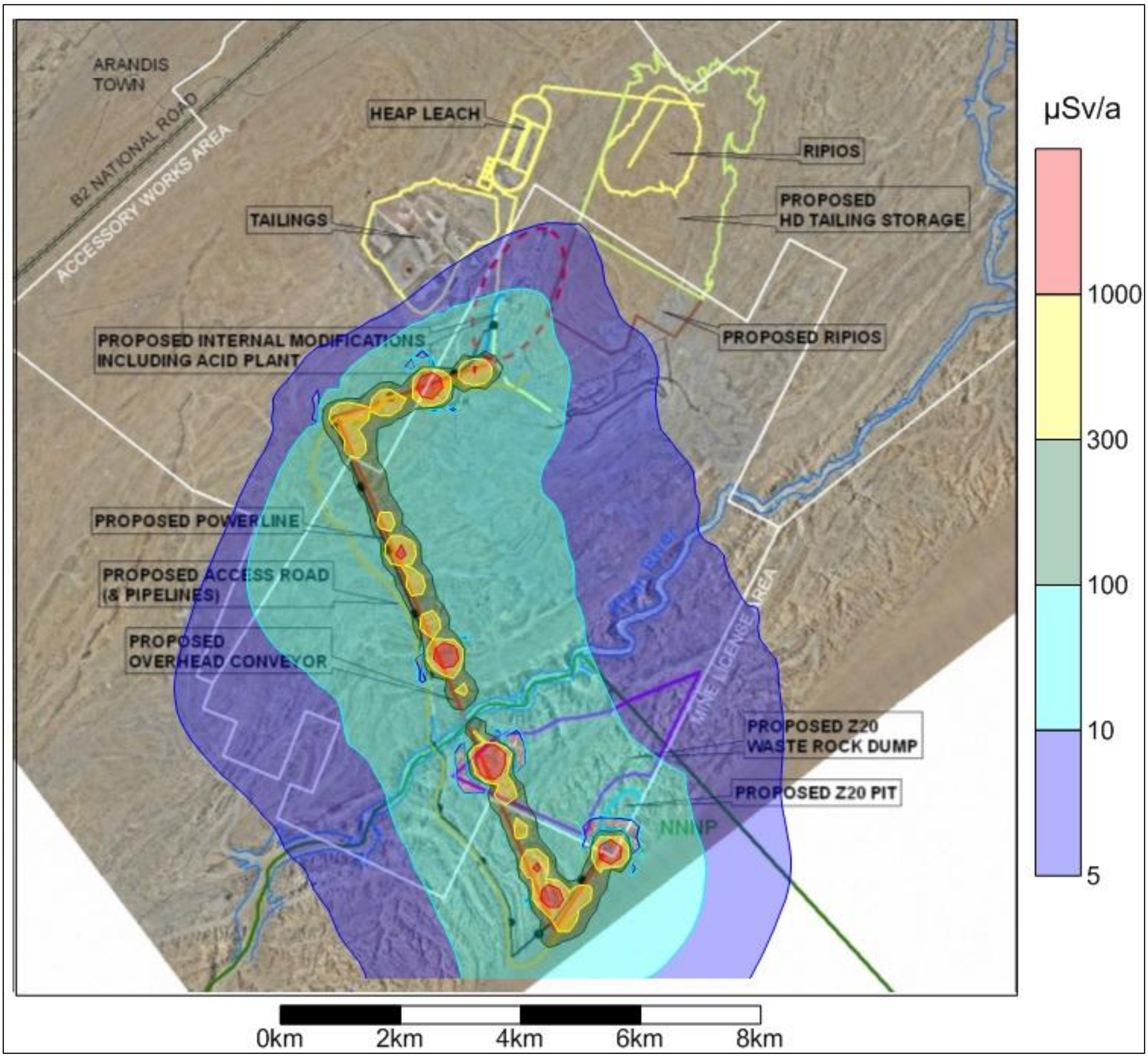

Figure 3: Calculated incremental external exposures (µSv.a^{-1}) from the unmitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors*.*

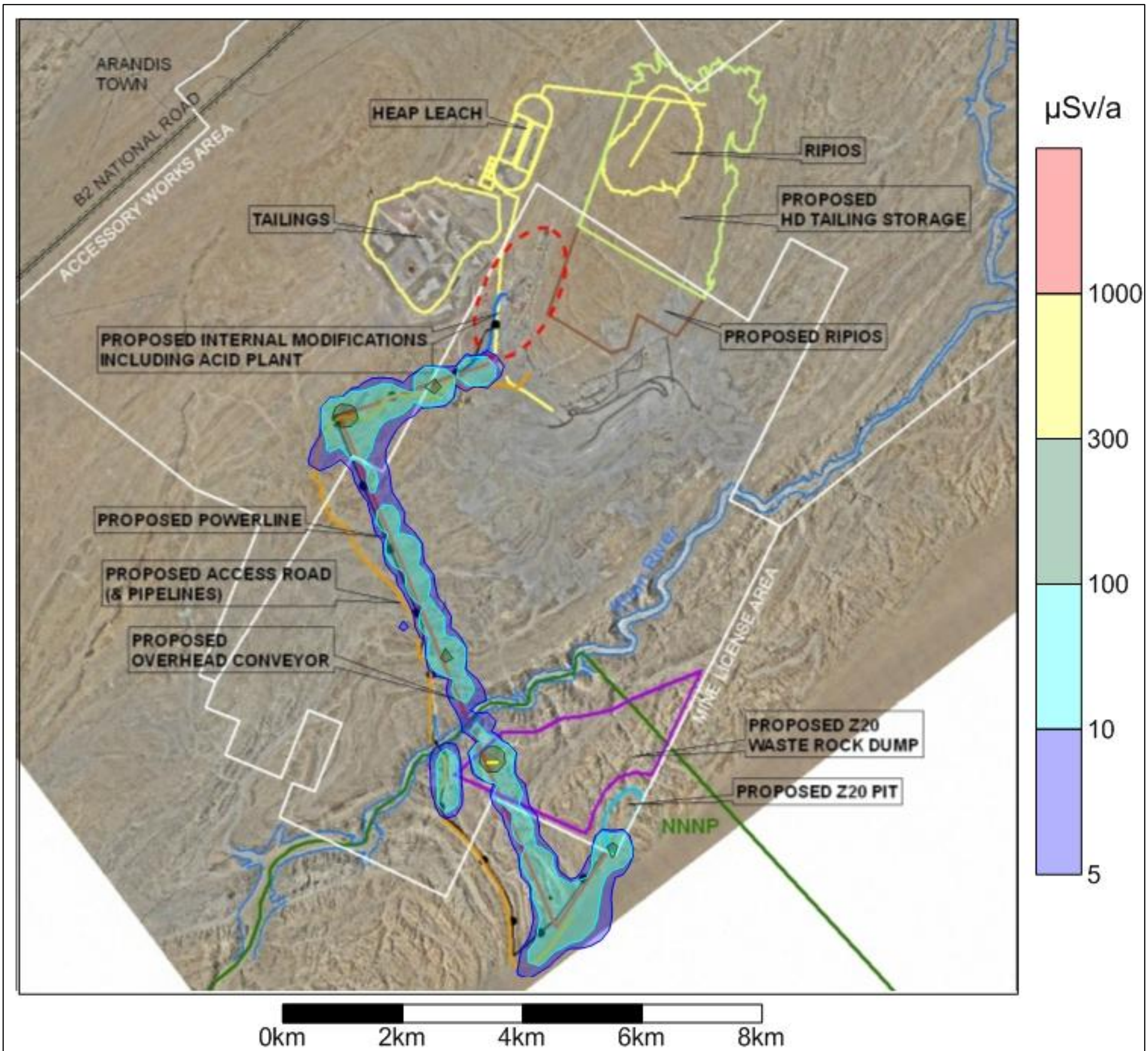

Figure 4: Calculated incremental external exposures (µSv.a^{-1}) from the mitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors.

7.6.2 Radiation Doses from Dust Inhalation

The predicted PM_{10} concentrations (Liebenberg-Enslin 2012: 36) and the respective calculated dust inhalation doses at each of the critical groups for the *baseline* operations are summarised in Table 5. Doses of four critical groups are trivial (i.e. below 10 µSv.a^{-1}), with the exception of Arandis Airport and the Khan Mine with dust inhalation doses of 17 µSv.a^{-1} and 43 µSv.a^{-1} respectively. An isopleth plot depicting the *baseline* dust inhalation doses for an adult exposed for 4380 hours outdoors and 4380 hours outdoors is presented in Figure 5.

Table 5: Predicted PM_{10} concentrations and respective calculated dust inhalation doses at each of the critical groups for the *baseline* operations

Critical Group	Annual Average PM_{10} (µg.m^{-3})	Period Outdoors (h.a^{-1})	Period Indoors (h.a^{-1})	Dose (µSv.a^{-1})
Arandis Town	3.40	4380	4380	7
E-Camp	4.41	2000	0	2
Arandis Airport	7.69	4380	4380	17
Khan Mine	20.1	4380	4380	43
Khan River	35.7	96	0	< 1
Husab Mine	4.55	2000	0	2

The calculated incremental dust inhalation doses at each of the critical groups for the infrastructure corridor operations are summarised in Table 6. All the doses are trivial (i.e. below 10 µSv.a^{-1}) for both unmitigated and mitigated conditions. Isopleth plots depicting the incremental unmitigated-, incremental mitigated-, cumulative unmitigated- and cumulative mitigated dust inhalation doses for an adult exposed for 4380 hours outdoors and 4380 hours outdoors are presented in Figure 6, Figure 7, Figure 8 and Figure 9 respectively.

For the construction phase similar dust concentrations as those derived for the unmitigated operational phase are expected. (Liebenberg-Enslin 2012: 56). This implies that similar or lower doses than those mentioned in Table 6 are expected during the construction phase at the respective critical groups.

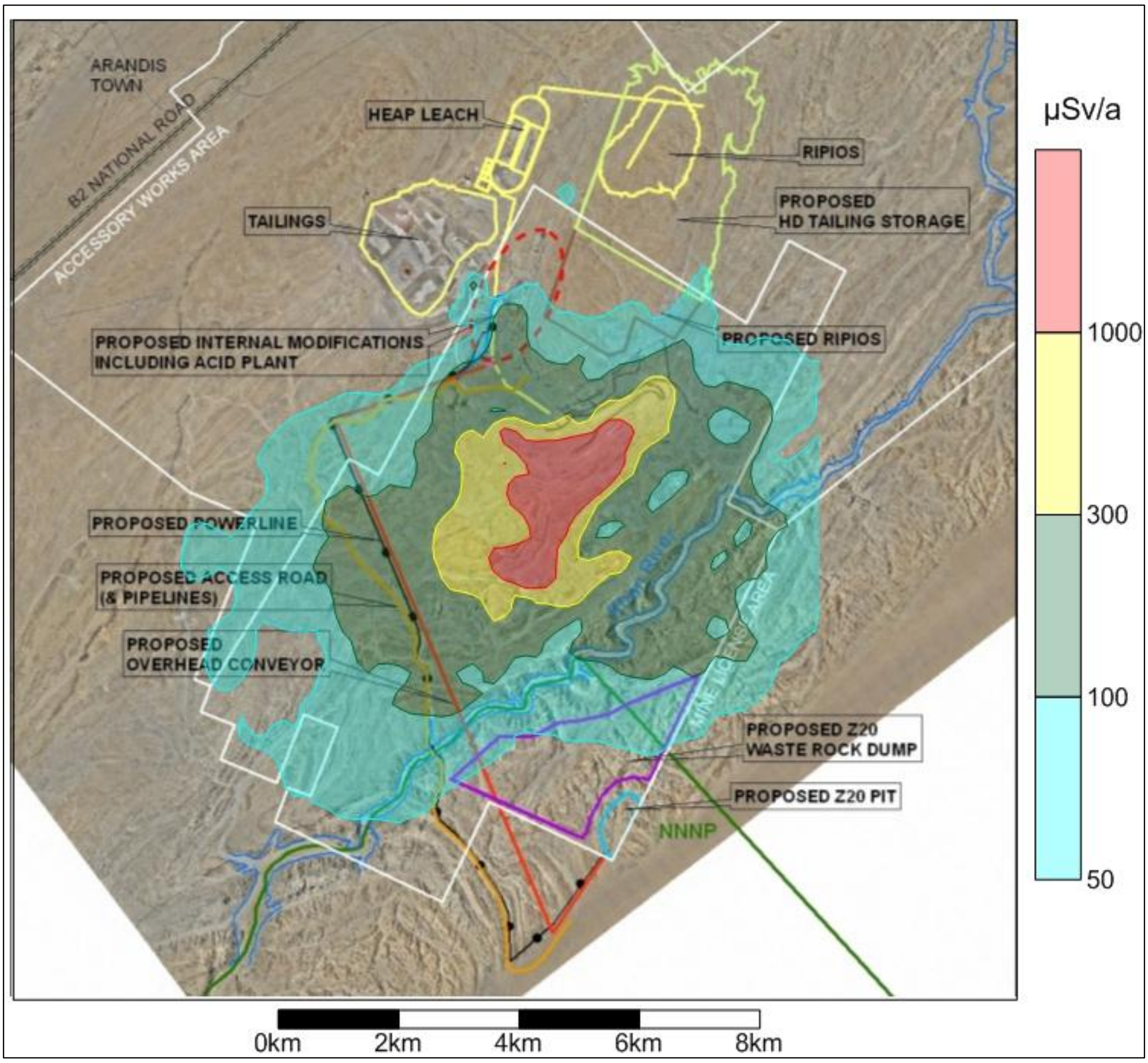

Figure 5: Calculated doses (µSv.a^{-1}) for dust inhalation from the *baseline* operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors***.***

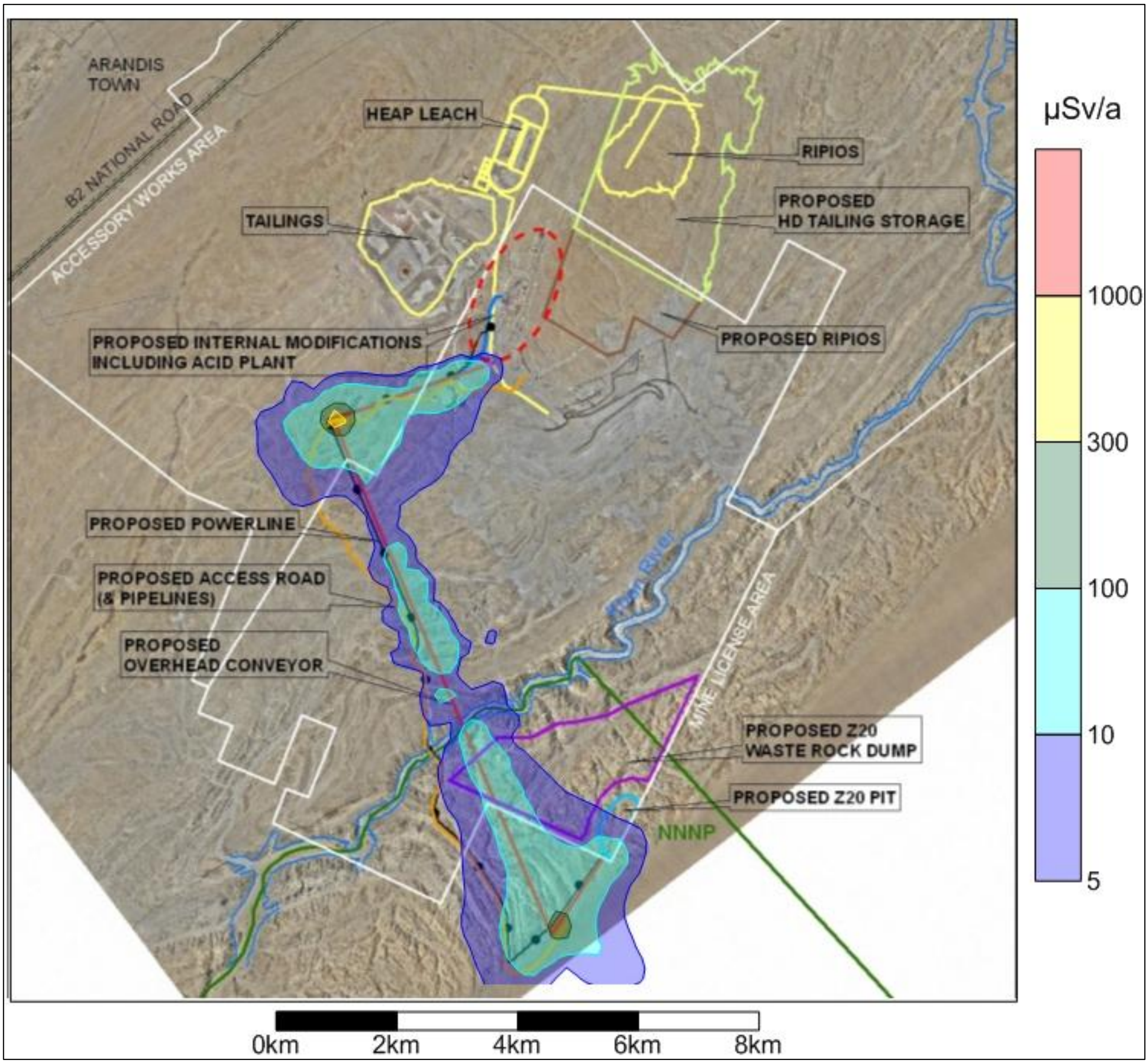

Figure 6: Calculated incremental doses (µSv.a^{-1}) for dust inhalation from the unmitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors.

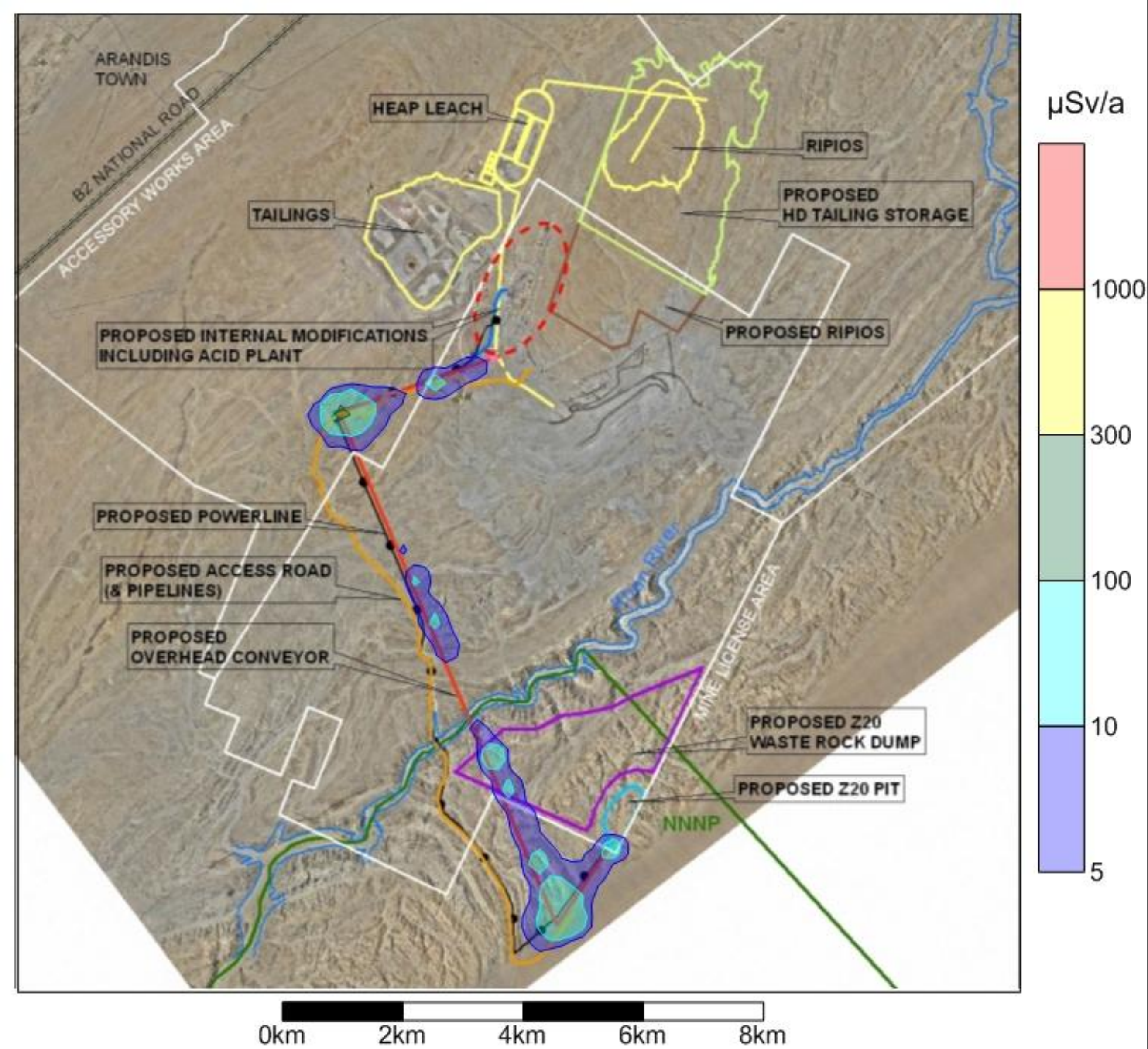

Figure 7: Calculated incremental doses (µSv.a^{-1}) for dust inhalation from the mitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors***.***

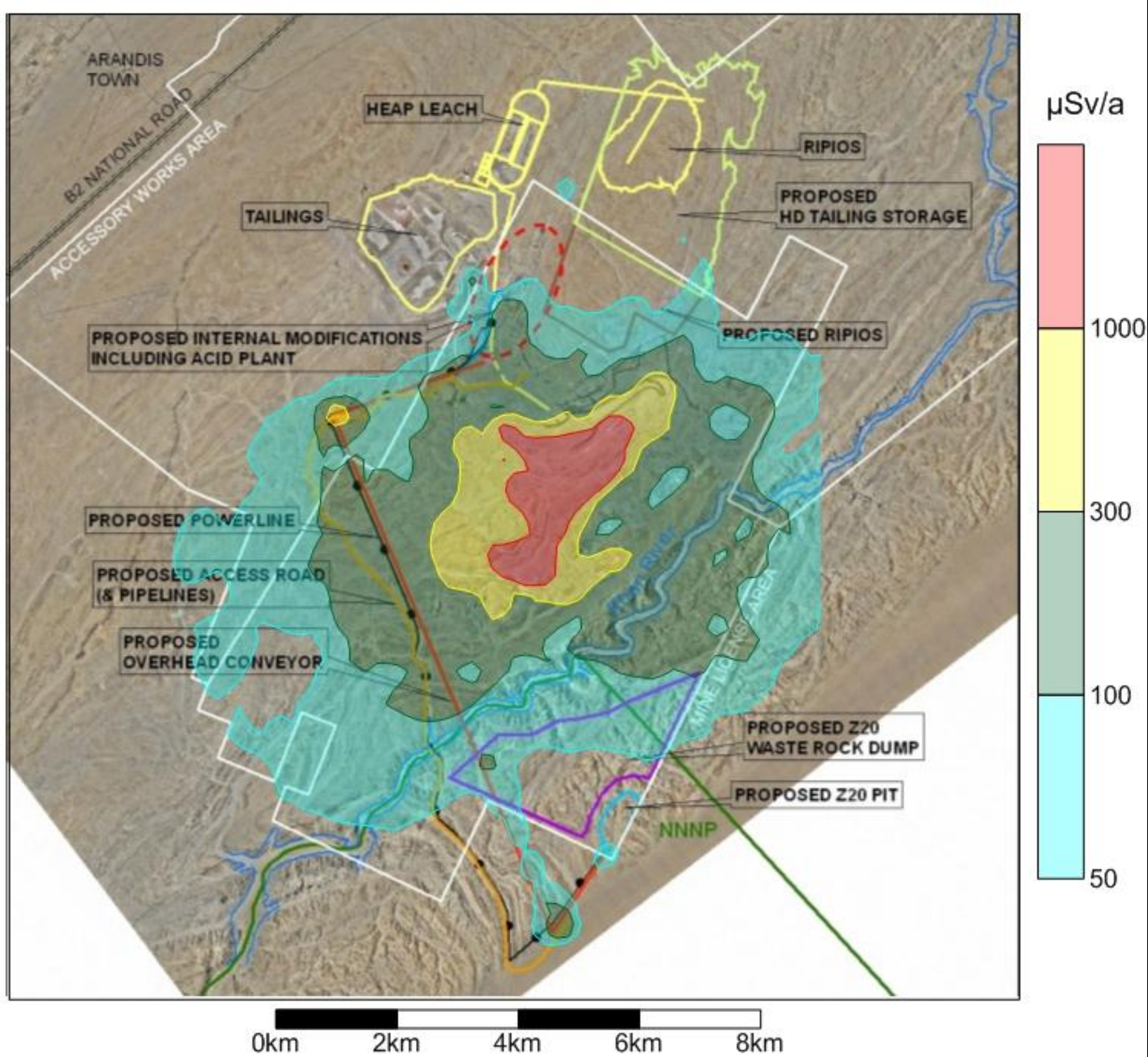

Figure 8: Calculated cumulative doses (µSv.a^{-1}) for dust inhalation from the unmitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors.

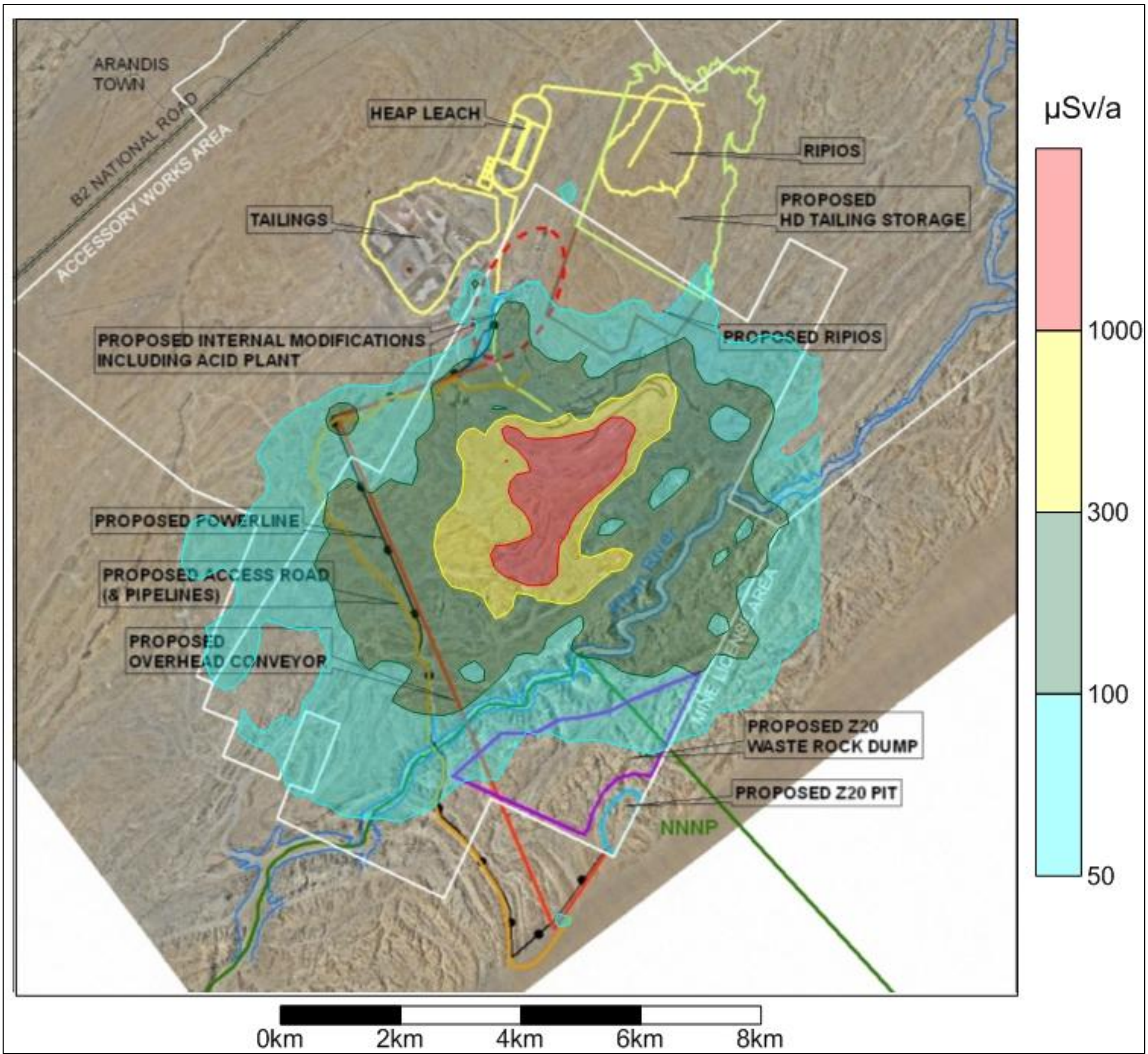

Figure 9: Calculated cumulative doses (μSv.a^{-1}) for dust inhalation from the mitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors*.*

Table 6: Calculated incremental dust inhalation doses at each of the critical groups for the unmitigated and mitigated infrastructure corridor operations

Critical Group	Period Outdoors ($h.a^{-1}$)	Period Indoors ($h.a^{-1}$)	Dose ($\mu Sv.a^{-1}$)	
			Unmitigated	Mitigated
Arandis Town	4380	4380	< 1	< 1
E-Camp	2000	0	< 1	< 1
Arandis Airport	4380	4380	< 1	< 1
Khan Mine	4380	4380	2	< 1
Khan River	96	0	< 1	< 1
Husab Mine	2000	0	< 1	< 1

7.6.3 Radiation Doses from Radon Inhalation

The calculated radon inhalation doses at each of the critical groups for the Base Case operations (from the previous assessment (De Villiers 2011: 44)) are assumed to apply to the *baseline* and summarised in Table 7. Doses of three critical groups are trivial (i.e. below 10 $\mu Sv.a^{-1}$), with the exception of Arandis Town, Arandis Airport and the Khan Mine with radon inhalation doses of 19 $\mu Sv.a^{-1}$, 37 $\mu Sv.a^{-1}$and 21 $\mu Sv.a^{-1}$ respectively. .

Table 7: Calculated radon inhalation doses at each of the critical groups for the Base Case operations

Critical Group	Period Outdoors ($h.a^{-1}$)	Period Indoors ($h.a^{-1}$)	Dose ($\mu Sv.a^{-1}$)
Arandis Town	4380	4380	19
E-Camp	2000	0	7
Arandis Airport	4380	4380	37
Khan Mine	4380	4380	21
Khan River	96	0	< 1
Husab Mine	2000	0	5

The calculated incremental radon inhalation doses at each of the critical groups for the infrastructure corridor operations are summarised in Table 8. All the doses are trivial (i.e.

below 10 µSv.a^{-1}) for both unmitigated and mitigated conditions. Isopleth plots depicting the incremental unmitigated- and mitigated radon inhalation doses for an adult exposed for 4380 hours outdoors and 4380 hours outdoors are presented in Figure 10 and Figure 11 respectively.

Table 8: Calculated incremental radon inhalation doses at each of the critical groups for the unmitigated and mitigated infrastructure corridor operations

Critical Group	Period Outdoors (h.a^{-1})	Period Indoors (h.a^{-1})	Dose (µSv.a^{-1})	
			Unmitigated	Mitigated
Arandis Town	4380	4380	< 1	< 1
E-Camp	2000	0	< 1	< 1
Arandis Airport	4380	4380	< 1	< 1
Khan Mine	4380	4380	< 1	< 1
Khan River	96	0	< 1	< 1
Husab Mine	2000	0	< 1	< 1

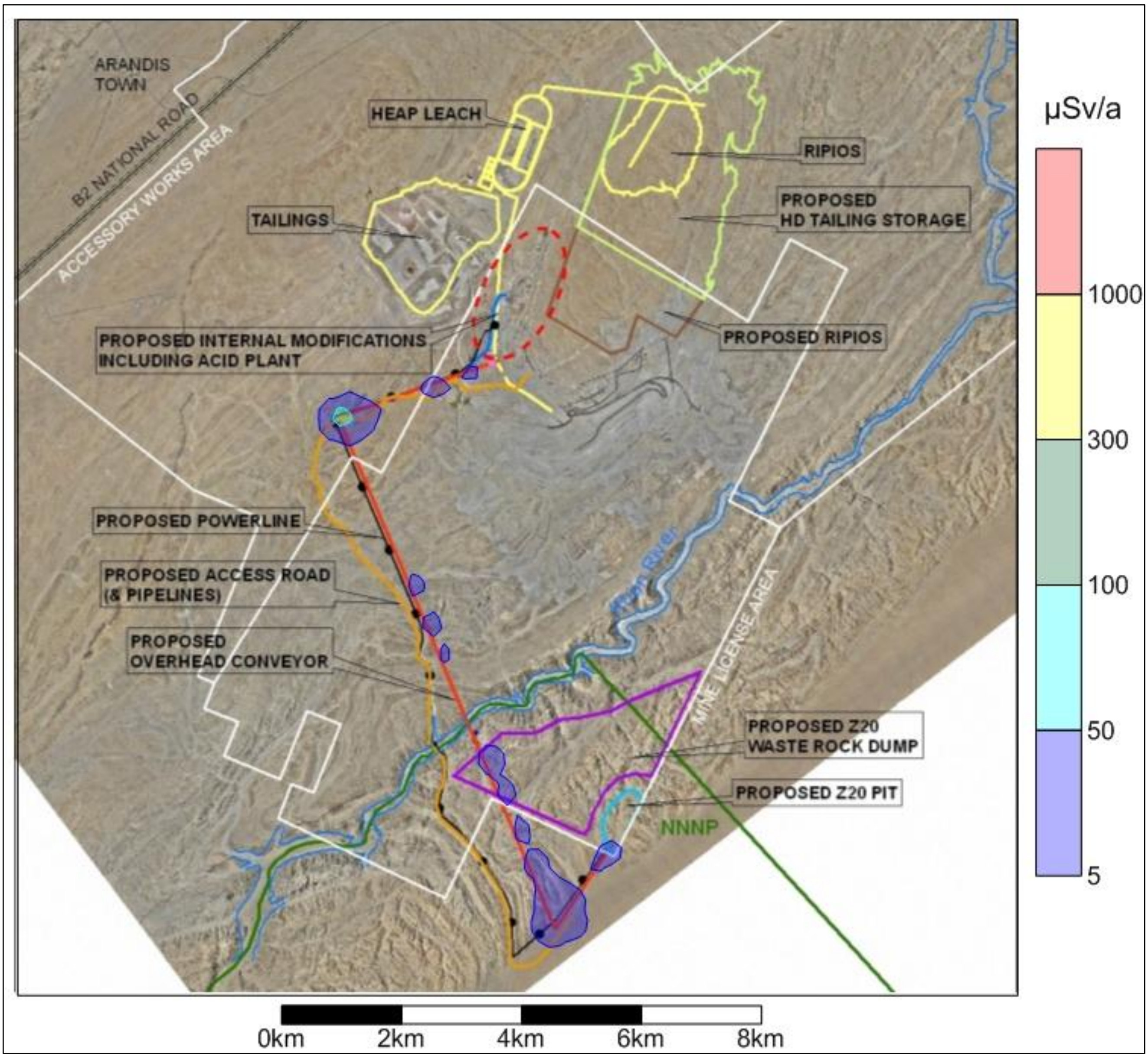

Figure 10: Calculated doses (μSv.a^{-1}) for radon inhalation from the unmitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors.

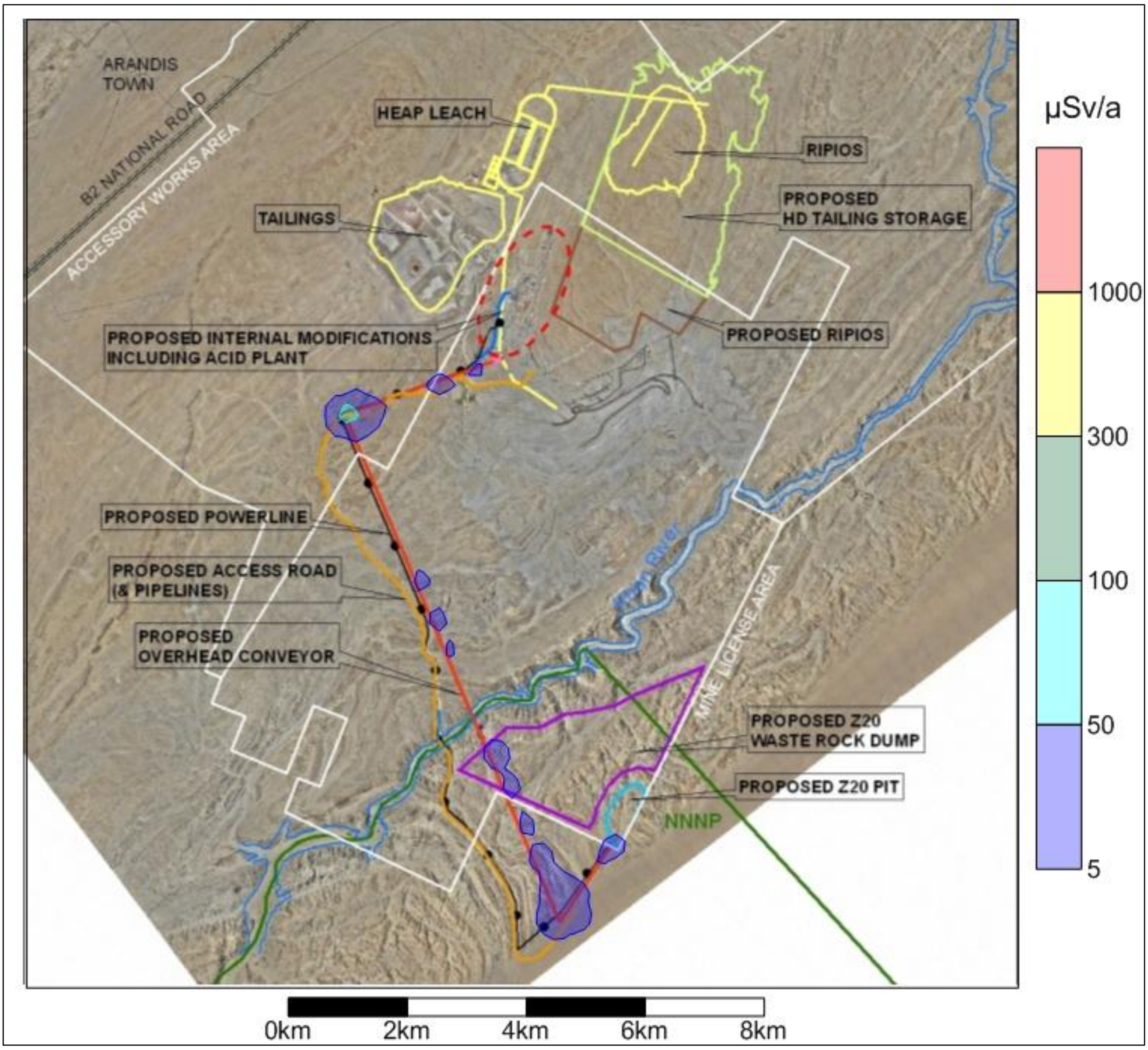

Figure 11: Calculated doses (μSv.a^{-1}) for radon inhalation from the mitigated infrastructure corridor operations for an adult exposed for 4380 hours outdoors and 4380 hours indoors***.***

7.6.4 Evaluation of the Total Dose against Radiological Criteria

The following radiological criteria are considered in the discussion below:

a) Doses below 10 µSv.a^{-1} are regarded as trivial and of no concern.
b) Doses below 300 µSv.a^{-1} are regarded as below the dose constraint (for the Rössing Mine), ranked as a low risk only needing low priority attention in terms optimization to keep doses As Low as Reasonably Achievable (ALARA).
c) Doses between 300 µSv.a^{-1} and 1000 µSv.a^{-1} are regarded as below the public dose limit, but of medium risk as they are above the source constraint and need medium priority attention for optimization to keep doses As Low as Reasonably Achievable (ALARA).
d) Doses above 1000 µSv.a^{-1} are above the public dose limit and assigned high risk, and need high priority in terms of attention for reduction to below the public dose limit.

The total doses (incremental and cumulative) to the critical groups in each Exposure Scenario due to external exposure, dust inhalation and radon inhalation are summarised in Table 9.

The total incremental doses due to unmitigated or mitigated infrastructure corridor operations are all below 10 µSv.a^{-1}. Cumulative doses, from the *baseline* and the proposed infrastructure corridor operations, ranged from a trivial 6 µSv.a^{-1} to a maximum value of 89 µSv.a^{-1} (at the Khan Mine site during unmitigated operations). This dose is more than three times lower than the dose constraint of 300 µSv.a^{-1}.

No measures, except the application of ALARA principles, are therefore recommended to safeguard the critical groups from dust deposition, dust inhalation or radon inhalation considering the proposed construction and operations of the infrastructure corridor.

There is no significant difference between the No-Go option and the go-ahead of the construction and operation of the infrastructure corridor. The decision to go forward with this project is therefore not depended on the radiological assessment but rather on other specialist studies and/or project considerations if relevant.

Error estimation for the calculated doses was not performed as uncertainties in weather data, estimated ore grades or radon exhalation rates were not available. As an approximation one can assume the same uncertainties as derived for the previous assessment (De Villiers 2011: 57), which are in the order of 70 % and 50 % for radon doses and dust doses respectively. Note that the doses are still lower than the dose constraint when the uncertainties are added to the respective doses.

7.6.5 SEIA Impact Significance Rating

The ICRP presents in its latest publication risk coefficients for a whole population (meaning not age-dependent) as 0.000055 per 1 mSv of exposure (that is 6 per 100 000 people) for fatal cancer and 0.000002 per 1 mSv of exposure for heritable effects (that is 2 per 1 million people) (ICRP 2007: 53).

Using the above mentioned ICRP risk coefficients it is likely that from the maximum adult dose of 89 $\mu Sv.a^{-1}$, as assessed in this report, there will be 6 fatal cancers per year per 1 million people exposed and 2 persons per year with heritable effects per 10 million people exposed i.e. the risk is very low. For the Rössing area of influence of approximately 50 000 people however this means not even one person is expected to develop fatal cancer or heritable effects due to Rössing's current or infrastructure corridor operations i.e. the possibility is very low.

Based on the Impact Significance Methodology presented by Aurecon, the results of this assessment and the conclusion given in the previous paragraph the following evaluation, which apply to the external exposure, dust inhalation and radon inhalation for unmitigated and mitigated operations, is done:

The EXTENT of the radiological risks is within the *Regional Category*. The Criteria for ranking the MAGNITUDE of impacts and PROBABILITY (of exposure to impacts) are based on the ICRP proposed data. Should a person contract cancer the MAGNITUDE is high as it can lead to fatality. However the probability of obtaining fatal cancer is linked to the dose risk coefficient and the dose received. In the case of the infrastructure corridor is the dose regarded as very low (lower than the dose constraint). For this reason the MAGNITUDE is taken as *Very Low* and the PROBABILITY taken as *Unlikely* (6 in a million per year). The DURATION is taken as *Long Term* as the cancer could remain post-closure. The CONFIDENCE is taken as *Certain,* the STATUS OF THE IMPACT as *Negative* and the REVERSIBILITY as *Irreversible* if a person contracts cancer.

The SEIA IMPACT SIGNIFICANCE rating for exposure from dust inhalation, radon inhalation and external exposure to members of the public for the mentioned Exposure Scenarios is therefore regarded as **"Very Low (-)."** The significance evaluations for the different exposure pathways are tabulated in Table 10.

8.0 ENVIRONMENTAL MANAGEMENT PLAN - RADIATION

This report deals with the impact of radioactive sources at the proposed Rössing infrastructure corridor on the surrounding public and other interests, but it relates mostly to the construction and operational thereof. Long-term (e.g. post-closure, decommissioning) requirements as well as general radioactive waste management requirements are not addressed in this report as these aspects form part of Rössing's radioactive waste management program or radiation protection program.

However, since the radiation impact is strongly related to the air quality, it is advised that the Air Quality Management Plan (Liebenberg-Enslin 2012: 55) be followed.

With the above-mentioned in mind, it should be noted that the Environmental Manager should ensure that during the rehabilitation activities the site is also restored to pre-mining conditions. This means that the dose from the rehabilitated site should not be significantly more than the background dose before mining commenced. Actions to accomplish this are explained by De Beer (2002: 36).

Table 9: Total calculated doses from the atmospheric pathways for the different Exposure Scenarios

Critical Group	Period Outdoors ($h.a^{-1}$)	Period Indoors ($h.a^{-1}$)	Dose ($\mu Sv.a^{-1}$)				
			Baseline	Incremental		Cumulative	
				Unmitigated	Mitigated	Unmitigated	Mitigated
Arandis Town	4380	4380	27	< 3	< 3	< 30	< 30
E-Camp	2000	0	11	< 3	< 3	< 14	< 14
Arandis Airport	4380	4380	57	< 3	< 3	< 60	< 60
Khan Mine	4380	4380	81	< 8	< 3	< 89	< 84
Khan River	96	0	< 3	< 3	< 3	< 6	< 6
Husab Mine	2000	0	< 8	< 3	< 3	< 11	< 11

Table 10: SEIA Impact Significance Rating Criteria for the various exposure pathways (applicable to unmitigated and mitigated operations during construction and operational phases).

Pathway	Type	Extent	Magnitude	Duration	Probability	Confidence	Reversibility	Significance
Dust Inhalation	Negative	Regional	Very Low	Long term	Unlikely	Certain	Irreversible	Very Low (-)
External Exposure	Negative	Regional	Very Low	Long term	Unlikely	Certain	Irreversible	Very Low (-)
Radon Inhalation	Negative	Regional	Very Low	Long term	Unlikely	Certain	Irreversible	Very Low (-)
Total	Negative	Regional	Very Low	Long term	Unlikely	Certain	Irreversible	Very Low (-)

9.0 RECOMMENDATIONS

The following are recommended for the infrastructure corridor construction and operation:

Dust fallout and airborne dust concentrations together with the respective radionuclide concentrations, should be measured in order to verify the findings of this report. Locations for these measurements may coincide with those recommended by the air quality specialist. In particular, measurements should be conducted in the river bed beneath the proposed conveyor position before construction, to establish a baseline of dust deposition, and during operation. This will present data to address public concerns regarding dust fallout that is transported in the river during a rain or flood event.

This radiological assessment was performed taking cognisance of specific critical groups. The scenarios may, however change with time. Rössing should therefore continuously study possible movement of people into the area that could influence the outcome of the studied scenarios. It is recommended to review, on an on-going basis, the validity of the identified critical group(s) and re-define these if changes are noticed.

10.0 CONCLUSIONS

The outcome of this public dose assessment indicated that, for the identified critical groups as per the defined Exposure Scenarios, the doses received from the relevant sources of exposure during the proposed construction and operation of the infrastructure corridor are trivial to low i.e. resulting in doses that are lower than the dose constraint of 300 $\mu Sv.a^{-1}$, even when assumed uncertainties are added to the dose.

Mitigation options, as described by the air quality study (Liebenberg-Enslin 2012) will reduce the mentioned doses but not by an ample amount, thus the SEIA impact significance rating will not change.

No measures, except the application of ALARA principles, are therefore recommended to safeguard the critical groups from unmitigated or mitigated dust deposition or dust inhalation considering the proposed construction and operations of the infrastructure corridor.

The SEIA impact significance is therefore **Very Low (-)** for both unmitigated and mitigated operations.

There seems to be no significant difference between the impacts of the current baseline operations and the cumulative impacts where the infrastructure corridor operations are added to the baseline operations. Since the impact significance is low for both instances it implies that the No-Go option is not dependent on the outcome of this radiological assessment, but rather other specialist studies and project considerations if relevant.

11.0 REFERENCES

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12.0 APPENDIX A: DOSE ASSESSMENT PARAMETERS

Table 11: Dose coefficients (Sv.h^{-1} per Bq.m^{-2}) to calculate doses from an external surface (Eckerman and Ryman 1993: 58)

A + after the nuclide symbol indicates the inclusion of radiation from the short-lived daughters up to the next listed nuclide

Age Group	^{238}U+	^{234}U	^{230}Th	^{226}Ra+	^{210}Pb+	^{210}Po	^{235}U+	^{231}Pa	^{227}Ac+	^{232}Th	^{228}Ra+	^{228}Th	^{224}Ra+
0 – 2 2 – 7 7 – 12 12 – 17 Adults	4.5E-13	3.0E-15	3.0E-15	6.3E-12	1.4E-13	3.0E-17	6.1E-13	1.5E-13	1.8E-12	2.2E-15	3.5E-12	8.8E-15	5.4E-12

Table 12: Dose coefficients used to calculate inhalation doses for the public impact assessment (ICRP 1995: 37)

Only the radionuclides in the decay series that will contribute significantly to the total doses were selected and are listed below.

Age Group	$Sv.Bq^{-1}$												
	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po	^{231}Pa	^{227}Ac	^{223}Ra	^{232}Th	^{228}Ra	^{228}Th	^{224}Ra
0 – 2	2.5E-05	2.9E-05	3.5E-05	2.9E-05	1.8E-05	1.4E-05	6.9E-05	2.0E-04	2.4E-05	5.0E-05	4.8E-05	1.3E-04	9.2E-06
2 – 7	1.6E-05	1.9E-05	2.4E-05	1.9E-05	1.1E-05	8.6E-06	5.2E-05	1.3E-04	1.5E-05	3.7E-05	3.2E-05	8.2E-05	5.9E-06
7 – 12	1.0E-05	1.2E-05	1.6E-05	1.2E-05	7.2E-06	5.9E-06	3.9E-05	8.7E-05	1.1E-05	2.6E-05	2.0E-05	5.5E-05	4.4E-06
12 – 17	8.7E-06	1.0E-05	1.5E-05	1.0E-05	5.9E-06	5.1E-06	3.6E-05	7.6E-05	1.1E-05	2.5E-05	1.6E-05	4.7E-05	4.2E-06
Adults	8.0E-06	9.4E-06	1.4E-05	9.5E-06	5.6E-06	4.3E-06	3.4E-05	7.2E-05	8.7E-06	2.5E-05	1.6E-05	4.0E-05	3.4E-06