APPENDIX O: RADIOLOGICAL STUDY

REPORT No.:	**NLM-SAR-09/002**
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TITLE:	**REPORT ON A RADIOLOGICAL PUBLIC HAZARD ASSESSMENT FOR LANGER HEINRICH**

1.0 AUTHORIZATION

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2.0 INTRODUCTION

Metago Environmental Engineers (Pty) Ltd (hereafter referred to as Metago) is presently performing an Environmental Impact Assessment (EIA) for the proposed expansion project of the Langer Heinrich Uranium Mine [1]. Necsa has been contracted to perform a Radiological Public Hazard Assessment as a specialist input to the EIA. This document describes the detail and results of the radiological assessment.

3.0 SCOPE OF THE ASSESSMENT

The present Minerals Act [2] of Namibia requires that the holder of a mineral licence shall prepare an Environmental Impact Assessment (EIA). Because the mining activities involve the mining of Naturally Occurring Radioactive Material (NORM), it is also required to perform a radiological assessment to be included as a specialist report in the EIA. Such an assessment mainly addresses the radiological impact of the mine to members of the public that may be exposed. International developments on the radiological impact to non-human species are still in its infancy and will not be considered. However, a general conclusion on the wider environmental/ecological impact will be made. The assessment will also not consider the occupational exposure of workers, but will look at some construction and exploration workers (drillers) staying on the site.

A pre-mining baseline study [3] as well as an initial EIA [4] has been performed for the Langer Heinrich Uranium mine. While the data from these studies will be referenced where required, the present study was performed independently, rather using more recent data from the present scoping report [1] and other specialist studies [5] and [6].

The operational experience of the mine is still short. While current operational and analytical data will be used to eliminate uncertainties in the original study, this assessment should still be regarded as an initial prospective assessment based on available data and conservative assumptions where data are lacking. By nature the process of prospectively assessing radiological risks is an uncertain process trying to predict future conditions, mainly through modelling and extrapolation exercises. A major aim of the prospective assessment is to identify the areas of uncertainty and to make proposals for the acquisition of such data through an environmental monitoring programme.

The assessment should be done within a framework of radiation protection and waste management principles and of regulatory requirements, which comprises the assessment context of the study. This is described in Section 4.0.

Although it is possible to perform a study of this nature using generic data, it is preferable to include site specific data and information. Section 5.0 is a summarized site and process description and includes radiological data accumulated to perform the prospective impact assessment from the current operations at Langer Heinrich. This section will mainly refer to other documents as to prevent duplication.

Due to information uncertainties associated with the future evolution of the site over the time scales of concern, a formal scenario generation process will not be followed. Instead a source-pathway-receptor approach is followed to define a limited set of exposure scenarios for dose assessments on the various pathways.

The approach followed to develop exposure scenarios is discussed in Section 6.0, together with a description of the pathway dependent scenarios considered in the assessment. A large effort in the assessment will be to calculate inhalation and deposition doses from radon and dust for adult members of the public on a grid basis as determined through air dispersion modelling. This will cover scenarios for the current mine conditions, as well as various planned extensions on the mine as described in [6].

Section 7.0 is devoted to a deterministic assessment of the radiological impact. First mathematical models are developed and then the deterministic public doses for each pathway are assessed as per the defined scenarios. The methodology and assessment of adult inhalation and deposition doses on a grid basis are also addressed.

The report is concluded in Section 8.0 and 9.0 with an evaluation of the public impact assessment results, including some general recommendations for additional information to be acquired through an environmental monitoring programme for a more detailed assessment. The evaluation above will be against international radiological criteria based on international radiation protection principles [8], [12]. In Section 9.2 an evaluation of the assessment results is also performed against environmental impact criteria presented in Section 4.5.

Section 10.0 presents the referenced documents.

Four appendices are attached to the report. Appendix A presents a map of the Langer Heinrich site and the surrounding environment. In Appendix B, the parameters, used in or adapted for the deterministic public dose calculations, are listed. Appendix C contains an Interaction Matrix containing all possible sources and pathways for Langer Heinrich, mainly to serve as reference for future assessments. In Appendix D the Earthlife Africa comments on the initial EIA applicable to this document are addressed.

4.0 ASSESSMENT CONTEXT

4.1 GENERAL

The main purpose of the assessment context is to define the scope and content of the assessment to be performed.

The radiological investigation will have the following objectives:

- Identify and quantify the radiological pollution sources associated with current activities and the proposed project (construction, operation, decommissioning and closure phases).
- The radiological study is a cross cutting study that from a pollution dispersion viewpoint must both provide input into the models and make use of the model conclusions of the air and water studies being conducted by Airshed and Bittner Water Consult CC. Discussions should also take place with the waste and water engineer – to correctly understand the pollution emission issues associated with the tailings dam, stockpiles and dirty water circuit.
- From a public health viewpoint, a clear distinction must be made between the mining licence area that is managed in accordance with occupational health and safety legislation, and the area beyond this defined boundary that falls under environmental and public exposure criteria – the study must focus on the environmental and public exposure.
- To describe the relevant legal framework with reference to national and international legislation, conventions and guidelines.
- Assess the cumulative environmental and public exposure radiological impacts for all relevant pathways (construction, operation, decommissioning and closure) – the assessment criteria that must be used are attached.
- To provide input, together with Metago, other specialists and Langer Heinrich, into the management measures going forward.

The assessment consists of a set of higher level assumptions and constraints that will reflect the regulatory requirements. As nuclear regulations in Namibia are still in the development phase [7], the recommendations by the International Atomic Energy Association (IAEA) [8] and International Commission on Radiological Protection (ICRP) will mainly be reflected. The assessment context also provides the means, by which the target audience is informed of what is to be included in the assessment, and the justification for these choices. Uncertainties in the prospective assessment are supplemented by assumptions. The prospective assessment report is concluded with recommendations for additional measurements in a proposed environmental monitoring programme to be used for improving the accuracy during a retrospective review of this hazard assessment to be performed according to regulatory requirements and guidance.

4.2 STAKEHOLDERS IN THE ASSESSMENT

This assessment is undertaken to provide confidence to various groups of people that the controls currently in place and envisaged will ensure that the impact of the mine do not pose a radiological risk to members of the public nor thus the intended extension add any unacceptable risks to the members of the public. These groups constitute the stakeholders (target audiences) of the assessment. More specifically the stakeholders can be defined as

(a) Langer Heinrich management for whom the assessment is being performed;

(b) The Namibian Atomic Energy Board, which as regulatory body, should overlook the process to ensure that the mining and processing activities are performed in accordance with regulatory guidance and requirements provided;

(c) The public in the vicinity of the mine as well associated local authorities; and

(d) Technical, scientific and environmental groups that might have an interest in the approach being followed and the subsequent results.

4.3 PURPOSE OF THE STUDY

The objective of the study is to perform an assessment of potential doses to members of the public, from various sources on the mine, for the expected current as well as planned future conditions at the mine.

This study excludes the assessment of occupational doses to workers.

4.4 REGULATORY REQUIREMENTS FOR THE IMPACT ASSESSMENT

4.4.1 Regulatory Framework

The Namibian Atomic Energy Board has only been inaugurated on 18 February 2009, and may need more time to develop a comprehensive regulatory framework. In this document ICRP and IAEA recommendations will mainly be reflected.

4.4.2 Radiological Protection Standards

Radiological protection standards are criteria set to ensure compliance with the basic principles of radiation safety and waste management. The standards applicable to Namibia are still being developed and this document will refer to international standards and recommendations, as contained in IAEA and ICRP documents [8], [9], [10], [11] and [12]. Amongst others, they ensure the protection of individual members of the public and their surrounding environment. For this purpose, dose and potential dose limits, dose constraints as well as radon action levels and other appropriate criteria are defined. The basic safety indicator for public impact assessments, is an individual dose limit, while for planning purposes, a dose constraint at some fraction of the dose limit is used.

The individual dose limit places an upper limit to the dose from all controllable 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 recommended dose limit for members of the public is 1 $mSv.a^{-1}$ [8] and [12]. Because the application of dose limits to a single authorized practice has some intrinsic difficulties, the international approach is to use the limit on a case by case basis only, while more generally a source-related dose constraint is applied for optimisation of the impact from a single authorized practice. A value of 0.3 mSv.a^{-1} is for instance recommended as a constraint for the management of waste from Uranium mining [10].

For radon, an action level of 200–400 Bq.m^{-3} is used as a criterion level requiring some action to be taken when the level is exceeded [11]. This relates to an annual dose of around 3 to 6 mSv.a^{-1}. The action level was, however, only made applicable when radon was regarded as incidental to the mining process and not when the material was mined for its radioactive properties. The latest ICRP recommendations [12] mentions optimization of radon doses below a constraint of 10 mSv.a^{-1}, with no distinction between mines. The ICRP indicated, however, that they are still investigating the exposure to radon. For this assessment the public impact of radon will be evaluated against the public dose limit and constraint mentioned in the previous paragraph but recommendations will also consider the present international uncertainty.

4.4.3 Assessment Guidance

Broad ICRP guidance on a radiological public hazard assessment is provided in [13]. The IAEA provide broad assessment guidance for mining waste management in [10] and some model guidance in [14]. This report will focus on the dose assessment detail, which will be discussed in Section 6.0 and Section 7.0.

4.4.4 Effects in the Future

One of the basic principles for site rehabilitation and the management of the radioactive waste, as associated with mine closure, is that this will be done in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today [9]. This implies that the assessment will include predictions of future impacts. Long-term predictions require various predictive modelling as well as experimental exercises. Predictive modelling for liquid effluents is incorporated and discussed in [5], including recommendations on improved future modelling. Generally it can also be expected that human technology and society will develop over the time scale of concern. This development is, however, unpredictable. Therefore, it is usual to make some assumptions in order to constrain the range of future human activities that are considered. A common assumption, also made in this study, is that only present-day technology, or technologies practised in the past will be considered in the assessment.

While predictive results presented in [5] will be considered, mitigation and rehabilitation strategies at mine closure still seem to be at a developmental stage. A complete predictive dose assessment also considering post-closure conditions seems to be impossible at the present stage. This assessment will hence be restricted to the results of simpler models applicable to the operational phase of the mine.

4.4.5 Safety from Control

If required, the impact from the mine can be reduced by various mitigating control measures during the operational phase, e.g. the rehabilitation of the mine tailings dams by using waste rock or filling existing pits with tailings from new pits. These strategies are also still at a developmental stage while their mitigation factors need input from others specialist reports. For these reasons this assessment will only be used to assist in defining broad recommendations for public impact controls, the technical detail and the quantitative reduction of doses due to such controls will be rather part of the strategies developed for mine closure and will not be dealt with in the present prospective assessment.

4.4.6 Radionuclides Considered in the Assessment

The radionuclides giving rise to the radiological impacts associated with the Langer Heinrich operations are those resulting from the U-238, U-235 and Th-232 decay series. The specific radionuclides in these decay series that are of importance and that should be included in the analysis were selected, where applicable with appropriate half-lives, from [24] and are:

(a) Long-lived alpha (α) emitters: U-238, U-234, Th-230, Ra-226, Po-210, Th-232, Th-228, Ra-224;

(b) Beta (β) emitters:- Pb-210, Ra-228; and

(c) Rn-222 (and its short-lived progeny).

In addition U-235 (α-emitter) with a half-life of 7.04E+08 years and its daughters will also be included in the analysis, but only when these could significantly contribute to doses. Radioactive decay and in-growth should be taken into consideration in predictive assessments, not only to avoid overly conservative results in the case of the slower transport processes, but also to account for the impact of the relevant decay products. This prospective assessment will, however, mainly be based on models, applied by other specialists and by using analytical results. Where data for some of the above nuclides are missing or unreliable in the analysis results, extrapolations from indicator nuclides will be performed and justified.

4.4.7 Model Development

Ideally, model development within the assessments should be performed through scenario development considering all exposure pathways and all possible present and future conditions. Where applicable, conceptual models should be developed to define scenarios for relevant exposure pathways. For the first iteration, only scenarios relating to normal non-disruptive conditions are considered.

All data used in the assessment are available for auditing, quality control and safekeeping.

Public dose assessment models consist of atmospheric, ground- and surface-water transfer models and finally biosphere models to relate the sources of radioactivity and radiation to the amount of radioactivity to which members of the public are exposed through external or internal exposure. Atmospheric and water modelling are reported on in other specialist reports [5], [6]. Parameters for biosphere modelling will be discussed in Section 7.0.

4.4.8 Critical Groups

Critical groups (redefined in [13] as Representative Individuals) are most likely to be found in the neighbourhood of the sources at the mine. Parameters typical of the critical group locations and expected human actions, behaviour and habits that might have an influence on the assessment are determined and used in the assessment. These include existing *actual* critical groups that might be influenced by the mining conditions, or *hypothetical* critical groups that might position themselves in areas adjacent to the sources during the period covered by the assessment or be involved in habitual activities that my expose them to radiation from mine sources. Due to the low population density and the lack of habit data specific to the region, more general data will be used for this assessment.

To calculate the doses to critical groups in general, the assumptions will be made that the critical groups consists of the age groups 0 to 2 (1) years, 2 to 7 (5) years, 7 to 12 (10) years, 12 to 17 (15) years and adults. For contour plots of doses from the atmospheric pathways, only adults will be considered.

4.4.9 Public Dose Assessment

The basis for any radiological impact assessment consists of site specific data related to the physical, chemical, biological and radiological characteristics of the site. From this perspective a description of site and surrounding environment is needed, as discussed in Section 5.0.

From the site description it would be possible to identify radioactive sources with the potential to expose members of the public, with the purpose to perform a source-pathway-receptor analysis. From this analysis possible exposure pathway to real and hypothetical critical groups among members of the public can be defined. A formal, systematic scenario generation and justification process will not be followed. Scenarios will rather be formulated through the screening of relevant sources and interacting media, as identified in an interaction matrix, given in Appendix C.

Details on the methodology used in the dose analysis will be provided, including the approaches followed to consider the effects of interacting media in the biosphere and mathematical models used to quantify these effects. The models for environmental transfer in the atmosphere, surface water and geosphere will form part of other specialist reports [5] and [6].

4.5 METAGO CRITERIA FOR IMPACT EVALUATION

Metago has also presented general criteria for the evaluation of the environmental impacts in a format involving the ranking various aspects of the impacts. These are presented in Table 1 and will be considered in Section 9.2.

Table 1: Criteria for Impact Evaluation

Criteria for ranking of the severity of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. Nor observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term.
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	**L**	Localized – Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national.
PROBABILITY (of exposure to impacts)	**H**	Definite/ Continuous
	M	Possible/ frequent
	L	Unlikely/ seldom

5.0 SITE AND PROCESS DESCRIPTION

The site infrastructure and process description, together with descriptions of the surrounding environment are presented in the Environmental Scoping Report [1] and elaborated on in the other specialist reports [5] and [6]. Where they refer to existing site infrastructure they are hence expected to be accurate but they may lack detail when referring to future facilities. The identification of any additional data requirements and subsequent surveys will be based on the assessment results. Where possible, e.g. as reported in [3], background conditions, against which public doses should be judged, will also be considered. Modelled dose results from sources associated with the mining operations are considered to be additional doses above the background.

Existing descriptions will not be repeated in this report. Only data relevant to the dose assessment are indicated below.

5.1 RADIOLOGICAL DATA FOR ASSESSMENT

Samples of solid materials were collected during a site visit, and analysed for their radionuclide concentrations. These will be used to convert gravimetric airborne and deposition concentrations in the air quality specialist report [6] to nuclide activities for a dose assessment. The samples relate, however, only to current operations and need to be supplemented for future operations, e.g. for the Western Pit, Central Pit and Eastern Pit. This could be done by assuming the same relative nuclide concentrations for the future materials and make linear corrections as per the expected ore grades for these pits relative to those for the current Pit A. The need for more samples to be collected and analysed over an extended period through an environmental monitoring programme will be discussed as outcome of this assessment.

5.1.1 Uranium Ore Grades and Nuclide Concentrations of Solid Samples

Several ore resource as originally described in the initial EIA [4] and confirmed during the operation of the mine is indicated in Table 2. The estimated geological resources for the future pits have been calculated by Langer Heinrich and are also presented in Table 2.

Table 2: Estimated Uranium ore grades for the current and future pits

Grade	Concentration (ppm)	Volume	Million ton	Average Grade Uranium concentration	Weighted Mean Ore Grade
		m^3	(Mt)	ppm	ppm
Pit A					
Waste	0.0 -250	3986095	9.6	74	74
Lower Grade	250-400	1129599	2.7	316	506
Medium Grade	400-650	897678	2.2	514	
High Grade	650.0 - >650	476810	1.1	954	
Pit D					
Waste	0.0 -250	6397500	15.3	105	105
Lower Grade	250-400	1732500	4.1	318	439
Medium Grade	400-650	802500	1.9	502	
High Grade	650.0 - >650	412500	1	813	
Future Western Pit					
Waste	0.0 -250	18637500	44.7	61	61
Lower Grade	250-400	1665000	4	315	591
Medium Grade	400-650	787500	2	508	
High Grade	650.0 - >650	1087500	2.6	1081	
Future Central Pit					
Waste	0.0 -250	28605000	6.9	52	52
Lower Grade	250-400	2235000	5.4	321	436
Medium Grade	400-650	1065000	2.6	491	
High Grade	650.0 - >650	420000	1	911	
Future Eastern Pit					
Waste	0.0 -250	28755000	69	59	59
Lower Grade	250-400	4252500	10	316	366
Medium Grade	400-650	1552500	3.7	482	
High Grade	650.0 - >650	97500	0.2	713	

A set of solid samples of various process materials were also collected at locations within the current mining operations prior to the assessment. These samples were sieved to separate the smaller (PM10) particles from the total solid particles (TSP). Both fractions of each sample were analysed for their radionuclide concentrations at an accredited radioanalytical laboratory.

The radioanalytical results are presented in Table 3. The U-238 values were also converted to part per million (ppm) uranium and were compared with the estimated ore grade date received from Langer Heinrich. Such a comparison is presented in Table 4. When comparing the analysed TSP ppm uranium values with the ore grades, the two sets of data seem to compare favourably with each other. Substantially larger nuclide concentrations were, however, analysed in the sieved (PM10) samples. This indicates that the uranium contents of the ore may generally be crushed to a finer size than the rest of the ore material. For this reason the analysed results for the sieved fractions were used in the radiological assessment and allocated to the PM10 airborne dust dispersion results in [6] as this would present more conservative results. The analysed TSP nuclide concentrations were again allocated to the modelled deposited concentrations in [6] as the larger particles were likely to represent a larger fallout fraction. Table 4 also indicate the mean ore grade derived by weighing with the masses of the various grades as this would relate to the mean impact.

Table 3: Results of the Radioactivity Analysis for Solid Samples (Bq.kg^{-1})

Sample No	Sample Description	^{238}U	^{234}U	^{226}Ra	^{210}Pb	^{235}U	^{232}Th	^{228}Ra	^{228}Th	^{40}K	Gross alpha	Gross beta	Uranium ppm
1	Tailings Dam Wall	210	212	77.9	112	9.66	52.7	36.1	27.1	882	1900	1380	17
2	Tailings Dam Wall Sifted	309	311	4070	271	14.2	32.3	< MDA	< MDA	310	3350	1370	25
3	Tailings Dam Beach A	15600	15700	6290	6810	716	< MDA	63	< MDA	323	67100	33600	1258
4	Tailings Dam Beach A Sifted	11800	11900	9340	8130	543	< MDA	< MDA	< MDA	390	76800	31000	952
5	Open Pit A	2840	2860	2300	2770	131	24.7	30	37	900	32300	10400	229
6	Open Pit A Sifted	8980	9050	1010	6600	413	35.9	< MDA	49.7	694	79700	34400	724
7	Top Soil SP	616	621	497	542	28.4	23.3	26.5	12	729	6380	2770	50
8	Top Soil SP Sifted	737	743	9410	841	33.9	37.7	< MDA	< MDA	597	9880	3800	59
9	ROM Low Grade	4900	4940	4550	4760	226	22.4	< MDA	< MDA	849	55900	17800	395
10	ROM Low Grade Sifted	11100	11200	15100	12600	510	40	< MDA	< MDA	654	99900	39300	895
11	ROM High Grade	10900	11000	11300	10600	500	27.3	< MDA	< MDA	927	127000	37900	879
12	ROM High Grade Sifted	17800	17900	899	16900	819	43.4	49	58	359	135000	66200	1435
13	Waste Rock Dump 3 & 4	211	213	204	230	9.72	25.4	29.8	26.1	842	2220	1790	17
14	Waste Rock Dump 3 & 4 Sifted	717	723	6340	951	33	45.8	< MDA	< MDA	570	16400	5400	58
15	Waste Rock Dump 1	1530	1540	2150	2680	70.5	11.1	< MDA	< MDA	893	20200	7400	123
16	Waste Rock Dump 1 Sifted	2300	2320	1250	6700	106	12	< MDA	< MDA	664	66600	21500	185
17	Waste Rock Dump 2	673	678	547	586	31	17.3	<	22	841	7730	3140	54

Sample No	**Sample Description**	**^{238}U**	**^{234}U**	**^{226}Ra**	**^{210}Pb**	**^{235}U**	**^{232}Th**	**^{228}Ra**	**^{228}Th**	**^{40}K**	**Gross alpha**	**Gross beta**	**Uranium ppm**
								MDA					
18	Waste Rock Dump 2 Sifted	1210	1220	121	1390	55.9	30.5	39	46.1	556	11300	4460	98
19	Access Road	66.4	67	61.7	58.6	3.06	22	24.5	20.2	754	836	1110	5
20	Access Road Sifted	110	110	566	< MDA	5.04	30.1	< MDA	< MDA	757	2100	1030	9
21	Haul Road	221	223	195	246	10.2	13.7	18	12	866	2930	1780	18
22	Haul Road Sifted	565	570	4850	662	26	21.5	< MDA	< MDA	361	9500	2840	46
23	Tailings Beach B	3820	3850	11800	10200	176	24.3	42	< MDA	729	93100	26500	308
24	Tailings Beach B Sifted	2820	2840	7100	9290	130	22.4	< MDA	< MDA	390	97400	24600	227

(The < MDA value refers to a value that is below the minimum detectable activity.)

Table 4: Comparison of ore grades and radioanalytical results

Grade	Average Grade Uranium concentration	Weighted Mean Ore Grade	Radioanalytical Results	
	ppm	ppm	Material	ppm U
Pit A			Open Pit A	229
Waste	74	74	Open Pit A Sifted	724
Lower Grade	316	506	ROM Low Grade	395
Medium Grade	514		ROM Low Grade Sifted	895
High Grade	954		ROM High Grade	879
Pit D			ROM High Grade Sifted	1435
Waste	105	105	Waste Rock Dump 1	123
Lower Grade	318	439	Waste Rock Dump 1 Sifted	185
Medium Grade	502		Waste Rock Dump 2	54
High Grade	813		Waste Rock Dump 2 Sifted	98

5.1.2 Radioactivity in Water

The ground water assessment in [5] indicates the highest risk of contamination to be through sub-surface flow associated with drainage within the Gawib River shallow alluvial sediments. Figures 33 to 38 in [5] illustrate the uranium concentration in the alluvium as well as the paleo-channel it overlays and the subsequent basement rock. This report evaluates aquatic exposure scenarios for the peak concentrations for the alluvium at the maximum distances presented in Figures 33 and 34. Only the alluvium is considered because this seems to be the only path of relevance for groundwater flow. The assessment considers the dose related to the use of the undiluted water as per the modelled concentration at a distance of 12.5 km, which relates to the confluence of the Gawib and Swakop rivers. A 20% dilution scenario at the confluence of the Gawib and Swakop Rivers is also evaluated. In addition, a background assessment for the Gawib River is performed based on analysis of uranium in bore-hole samples [5].

5.2 HUMAN BEHAVIOUR CHARACTERISTICS

The main human behaviours for members of the public, which are likely to be impacted by the mine, are the tourist actions close to the mine. These involve unscheduled visits by tourists and entail a maximum stay of a week at Bloedkoppie. Exposure via the radon and dust pathways from the tailings dams and other sources are assessed as per the modelled radon and dust concentrations in [6].

Direct impacts via the aquatic pathway are related with the use of water from the Swakop River for direct consumption and for agricultural use. These will relate to times following mine closure and will only be assessed to present a preliminary indication for more elaborate water modelling. Hypothetical receptors and scenarios for water consumption and agricultural activities will be considered.

Impacts of contractors on the site relate to construction workers staying on the site and drillers involved in exploration. The location for a Drillers Camp and the Constructors camp are indicated in Figure 2.

6.0 SCENARIO DEVELOPMENT

6.1 SOURCE-PATHWAY-RECEPTOR ANALYSIS

6.1.1 General

Due to uncertainties already mentioned above a formal systematic source-pathway-receptor analysis process will not be followed for the prospective assessment to develop scenarios. A more generic process will rather be followed as per the human behaviour characteristics identified in Section 5.2 to identify the existing but also some hypothetical source-receptor-pathway combinations, which will then be analysed as per the detail below.

6.1.2 Sources

6.1.2.1 Radon Sources

Radon sources are caused by the exhalation of radon from material containing enhanced levels of Ra-226. Most important would be the radon exhalation from the existing and future tailings dams, with lower emissions possible from extended waste rock piles and even lesser amounts from ore stockpiles. The more important sources will be considered in this assessment, as per the Mining scenarios presented in Section 6.1.2.2 below. The results will be used to present recommendations on the necessity for additional sources to be considered in future assessments. The radon sources will vary over the different mining phases due their size and their Ra-226 concentrations. The details about the source sizes are discussed in [6] while Ra-226 concentrations were taken from Table 3.

6.1.2.2 Dust Sources

Dust sources will vary depending on the mining operations at a typical mining stage. For this assessment these mining stages are divided into 4 mining scenarios, defined below and described in detail in [6]:

- *Current Mining Scenario 1: Current (Baseline) operation and construction operations.*
- *Future Mining Scenario 1: Future Western Pit.*
- *Future Mining Scenario 2: Future Central Pit.*
- *Future Mining Scenario 3: Future Eastern Pit.*

All the above mining scenarios will generate dust from the following mining operations (see Section 8 of [6] for detail):

- *Material handling operations*
- *Wind erosion*
- *Drilling*
- *Blasting*
- *Tipping*
- *Excavations*
- *Crushing and Screening*
- *Vehicle activity on paved roads (will not be assessed)*
- *Vehicle activity on unpaved roads*

The amount of dust from each of these activities will, however, vary at the different receptors locations mainly due to a different activity levels, source-receptor distances and due to a different radionuclide composition of each source. Therefore the dose to each receptor will be calculated for the source generated by each operation during the different mining scenarios.

6.1.2.3 Aquatic Sources

Aquatic sources are discussed in detail in [5] and are summarized in Table 5.

Table 5: Aquatic Source total Uranium concentration.

	Scenario Description	Total Uranium (ppm)	Total Uranium Activity (Bq)
Scenario 1:	Alluvium (conservative case) -12.5 km (No Dilution)	2.0	49
Scenario 2:	Alluvium (conservative case) -12.5 km (20% Dilution)	0.40	9.8
Scenario 3:	Alluvium (realistic case) -12.5 km (No Dilution)	0.60	15
Scenario 4:	Alluvium (realistic case) -12.5 km (20% Dilution)	0.12	2.9
Scenario 5:	Natural Background (Boreholes WW41180 - WW41182 Average uranium concentration)	0.091	2.2

Only uranium is considered in this assessment because it was the only one determined in [5] and is the only nuclide expected to be of significance due to its solubility and mobility in aquatic systems.

6.1.3 Pathways

6.1.3.1 External Exposure

Experience at other mines indicates that direct external exposure to radiation from mine sources become only important when members of the public are living on areas containing mine ore or residues. While this pathway should be further investigation for post-closure conditions, it is not considered in this prospective assessment as members of the public will not have access to such areas during plant operation. A calculation for a large wall of ore containing 7 Bq/g natural uranium indicated that a trivial dose of 10 μSv.a^{-1} will not be exceeded at a distance of 0.5 km from the source. This should hence be the limit for permanent public access to the mine sources.

External exposure may also occur from soil contamination due to deposited airborne or waterborne activity. These will be treated as part of the atmospheric or aquatic pathways or as secondary ingestion pathways. For natural radionuclides external exposure to airborne radioactivity is, however, negligible, when compared to inhalation and will not be assessed.

6.1.3.2 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 sources to the receptors. Details on environmental transfer via the atmospheric pathway are dealt with in [6]. Experience at other mines indicated that the atmospheric pathway is important, but only close to the radon and dust sources. The pathway will hence be investigated for critical groups close to the radon and dust sources discussed 6.1.2.1 and 6.1.2.2 above. The pathway will mainly consider the inhalation sub-pathway. While assessments at other mines indicate that deposition of dust contributes an insignificant dose, this will also be assessed for Langer Heinrich.

6.1.3.3 Aquatic Pathway

The aquatic pathway is characterised by the groundwater pathways and the surface water pathway. Groundwater contamination beneath the tailings dam is possible, after which radionuclides can be transported through groundwater flow to aquifers. The surface water pathway is very similar to the groundwater pathway, except that the transport of radionuclides from the sources to the receptors is along surface water bodies. For Langer Heinrich the surface water pathway seems, however, to be of less importance and restricted to the occasional occurrence of surface run-off following heavy rain. Details on environmental transfer via the aquatic pathway are dealt with in [5].

6.1.3.4 Secondary Pathways

At the points of impact at the receptors, the contributions from the atmospheric and aquatic pathways provide source terms for the secondary pathways. It is at these points where the public can get exposed to radiation through secondary transfer via the biosphere. This include, for example, the drinking of contaminated water, eating of food grown on contaminated land (through irrigation or deposition), or eating of livestock (through living in or drinking contaminated water or eating contaminated plants).

6.1.4 Receptors

Specific critical groups will be assessed for the atmospheric pathways and a hypothetical critical group will be assessed for the aquatic pathway.

6.2 INTERACTION MATRIX

An interaction matrix is a useful tool to use in a systematic approach for a source-pathway-receptor analysis. It provides a means to identify the interacting media between sources, pathways and receptors and to represent these in a visual and transparent manner. For this assessment a generic interaction matrix for a typical uranium mine is provided in Appendix C. This serves as a guide and tool for model development not only for the present assessment but also for future assessments during the operational as well as closure and post closure phases.

6.3 CRITICAL GROUPS AND EXPOSURE SCENARIOS

6.3.1 General

Distinction is made between the mining scenarios related to different mining operations (see Section 6.1.2.2) and exposure scenarios describing the exposure conditions developed for the human receptors. The section below provides detail on the various exposure scenarios as per the source-pathway-receptor analysis described in Section 6.1 and the motivations provided for the limited or generic approach during the present prospective assessment. It should be noted that the exposure scenarios mostly covered only some pathways and that the assessment is mostly performed for each source separately. The assessment of total doses may therefore require the summation of doses and different sources for different scenarios applicable to the same group.

6.3.2 Normal Evolution Condition Scenarios

For this assessment, conceptual models for a total of six exposure scenarios are developed below for normal evolution conditions. Three scenarios are then duplicated and used for assessments on the background conditions.

6.3.2.1 Exposure Scenario 1: Tourist at Bloedkoppie

This scenario will primarily look into exposures via the atmospheric pathway. The critical group is assumed to consist of adults exposed to radon and long lived radioactive dust as emitted for the various mining scenarios at Langer Heinrich, which may also deposit in the area. The people visiting the area will not consume any local water or food. The aquatic and food pathways are hence not considered for this scenario. It is also assumed that the people will stay a maximum of one week (168 hours) at the site. Exposure Scenario 1 is schematically presented in Figure 1 and the location of Bloedkoppie is indicated in Figure 2.

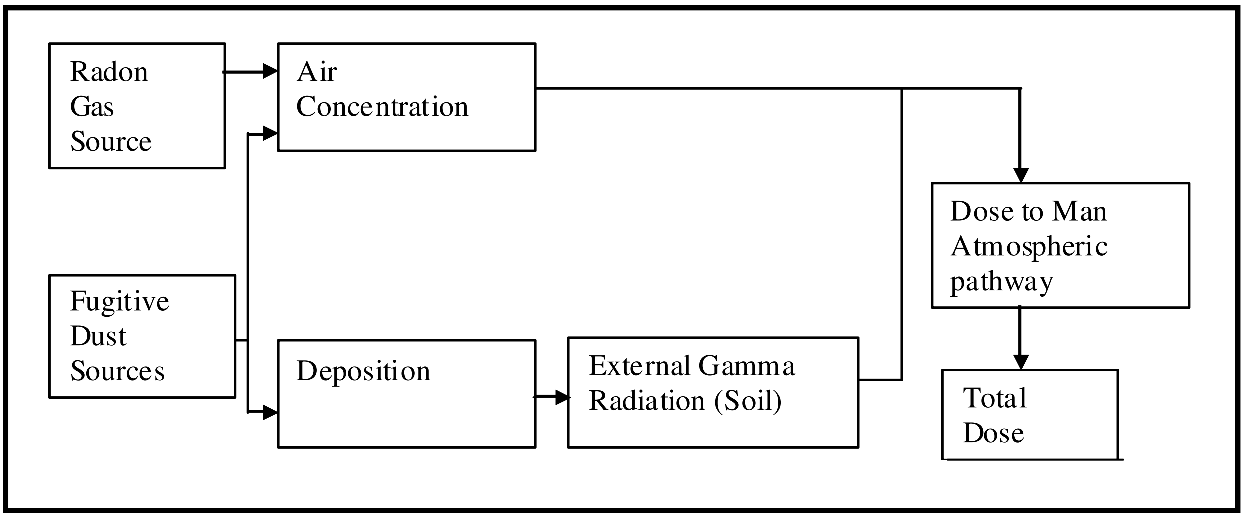

Figure 1: **Schematic presentation of Exposure Scenario 1: Tourist at Bloedkoppie**

6.3.2.2 Exposure Scenario 2: Driller/Exploration

This scenario will primarily look into exposures at the drillers' temporary dwelling camp situated at the eastern side of the mining site as indicated in Figure 2. All drillers are adults and according to the current situation they are staying in the camp for 4 days a week and are off site for 3 days a week. As they will be regarded as radiation workers only the exposure time during off times will be used i.e. 12 hours per day indoors or 2496 hours per annum. The drillers will not consume any local water or food. The aquatic and food pathways are not considered for this scenario. As for Exposure Scenarios 1 the atmospheric pathway is of primary importance. Exposure Scenario 2 is also schematically presented in Figure 1.

6.3.2.3 Exposure Scenario 3: Contractors

This scenario will primarily look into exposures of the contractors in the proposed temporally contractors camp as indicated in Figure 2. This scenario is similar to Exposure Scenario 2, only difference being the exposure time. All contractors will be adults and are staying in the camp for 6 days a week and off site for 1 day a week. Although contractors will stay at Langer Heinrich for different amounts of time, for this exposure scenario it is conservatively assumed that a person will stay for 12 months. As they are also regarded as radiation workers only the exposure time during off times will be used i.e. 12 hours per day indoors or 3744 hours per annum. In addition, the exposure scenario is only evaluated for a 12 month period in terms of the current mine operations since they will not be on site when the future expansion commences.

Figure 2: **Location of sensitive receptors as described in Exposure Scenarios 1-3.**

6.3.2.4 Exposure Scenario 4: Hypothetical Agricultural Group

This hypothetical scenario considers a small farming community living on the banks of the Swakop River downstream of the confluence of the Gawib and Swakop Rivers, approximately12.5 km from the possible source of contamination. The location of this hypothetical farm is within the National Naukluft Park and the nearest real farm seems to be located only further downstream in the Swakop River at 35 km from confluence of the Gawib and Swakop. The hypothetical location is selected because water modelling data is available for up to this point as per [5] and would hence present a conservative dose for a real group downstream. The critical group receives a potential dose through aquatic pathways only. It is assumed that the critical group obtains all their water from the Swakop River as groundwater and that the human ingestion pathway is extended to include the dose contribution from vegetable and animal consumption. This scenario is schematically presented in Figure 3 and included the following pathways, drinking water and milk and eating animal products like beef, mutton, pork, poultry, eggs, where the animals were again ingesting contaminated water, fodder like grass or cereal and sometimes even soil. The Uranium concentrations presented in Table 5 will be used for this assessment.

It is further assumed that the soil contamination builds up to equilibrium while in practice this may not happen due to the high salt concentration in the Swakop River, allowing irrigation only for a limited period.

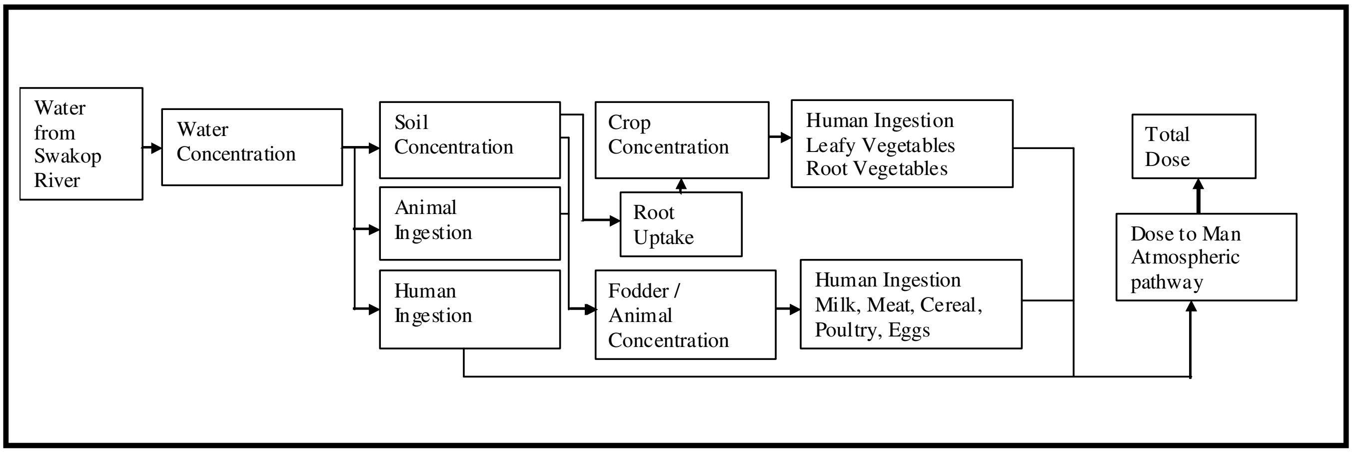

Figure 3: **Schematic presentation of Exposure Scenario 4: Hypothetical Agricultural Group**

6.3.2.5 Exposure Scenario 5: Background Aquatic Scenario

This scenario will be similar to the hypothetical agricultural scenario above but looking at the analysed radionuclide concentration in boreholes WW41180 - WW41182 in the Swakop River as presented in Appendices in [5]. It will hence relate to a background dose for this agricultural group.

6.3.2.6 Exposure Scenario 6: Hypothetical Food Consumer Group

This group are a hypothetical group consuming green and root vegetables marketed by the farming community mentioned in Exposure Scenario 4 above. Due to the limited production capability of the region, it is assumed that the food consumer group obtains only 10 % of their food intake from this source.

6.3.3 Disruptive Scenarios

Consideration of scenarios for disruptive events falls outside the scope of this prospective assessment. They can better be considered in future iterations or in a post-closure assessment together with assessments related to institutional control failures.

7.0 RADIOLOGICAL HAZARD ASSESSMENT

7.1 GENERAL

This section involves a deterministic assessment of the radiological impact to the critical groups of each defined exposure scenario, using the conceptual models above together with suitable parameters. This analysis is presented in Section 7.2 to Section 7.6 below.

7.2 SOURCE TERM ASSESSMENT METHODOLOGY

7.2.1 Radon Source Terms

Radon exhalation source terms can be measured experimentally, but such data are presently unavailable for Langer Heinrich. For this prospective assessment, radon exhalation source terms will hence be calculated from the estimated Ra-226 concentrations assuming published values for the emanation and diffusion coefficients for uranium mine tailings.

The radon flux at the surface of a flat surface of tailings material with a uniform density and Ra-226 content is presented by [18]

$$F_t = R \,.\, \rho \,.\, E \,.\, \sqrt{\lambda \,.\, D_t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

F_t = Radon flux at the surface of the tailings dam [$\text{Bq.m}^{-2}.\text{s}^{-1}$]
R = Ra-226 concentration in the tailings [Bq.g^{-1}]
ρ = Bulk density of tailings (assumed to be 1500 kg.m^{-3}) [kg.m^{-3}]
E = Emanation coefficient of tailings (assumed to be 0.2) [-]

λ = Decay constant of Rn-222 (2.06E-06 s^{-1}) [s^{-1}]
D_t = Diffusion coefficient of tailings (assumed to be 1.0E-06 $m^2.s^{-1}$) [$m^2.s^{-1}$]

The total source strength is obtained by multiplying the flux by the total surface area of the emanating surface of the tailings dam or other sources.

7.2.2 Dust Source Terms

Gravimetric dust source terms are assessed in [6] and will be converted to activity source terms using the radioanalytical results in Table 3.

7.2.3 Aquatic Source Terms

The input concentrations for the aquatic sources in the groundwater model were set at 200 ppm for uranium and are discussed in [5]. The derived values used for this assessment is indicated in Table 5.

7.3 ASSESSMENT OF ATMOSPHERIC AND AQUATIC TRANSFERS

Atmospheric transfer of radon and dust emissions is usually modelled by dispersion models, covering the region between the sources and receptor locations.

The radon dispersion modelling, as reported in [6] is performed assuming a unit radon flux from the various sources considered. The radon concentrations reported will hence be adjusted linearly to the flux calculated for each source as per the analysed Ra-226 concentration in the source material, as per equation (1).

Gravimetric dust concentrations are assessed in [6] and will be converted to activity using the radioanalytical results in Table 3.

7.4 DOSE ASSESSMENT METHODOLOGY

7.4.1 External Exposure Pathway

External exposure occurs when soil is contaminated either through the deposition of airborne radioactivity or through the irrigation of soil with contaminated water. In the case of deposited material, the activity is present as a thin cover layer. The external dose is in this case calculated from the surface activity concentration of the soil by using published dose coefficients. Dose coefficients are factors (sometimes also referred to as dose conversion factors), presenting the dose per unit activity or dose rate per unit activity concentration. For external radiation it presents the dose rate in $\mu Sv.h^{-1}$ at a distance of 1 metre above an infinite plane source of unit surface activity concentration in $Bq.m^{-2}$. In the case of irrigated soil the activity is more likely to penetrate the soil to generate a thick slab of radioactive soil. The external dose is in this case calculated from the volume activity concentration of the soil by using published dose coefficients, presenting the dose rate in μSv.h^{-1} at a distance of 1 metre above an infinite slab source of unit mass activity concentration in Bq.g^{-1}.

The mathematical model for external gamma radiation is given by

$$DEXT_{soil} = 1.0E+06 \, . \, Conc_{soil} \, . \, DC_{ext} \left(EP_O + EP_I \, . SF \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where

$DEXT_{soil}$ = External dose from the contaminated soil [μSv.a^{-1}]
$Conc_{soil}$ = Soil surface or soil mass activity concentration [Bq.m^{-2}]or [Bq.g^{-1}]
DC_{ext} = Dose coefficient for external exposure [Sv.h^{-1} per Bq.m^{-2}] or [Sv.h^{-1} per Bq.g^{-1}]
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 are taken from [19] and are presented in Table 16 and Table 17: in Appendix B.

7.4.2 Radon Inhalation Pathway

The dose from the exposure to inhaled radon daughters is calculated from modelled indoor and outdoor radon gas concentrations, by multiplication with appropriate conversion factors. For the respective exposure times refer to Section 6.3.2. The indoor and outdoor concentrations are 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 [11]. The conversion factors for radon are age-independent and will be used.

The mathematical model for radon is given by

$$D_{Radon} = 1.0E+03 \, . \left(Conc_i \, . \, F_i \, . T_i + Conc_o \, . \, F_o \, . T_o \right) . \, CC_{Rn} \, . \, DC_{Rn} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where

D_{Radon} = Dose from radon exposure [μSv.a^{-1}]
$Conc_i$ = Indoor radon concentration [Bq.m^{-3}]
F_i = Indoor equilibrium factor (0.4)
T_i = Indoor exposure period [h.a^{-1}]
$Conc_o$ = 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}]
= (5.6E-6 as per [11])
DC_{Rn} = Dose coefficient for radon exposure [mSv.h^{-1} per mJ.m^{-3}]
= (1.1 for the public and 1.4 for workers)

7.4.3 Dust Inhalation Pathway

The dose from the exposure to inhaled radioactive airborne dust is calculated from estimated outdoor dust activity concentrations (also assumed to apply to indoor conditions) by multiplication with appropriate conversion factors. To calculate the inhalation dose from airborne radioactive dust, it is necessary to make certain assumptions concerning the behaviour of the critical group:

(a) For the respective exposure times refer to Section 6.3.2.

(b) For the members of the critical groups from each exposure scenario a breathing rate of 0.93 m^3/h was assumed because the scenarios were for non-occupational exposure thus also implying sleeping of 8 hours also as indicated in Table 13 in Appendix B.

The dose coefficients (Sv.Bq^{-1}) for inhalation were taken from [8], [22] (See Table 14). The mathematical model to calculate the dust inhalation dose is given by:

$$D_{inh,Dust} = 1.0E + 06 \, . \, Conc_{Dust} \, . \, DC_{inh} \, . \, (T_o + SF \, . \, T_i) \, . \, BR \, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where this and other equations apply to each radionuclide and where

$D_{inh,Dust}$ = Inhalation dose from radioactive airborne dust [µSv.a^{-1}]
$Conc_{Dust}$ = Radionuclide concentration in airborne dust [Bq.m^{-3}]
DC_{inh} = Nuclide-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 each public age group (See Table 13) [m^3.h^{-1}]

7.4.4 Dust Deposition

Through the process of deposition and re-suspension, airborne activity can be redistributed. Modelled results for dust deposition rates are provided by the dispersion modelling in [6]. While the dust may be re-suspended, a suitable re-suspension factor could not be found for a desert environment. A re-suspension factor of around 2E-06 m^{-1} [23] seems to be more related to on-mine activities. For this reason an accumulation period of 5 years for environmental outdoor conditions is assumed for the deposited dust where-after the source is assumed to have reached an equilibrium state. For temporary facilities planned for the current phase of the mine only 1 year accumulation period is assumed with no indoor shielding factor. Permanent buildings, erected after 5 year deposition, are assumed to have a floor with a shielding factor of 0.1. External doses are determined from the deposition sources above, assumed to be an infinitely large surface source as per the methodology in Section 7.4.1 above.

7.4.5 Water Ingestion Pathway

The dose from the consumption of radioactively contaminated water is calculated from uranium concentrations of the water as per Table 5, by multiplication with appropriate conversion factors. The dose coefficients (Sv.Bq^{-1}) for ingestion were taken from [8], [22] (See Table 15). The mathematical model to calculate the water ingestion (drinking) dose is given by:

$$D_{ing,water} = 1.0E+06\ .\ Conc_{water}\ .\ DC_{ing}\ .\ CR_{water} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where

$D_{ing,water}$	=	Ingestion dose from drinking contaminated water	[μSv.a^{-1}]
$Conc_{water}$	=	Radionuclide concentration in water	[Bq.L^{-1}]
DC_{ing}	=	Dose coefficient for ingestion	[Sv.Bq^{-1}]
CR_{water}	=	Annual water consumption rate	[L^{-1}.a^{-1}]

7.4.6 Soil Activity

Soil can become contaminated in the following two ways:

(a) The deposition of dispersed airborne radioactivity.
(b) The transfer of radioactivity in water to the soil during irrigation.

Deposition and irrigation will increase the activity of the top layer of the soil. This soil may be ingested directly (especially by children), but may also increase the amount of activity available for uptake by plants, and eventually reach the critical group through secondary pathways.

Dust deposition is discussed in Section 7.4.4. To derive soil concentrations from water used for irrigation purposes, the following approach is used. The very conservative assumption is made that a state of equilibrium exists between the concentration in water and the concentration in the soil at a constant irrigation rate. Given the concentration in water, the concentration in soil can be calculated using the following formula:

$$I_{Irr} = \frac{C\,(\theta + \rho\, K_d)}{\rho} \quad \ldots\ldots(6)$$

where

I_{Irr}	= Concentration in the soil due to irrigation	[$Bq.kg^{-1}$]
C	= Concentration in irrigation water	[$mBq.L^{-1}$ *or* $Bq.m^{-3}$]
ρ	= Dry bulk density of soil	[$kg.m^{-3}$]
θ	= Volumetric moisture content	[$m^3.m^{-3}$]
K_d	= Distribution coefficient (adsorption coefficient)	[$m^3.kg^{-1}$]

From Equation 6, it is clear that the distribution coefficient is an important parameter in determining the soil concentration. A high K_d-value will lead to higher soil concentrations and *vice versa*. The uncertainties that exist in K_d-values are transferred to the soil concentrations and therefore, to the rest of the dose assessment. K_d-values for sandy soil [21] and water-to-soil concentrations factors, calculated from these by using equation (6) are presented in Table 18 and Table 20 in Appendix B. This soil concentration is assumed to be in the top ploughed layer of the soil to present an infinite slab in terms of the external dose.

7.4.7 Soil Ingestion Pathway

The mathematical model to calculate the ingestion dose from eating the contaminated soil, is given by

$$D_{ing,soil} = 1.0E+06\,.\,Conc_{soil}\,.\,DC_{ing}\,.\,CR_{soil} \quad \ldots\ldots(7)$$

where

$D_{ing,soil}$	= Ingestion dose from eating contaminated soil	[$\mu Sv.a^{-1}$]
$Conc_{soil}$	= Radionuclide concentration in soil from deposition/irrigation	[$Bq.kg^{-1}$]
DC_{ing}	= Dose coefficient for ingestion	[$Sv.Bq^{-1}$]
CR_{soil}	= Annual soil consumption rate	[$kg.a^{-1}$]

The dose coefficient ($Sv.Bq^{-1}$) for ingestion was taken from [8], [22] (See Table 15), while the annual soil consumption rate for the various age groups is presented in Table 19.

7.4.8 Secondary Crop Ingestion Pathway

The mathematical model to calculate the ingestion dose from eating crops like cereals, fruit, leafy or root vegetables, which again were grown on the contaminated soil, is given by

$$D_{ing,crops} = 1.0E+06\ .\ Conc_{soil}\ .\ DC_{ing}\ .\ CR_{crops}\ .\ CF_{crops} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8)}$$

where

$D_{ing,crops}$ = Ingestion dose from eating crops [μSv.a^{-1}]
$Conc_{soil}$ = Radionuclide concentration in soil from deposition/irrigation [Bq.kg^{-1}]
DC_{ing} = Dose coefficient for ingestion [Sv.Bq^{-1}]
CR_{crops} = Annual crop consumption rate [kg.a^{-1}]
CF_{crops} = Concentration factor from soil to crops [-]

The annual consumption rate for various crops by the various age groups [21] is presented in Appendix B, while the concentration factors from the contaminated soil to the various crops are presented in Table 20.

7.4.9 Secondary Animal Product Ingestion Pathway

The mathematical model to calculate the ingestion dose from drinking milk and eating animal products like beef, mutton, pork, poultry, eggs, where the animals were again ingesting contaminated water, fodder like grass or cereal and sometimes even soil, is given by:

$$D_{ing,product} = 1.0E+06\ .\ TC_{product}\ .\ DC_{ing}\ .\ CR_{product}\ .$$
$$\left[\left(Conc_{soil}\ .\ CR_{soil} + Conc_{soil}\ .\ CF_{fodder}\ .\ CR_{fodder}\right) + \left(Conc_{water}\ .\ CR_{water}\right)\right] \ldots\ldots\ldots\ldots\ldots \text{(9)}$$

where

$D_{ing,product}$ = Ingestion dose from consuming the product [μSv.a^{-1}]
$TC_{product}$ = Transfer coefficient for product [d.kg^{-1}]
DC_{ing} = Dose coefficient for ingestion [Sv.Bq^{-1}]
$CR_{product}$ = Annual product consumption rate [kg.a^{-1}]
$Conc_{soil}$ = Soil specific activity concentration from deposition or irrigation [Bq.kg^{-1}]
CR_{soil} = Daily soil consumption rate of animal [kg.d^{-1}]
CF_{fodder} = Concentration factor from soil to fodder [-]
CR_{fodder} = Daily fodder consumption rate of animal [kg.d^{-1}]
$Conc_{water}$ = Water specific activity concentration [Bq.L^{-1}]

CR_{water} = Daily water consumption rate of animal [L.d^{-1}]

For Langer Heinrich the secondary animal product ingestion pathways are only applicable to Exposure Scenario 4 and the pathways are illustrated in Figure 3.

The following data from [21] is used and summarised in the following Tables in Appendix B:

- The annual consumption rate of animal products by humans of various age groups;
- Table 19.
- The concentration factors from the contaminated soil to grass and other crops; Table 20.
- The transfer coefficients from the various animal products; Table 22.
- The consumption rates of grass, fodder or cereal by various animals; Table 23.

7.5 ASSESSMENT

The mathematical models, as detailed in 7.4, were developed as interconnecting worksheets on a Microsoft Excel spreadsheet file. By using best estimates of published parameter values [21] (see Appendix B), deterministic doses were assessed for the different pathways applicable to the critical group of each normal evolution scenario developed in Section 6.3.2. Assessment detail and the results are presented in Section 7.6.

7.6 RESULTS

Dose assessment results for the atmospheric pathway are presented below.

7.6.1 Radon Inhalation Pathway

The radon dispersion results for each of the mining operations obtained from [6] was calculated using a radon source with a radon flux of 1 Bq/m^2. To reflect the real situation as indicated by the radioanalytical results (see Table 3), a radon flux correction was done. This correction factor was calculated by using Equation 1 and the Ra-226 value of the sample that linked to the mining operation but also had the highest impact e.g. *Blasting* was linked with the *Open Pit A* sample (see Table 6 for these correlations). As no samples were taken indoors, it was assumed that the indoor and outdoor concentrations are equal. The resulting correction factors were multiplied with the applicable radon dispersion results and converted to a dose for an adult (although radon doses are age-independent) by using Equation 3 and a one year exposure time (that is 4380 hours indoors and 4380 hours outdoors). The doses for all the mining operations were added to obtain the total radon inhalation dose. This was done for all the mining scenarios (given in Section 6.1.2.1). The total radon inhalation dose results, indicated as contour plots, are depicted in Figure 4 to Figure 7.

From the above-mentioned results, the doses for the different Exposure Scenarios (per Section 6.3.2) were derived firstly by obtaining the yearly dose at the locations and secondly correcting it for the applicable exposure times by applying Equation 3. The respective total radon inhalation doses are summarised in Table 7.

Table 6: Mining operations linked to the samples that were analysed for radioactivity.

Mining Operation	Sample
Crushing	Weighted mean of ROM Low Grade and ROM High Grade
Drilling	Open Pit A
Blasting	Open Pit A
Unpaved roads	Haul roads
Excavation	Open Pit A
Tipping	Weighted mean of ROM Low Grade and ROM High Grade
Wind erosion	Weighted mean of Tailing Dam Wall and Tailing Dam Beach

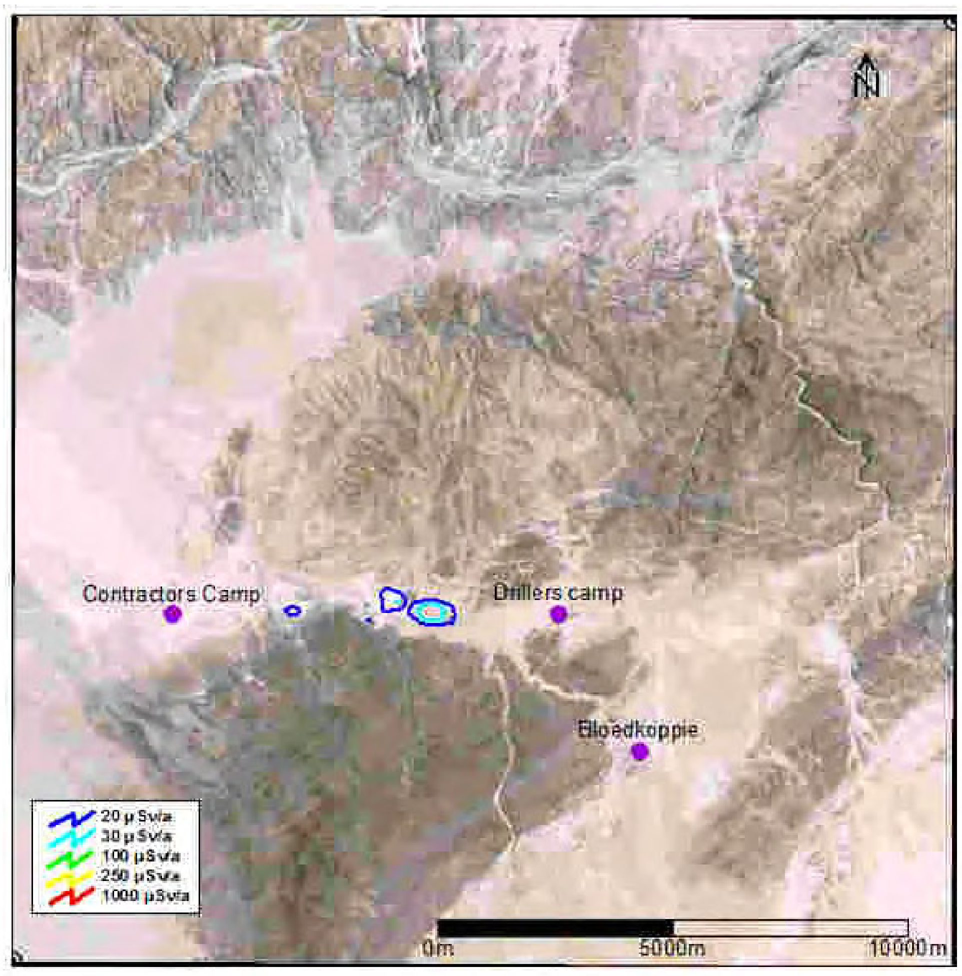

Figure 4: **Calculated doses (µSv.a^{-1}) for Radon Inhalation from the Current mine operations for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

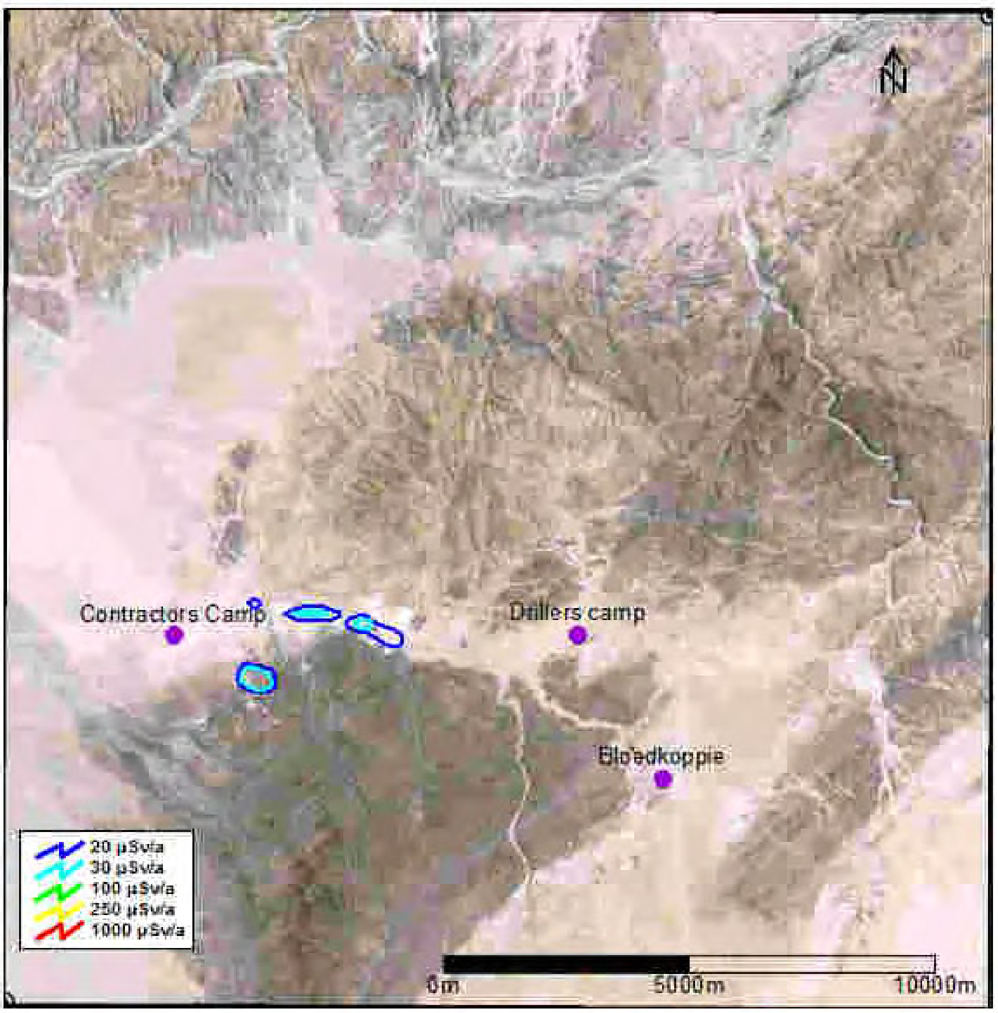

Figure 5: **Calculated doses (µSv.a^{-1}) for Radon Inhalation from the future Western Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors).**

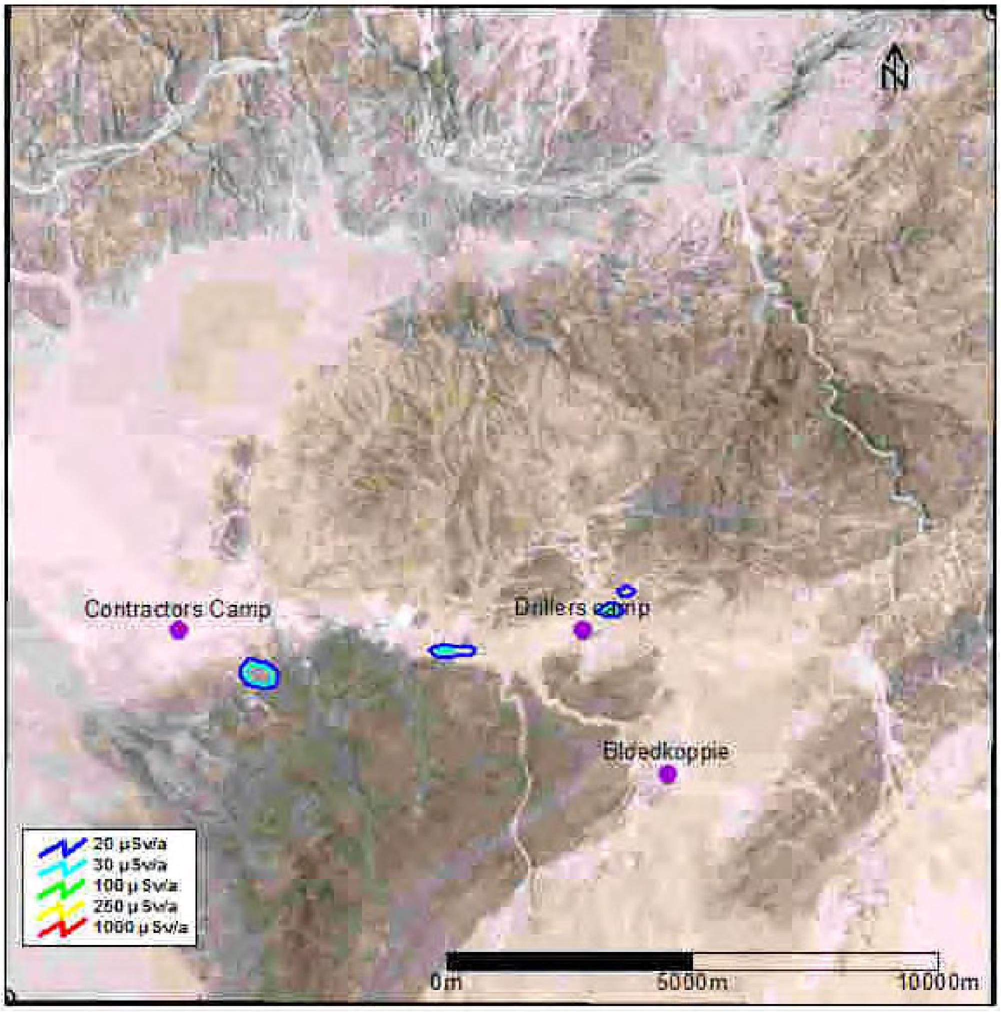

Figure 6: **Calculated doses (µSv.a^{-1}) for Radon Inhalation from the future Central Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

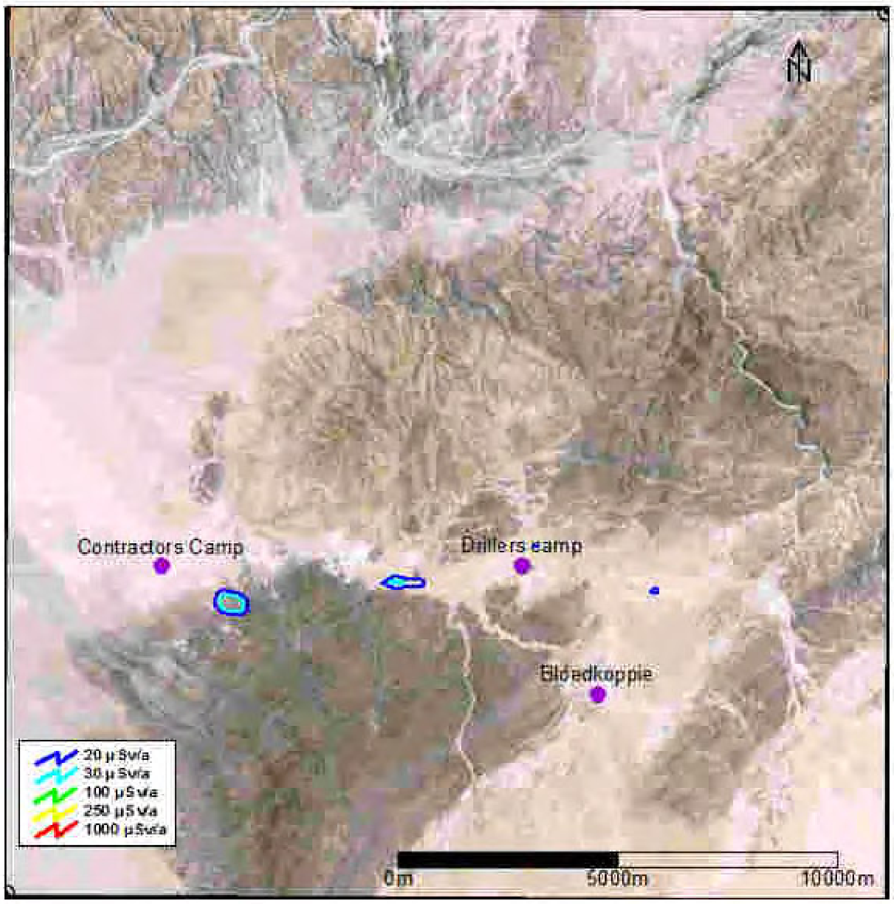

Figure 7: **Calculated doses (µSv.a^{-1}) for Radon Inhalation from the future Eastern Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

Table 7: Doses (µSv.a^{-1}) from Radon Inhalation for the different Exposure Scenarios.

Exposure Scenario	Current Operations	Future Western Pit	Future Central Pit	Future Eastern Pit
1	0.046	0.046	0.041	0.041
2	0.70	0.44	1.5	1.3
3	0.51	-	-	-

7.6.2 Dust Inhalation Pathway

The PM10 dust dispersion results were used to determine the dose due to dust inhalation. These results, obtained from [6], for each of the mining operations were changed to radionuclide concentrations by multiplying with the total radionuclide concentrations (see Table 3) of the samples that are linked to the mining operation (see Table 7 and discussion thereof in 7.6.1). As no samples were taken indoors, it was assumed that both the indoor and outdoor concentrations are equal. The resulting concentrations were converted to a dose for an adult by using Equation 4 with a breathing rate of 0.93 m^3h^{-1} and a one year exposure time (that is 4380 hours indoors and 4380 hours outdoors). The doses for all the mining operations were added to obtain the total dust inhalation dose. This was done for all the mining scenarios (given in Section 6.1.2.2). The total dust inhalation dose results, indicated as contour plots, are depicted in Figure 8 to Figure 11.

From the above-mentioned results, the adult doses for the different Exposure Scenarios (per Section 6.3.2) were derived firstly by obtaining the yearly dose at the locations and secondly correcting it for the applicable exposure times by applying Equation 4. The respective total dust inhalation doses are summarised in Table 8. Doses for other age groups relate to the adult doses through conversion to other inhalation rates and dose coefficients. Performing such a correction indicates lower doses for children, except for the 15 year age group where the dose from Po-210 exceeds the adult dose by 7 % and the dose from Ra-223 (U-235 series) exceeds the adult dose by 14 %. This applies only to the Bloedkoppie scenario, where these increases will still result in very low doses below 1 $\mu Sv.a^{-1}$ as per Table 8.

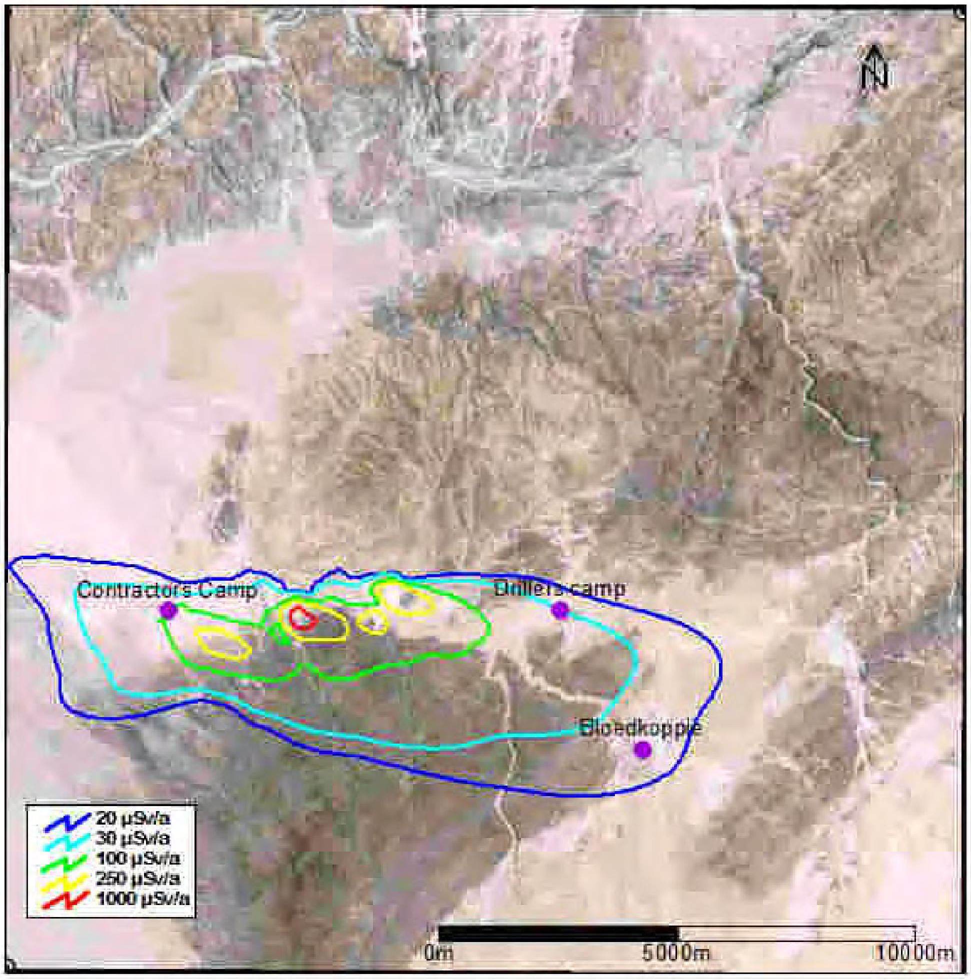

Figure 8: Calculated doses (µSv.a^{-1}) for Dust Inhalation from the Current mine operations for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors).

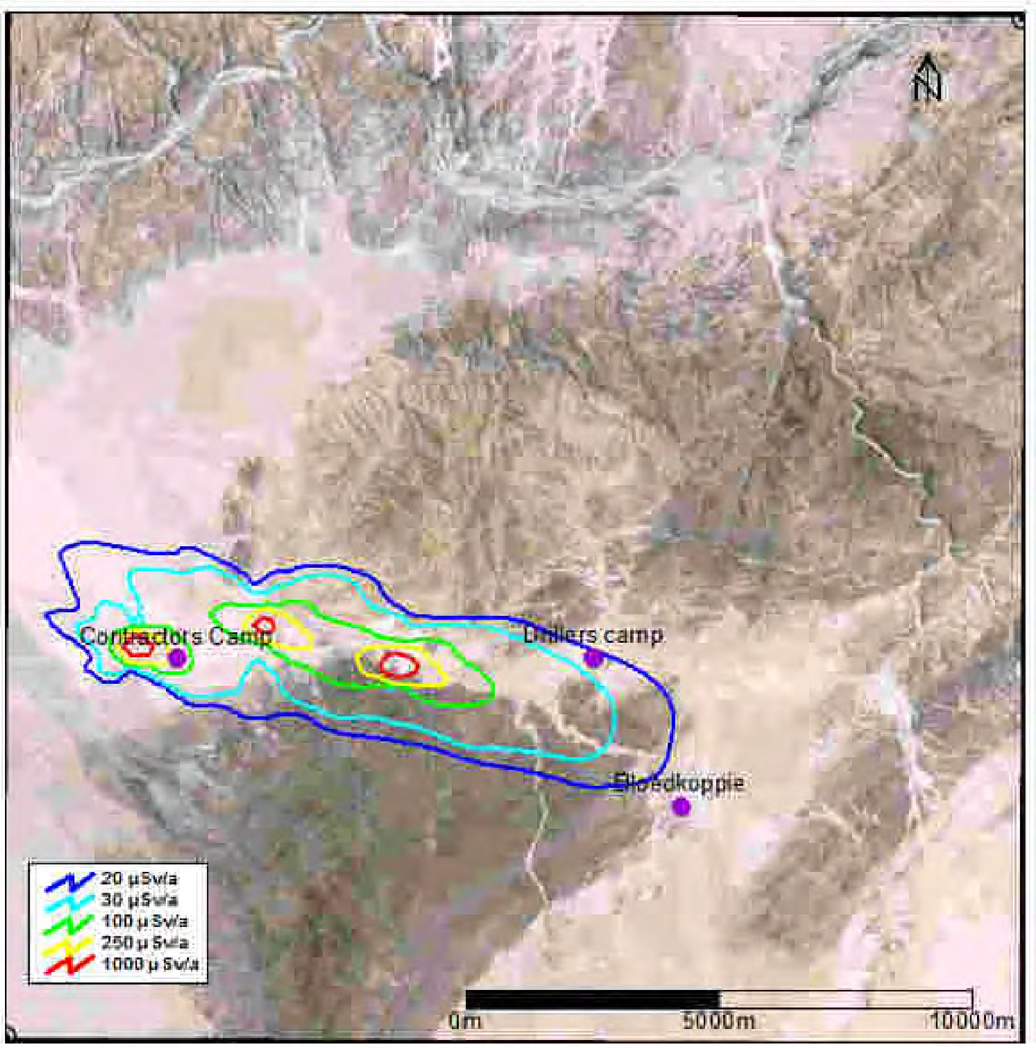

Figure 9: **Calculated doses (µSv.a^{-1}) for Dust Inhalation from the future Western Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors).**

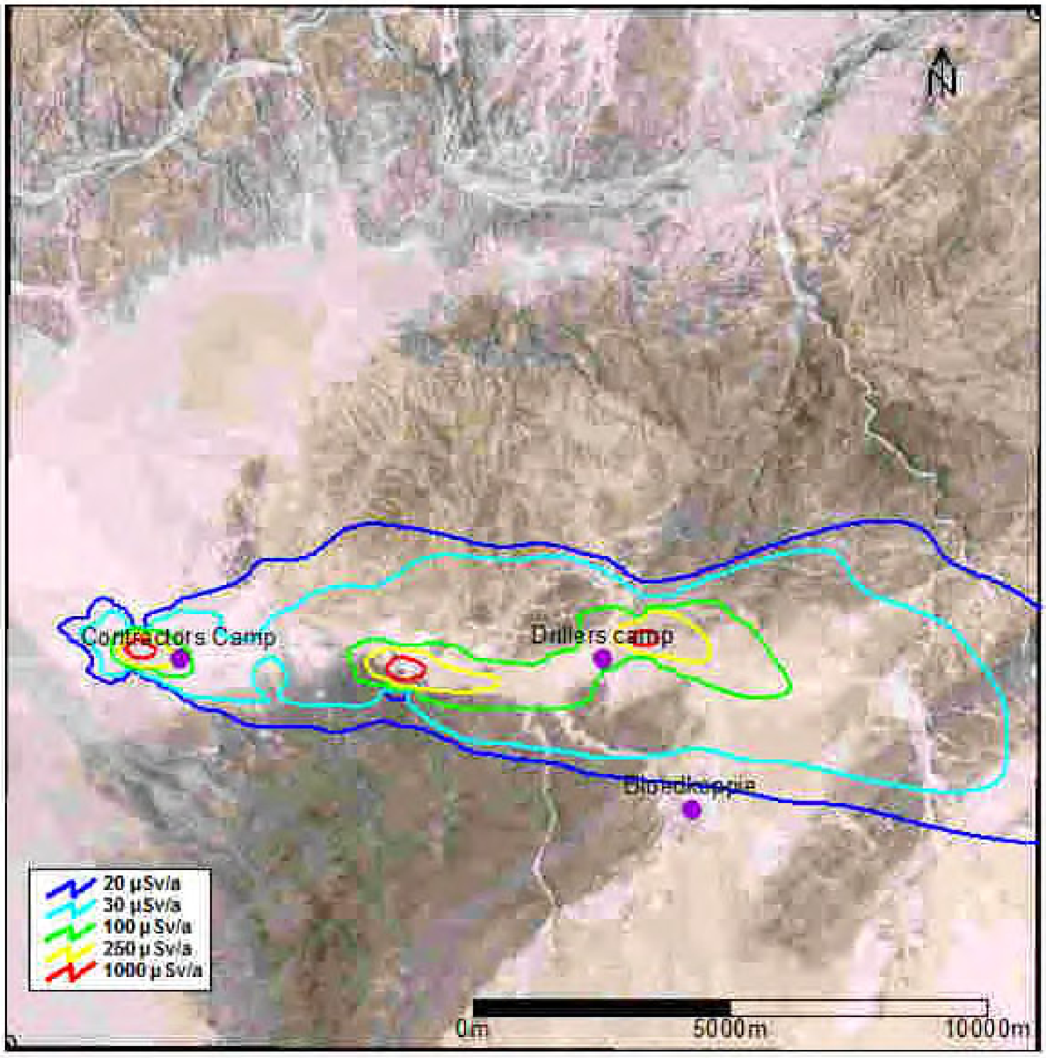

Figure 10: **Calculated doses (µSv.a^{-1}) for Dust Inhalation from the future Central Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

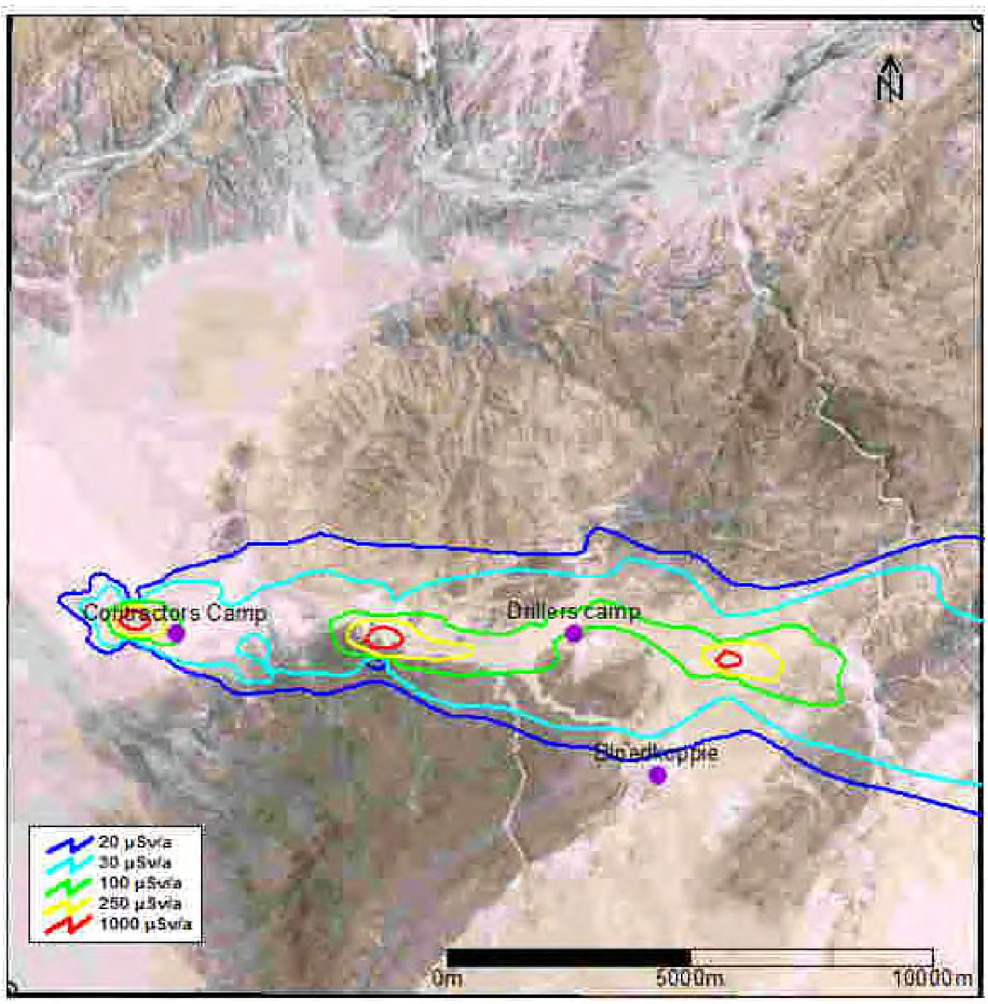

Figure 11: **Calculated doses (µSv.a^{-1}) for Dust Inhalation from the future Eastern Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

Table 8: Doses (µSv.a^{-1}) from Dust Inhalation for the different Exposure Scenarios.

Exposure Scenario	Current Operations	Future Western Pit	Future Central Pit	Future Eastern Pit
1	0.44	0.29	0.27	0.27
2	8.5	6.3	46	28
3	43	-	-	-

7.6.3 External Exposure to Deposited Dust

The TSP dust dispersion results were used to determine the dose due to dust deposition. These results, obtained from [6], for each of the mining operations were changed to radionuclide concentrations by multiplying with the product of the Uranium-238 radionuclide concentrations (see Table 3) of the samples that are linked to the mining operation (see Table 9 and discussion thereof in 7.6.1) and a 1 year dust deposit time (see Section 7.4.4). As no samples were taken indoors, it was assumed that both the indoor and outdoor concentrations are equal. The resulting concentrations were converted to a dose for an adult by using Equation 2 with a one year exposure time (that is 4380 hours indoors and 4380 hours outdoors). The doses for all the mining operations were added to obtain the total dust deposition dose. This was done for all the mining scenarios (given in Section 6.1.2.2). The total dust inhalation dose results, indicated as contour plots, are depicted in Figure 12 to Figure 15.

From the above-mentioned results, the doses for the different Exposure Scenarios (per Section 6.3.2) were derived firstly by obtaining the yearly dose at the locations and secondly correcting it for the applicable exposure times by applying Equation 2. The respective total dust deposition doses are summarised in Table 9. External doses from deposited dust are age-independent and apply to both adults and children.

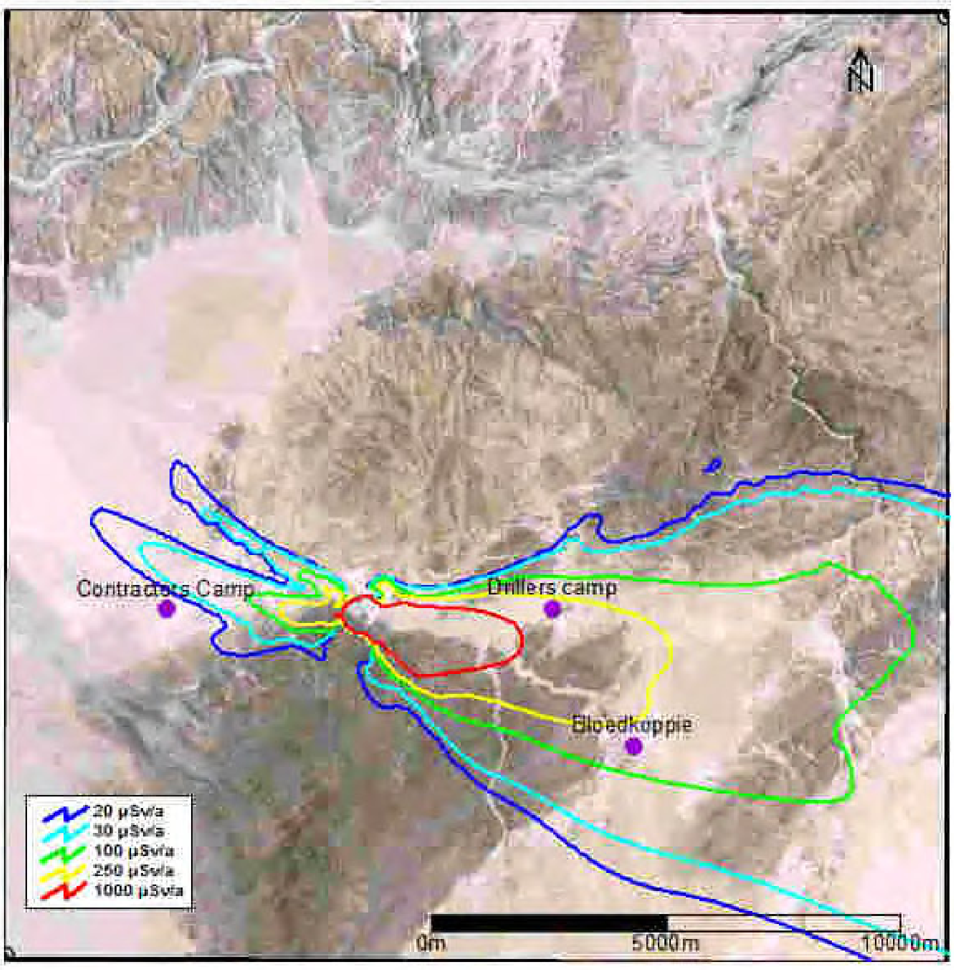

Figure 12: **Calculated doses (µSv.a^{-1}) for Dust Deposition from the Current mine activities for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

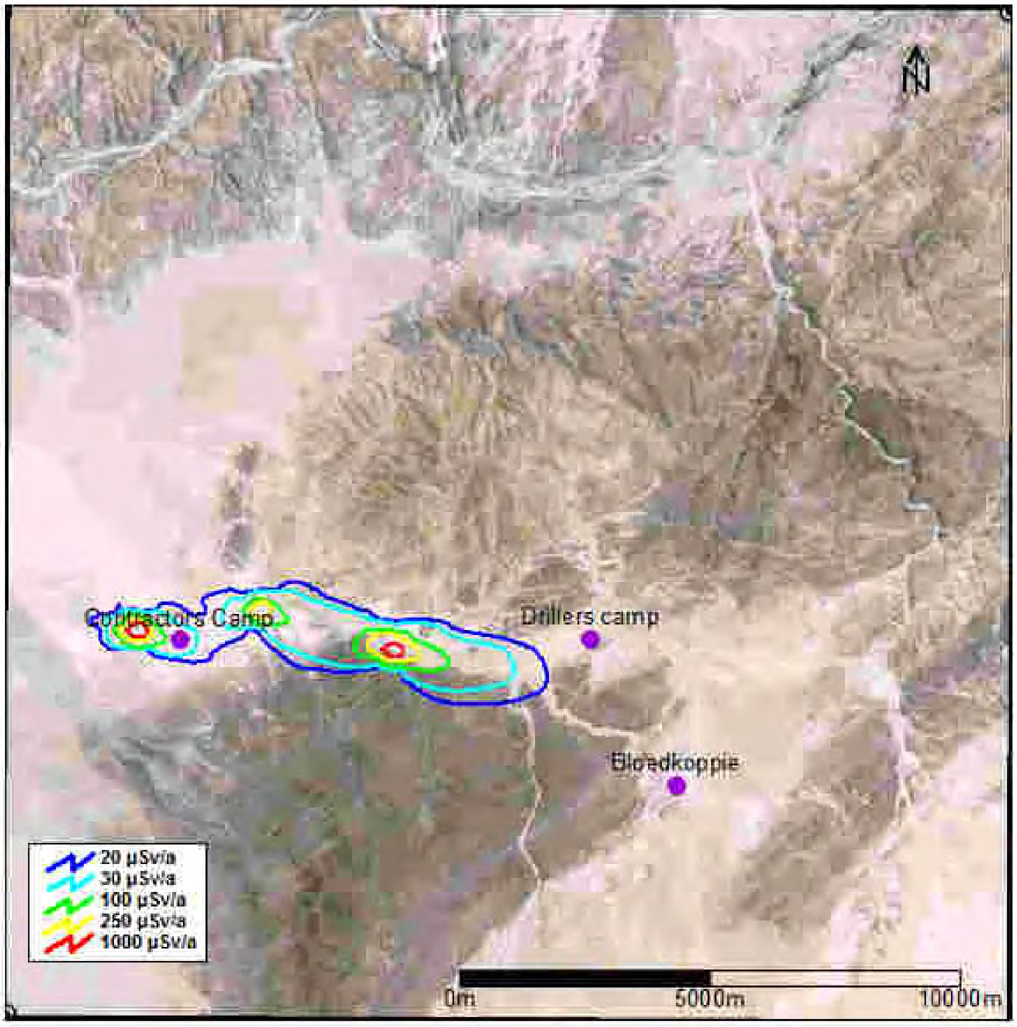

Figure 13: Calculated doses (µSv.a^{-1}) for Dust Deposition from the future Western Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)

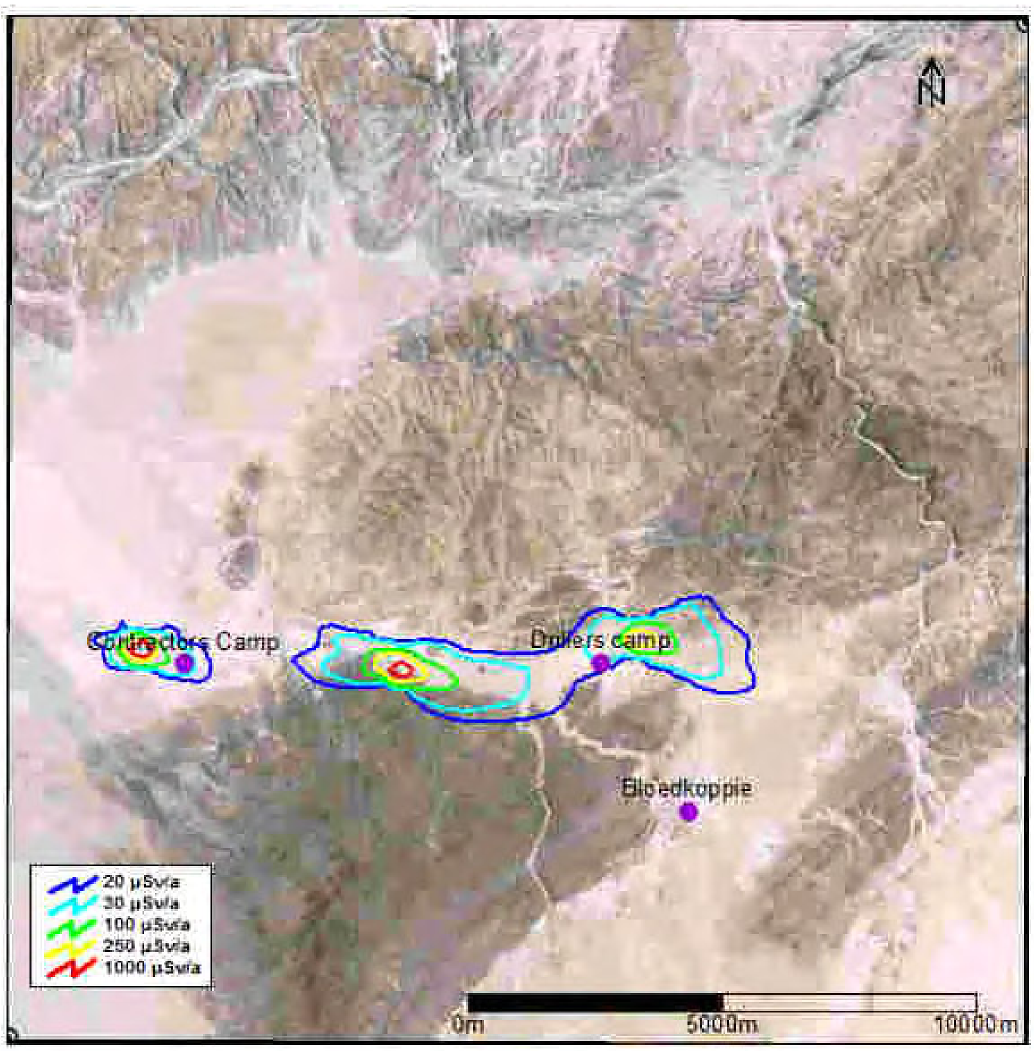

Figure 14: **Calculated doses (µSv.a^{-1}) for Dust Deposition from the future Central Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

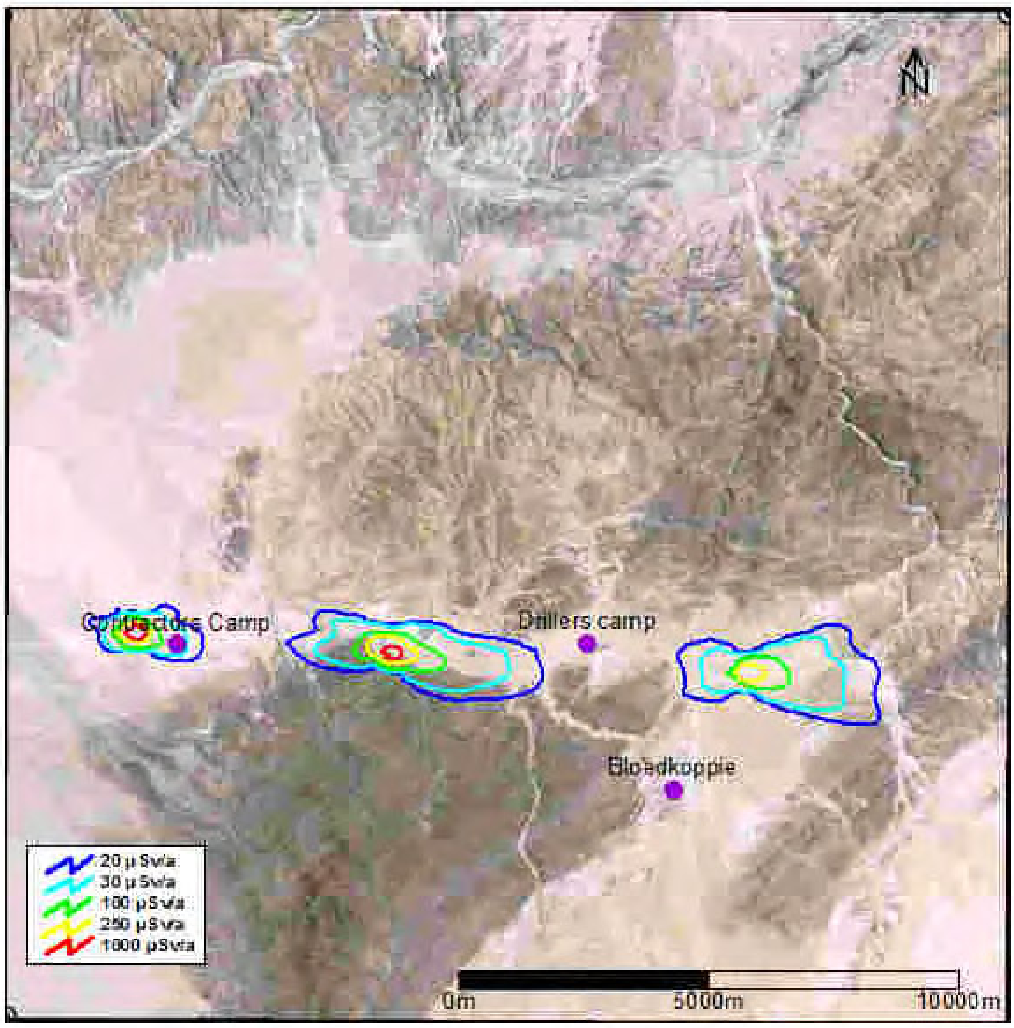

Figure 15: **Calculated doses (µSv.a^{-1}) for Dust Deposition from the future Eastern Pit for an adult exposed for 8760 hours (4380 hours indoors and 4380 hours outdoors)**

Table 9: Doses (µSv.a^{-1}) from Dust Deposition for the different Exposure Scenarios.

Exposure Scenario	Current Operations	Future Western Pit	Future Central Pit	Future Eastern Pit
1	3.4	0.086	0.067	0.077
2	114	2.6	7.7	3.4

3	5.1	-	-	-

7.6.4 Total dose due to Atmospheric pathway

The total doses to the critical group in each Exposure Scenario due to atmospheric pathways are summarised in Table 10.

Table 10: Total doses (µSv.a^{-1}) from the atmospheric pathways for the different Exposure Scenarios.

Exposure Scenario	Current Operations	Future Western Pit	Future Central Pit	Future Eastern Pit
1	3.9	0.42	0.38	0.39
2	123	9.3	55	33
3	49	-	-	-

7.6.5 Dose from Aquatic Pathway

The aquatic pathways involve all those pathways related to the use of water. This includes the consumption of the water, the irradiation to and ingestion of irrigated soil and the small scale secondary ingestion of contaminated food. The assessment includes aquatic pathways as discussed in 6.3.2 for the Hypothetical Agricultural group, Hypothetical Food Consumer Group and Background aquatic sources.

The calculated doses apply to adults. Children may receive different doses due to lower consumption figures and higher dose coefficients. Only uranium was modelled for the aquatic pathway. Extrapolating the adult doses to children indicates that doses for the 15 year age group may be underestimated by up to 27 % for U-238 and U-234. This will be considered when evaluating the results in Table 11.

Table 11: Dose in µSv.a^{-1} as per Exposure Scenario descriptions.

Exposure Scenario	Pathways	Scenario 1: Alluvium (conservative case) -12.5 km (No Dilution)	Scenario 2: Alluvium (conservative case) -12.5 km (20% Dilution)	Scenario 3: Alluvium (realistic case) - 12.5 km (No Dilution)	Scenario 4: Alluvium (realistic case) -12.5 km (20% Dilution)	Scenario 5: Natural Background (Boreholes WW41180 - WW41182 Average Uranium concentration)
Exposure Scenario 4: Hypothetical Agricultural Group and Exposure Scenario 5: Background Aquatic Scenario						
	Drinking water	1681	336	504	101	77
	Soil ingestion	3	1	1	0	0
	External soil	24	5	7	1	1
	Milk	93	19	28	6	4
	Beef	911	182	273	55	41
	Mutton	219	44	66	13	10
	Poultry	63	13	19	4	3
	Eggs	21	4	6	1	1
	Grain	14	3	4	1	1
	Leafy vegetables	38	8	11	2	2
	Root vegetables	355	71	106	21	16
	Fruit	2	0	1	0	0
	Total	**3424**	**685**	**1027**	**205**	**157**
Exposure Scenarios 6 Hypothetical Food Consumer	Leafy vegetables	3.8	0.8	1.1	0.2	0.2
	Root vegetables	36	7.1	11	2.1	1.6
	Total	**40**	**7.8**	**12**	**2.3**	**1.8**

8.0 DISCUSSION OF RESULTS AND RECOMMENDATIONS

8.1 EVALUATION AGAINST RADIOLOGICAL CRITERIA

The following radiological criteria are considered in the discussion below:

i. Doses below10 µSv.a^{-1} are regarded as trivial and of no concern.
ii. Doses below 300 µSv.a^{-1} are regarded as below a source constraint (for the Langer Heinrich Mine), ranked as a low risk only needing low priority attention in terms optimization to keep doses As Low as Reasonably Achievable (ALARA).

iii. 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).

iv. Doses above 1000 µSv.a^{-1} are above the public dose limit, of high risk, and need high priority in terms of attention for reduction to below the public dose limit.

8.1.1 Radon Inhalation

The doses due to radon inhalation are summarised in Table 7. The assessed dose from Radon Inhalation to public visiting Bloedkoppie (Exposure Scenario 1) is trivial (smaller than 10 µSv.a^{-1}), for the current and planned future phases considered for the mine. The dose is age independent and also applies to children. No measures are hence recommended to safeguard the public from radon inhalation at Bloedkoppie, considering both the current and future operational phases of the mine.

The assessed dose from Radon Inhalation to the drillers (Exposure Scenario 2) is also trivial (smaller than 10 µSv.a^{-1}), for the current and planned future phases considered for the mine. No measures are hence recommended to safeguard the drillers from radon inhalation at the drillers camp, considering both the current and future operational phases of the mine.

The assessed dose from Radon Inhalation to the construction workers (Exposure Scenario 3) is also trivial (smaller than 10 µSv.a^{-1}), for the current and planned future phases considered for the mine. No measures are hence recommended to safeguard the construction workers from radon inhalation at the construction camp, considering both the current and future operational phases of the mine.

8.1.2 Dust Inhalation

The doses due to dust inhalation are summarised in Table 8. The assessed dose from Dust Inhalation to public visiting Bloedkoppie (Exposure Scenario 1) is trivial (smaller than 10 µSv.a^{-1}), for the current and planned future phases considered for the mine. The dose is age dependent but remains trivial even if adapted to children. No measures are hence recommended to safeguard the public from dust inhalation at Bloedkoppie, considering both the current and future operational phases of the mine.

The assessed dose from Dust Inhalation to the drillers (Exposure Scenario 2) is also low for the current and future scenarios considered, not exceeding 46 µSv.a^{-1}. Again no priority measures seem necessary.

For the contractors at the contractor camp (Exposure Scenario 3) the assessed dose from Dust Inhalation for the present operations is also low at a maximum of 43 µSv.a^{-1}. The contractor project is only planned for 12 months; hence no priority measures seem necessary.

8.1.3 Dust Deposition

The doses due to dust deposition are summarised in Table 9. The assessed dose from Dust Deposition to public visiting Bloedkoppie (Exposure Scenario 1) is trivial (smaller than 10 μSv.a^{-1}), for the current and planned future phases considered for the mine. The dose is age dependent but remains trivial even if adapted to children. No measures are hence recommended to safeguard the public from dust deposition at Bloedkoppie, considering both the current and future operational phases of the mine.

The assessed dose from Dust Deposition to the drillers (Exposure Scenario 2) is also low at 114 μSv.a^{-1}. For future scenarios considered this may even reach below 10 μSv.a^{-1} if the later deposited dust becomes dominant. No priority measures seem necessary.

For the contractors at the contractor camp (Exposure Scenario 3) the assessed dose from Dust Deposition for the present operations is trivial (smaller than 10 μSv.a^{-1}). The contractor project is only planned for 12 months.

However, it must be noted that the doses for the current phase is higher than that of the future phases. The reason for this is the inclusion of the construction phase with the current phase, which is not present in future scenarios.

8.1.4 Total Dose for Atmospheric Pathways

While the total doses for the atmospheric pathway are slightly higher, the conclusions are similar to those above for the dust deposition pathway.

8.1.5 Aquatic Source Pathway Assessments

From Table 11 the dose to the various Exposure Scenarios can be concluded as follow:

For Exposure Scenario 4, the Hypothetical Agricultural Group, the dose due to radiological contamination in the Alluvia is above the public dose limit if the released activity is not diluted in the Swakop River. This result applies when doses are calculated conservatively and realistically. Only when dilution by a factor of 5 is considered the dose become close to the dose constraint of 300 μSv.a^{-1}. High priority attention is hence required to avoid this scenario as per the criteria above. This is in line with the recommendations in [5]. The evaluation above will be similar when considering a 27 % higher dose for the 15 year age group. The construction of barrier systems to prevent the contaminated water leaving the site should be considered with high priority.

The dose calculations summarised in Table 11 should be read with document [5]. The calculated values of the doses will also be influenced by time.

The assessed dose of approximately 160 μSv.a^{-1} due to natural background is well below the public dose limit but is a non-controllable source and not relevant.

8.1.6 Estimate of Total dose from all Pathways

The critical groups for the atmospheric and aquatic pathways are different and the doses from these pathways do not need to be summed for the total dose.

8.1.7 Radiological Waste Management

Namibia draft regulations require that an application must be accompanied by a Radiation Management Programme that addresses in particular radioactive waste management. Langer Heinrich must therefore compile a radioactive waste management programme and must take cognizance of the fact that the use of the waste rock dump for the disposal of radioactive waste could change in the future.

8.2 BACKGROUND RADIOLOGICAL CONDITIONS

An uncompleted report on a baseline assessment for Langer Heinrich was presented to Necsa [3]. Several measurement results are still outstanding from this report. A number of files containing monitoring data were also provided by the RP Group at Langer Heinrich. The latter mainly involve measurements at occupational occupied areas. The following results were nonetheless useful:

From the baseline radon concentrations at seemingly on-site locations vary from 110 – 224 Bq.m^{-3}. For the 50% outdoor and 50% indoor scenario used in this assessment these concentrations relate to an annual dose range of 3 – 11 mSv.a^{-1}. From the RP files similar concentrations are reported for some occupational areas. From the same files lower concentrations were recorded at Bloedkoppie and some occupational areas e.g. Tailings dam. The latter range is in the order of 20 - 30 Bq.m^{-3}. For the same scenario this relates to an annual dose range of 0.6 – 1 mSv.a^{-1}. Against the baseline and RP measurements the modeled contribution of the mine seems small.

Airborne results are still missing from the baseline report. While the RP results relate only to occupational areas.

External gamma dose rates are reported in the baseline report. Three locations seem to be at previous mined areas and were not considered (2.2 – 3.2 μSv.h^{-1}). The others range from 0.07 to 0.61 μSv.h^{-1}, which would present maximum public doses of 0.5 – 4.3 mSv.a^{-1}. These could serve as rehabilitation levels for post closure.

9.0 EVALUATION AGAINST EIA CRITERIA

9.1 ICRP APPROACH TO RISK

The ICRP has estimated the probability of a fatal cancer by relying mainly on studies of the Japanese survivors of the atomic bombs and their assessment by bodies such as UNSCEAR and BEIR. The ICRP uses the term detriment to represent the combination of the probability of occurrence of a harmful health effect and a judgement of the severity of that effect. The many aspects of detriment make it undesirable to select a single quantity to represent the detriment and the ICRP has therefore adopted a multi-dimensional concept. Nonetheless the ICRP present the following table as a detriment-adjusted nominal risk coefficient (10^{-2} Sv^{-1}) for stochastic effects after exposure to radiation at low dose rate.

Exposed population	Cancer (Fatal and Non-fatal)	Heritable effects	Total
Whole population	5.5	0.2	5.7
Adult Worker	4.1	0.1	4.2

On the basis of these calculations the ICRP proposes nominal probability coefficients for detriment-adjusted cancer risk as 5.5 E-2 Sv^{-1} for the whole population and 4.1 E-1Sv^{-1} for adult workers. These values relate to the probability of contracting cancer when a dose of 1 Sv is received. Following the doses calculated in this assessment, it means that the possibility is very low.

9.2 EIA RISKS

The Criteria for ranking the DURATION of impacts and PROBABILITY (of exposure to impacts) are based on the ICRP proposed data. Should a person contract cancer the duration 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 Langer Heinrich the dose is regarded as low.

The radiological criteria as discussed in Section 8.1 were linked to the criteria for impact assessment and are given in Table 12.

Table 12: Radiological criteria linked to impact assessment criteria.

		Criteria for ranking of the severity of environmental impacts	Criteria for ranking the DURATION of impacts	Criteria for ranking the SPATIAL SCALE of impacts	PROBABILITY (of exposure to impacts
Exposure Scenario 1: Tourist at Bloedkoppie					
	Current Mining Scenario 1: Current (Baseline) operation and construction operations	L	H	M	L
	Future Mining Scenario 1: Future Western Pit	L	H	M	L
	Future Mining Scenario 2: Future Central Pit	L	H	M	L
	Future Mining Scenario 3: Future Eastern Pit	L	H	M	L

		Criteria for ranking of the severity of environmental impacts	Criteria for ranking the DURATION of impacts	Criteria for ranking the SPATIAL SCALE of impacts	PROBABILITY (of exposure to impacts
Exposure Scenario 2: Driller / Exploration					
	Current Mining Scenario 1: Current (Baseline) operation and construction operations	L	H	M	L
	Future Mining Scenario 1: Future Western Pit	L	H	M	L
	Future Mining Scenario 2: Future Central Pit	L	H	M	L
	Future Mining Scenario 3: Future Eastern Pit	L	H	M	L

		Criteria for ranking of the severity of environmental impacts	Criteria for ranking the DURATION of impacts	Criteria for ranking the SPATIAL SCALE of impacts	PROBABILITY (of exposure to impacts
Exposure Scenario 3: Construction Workers					
	Current Mining Scenario 1: Current (Baseline) operation and construction operations	L	H	M	L
	Future Mining Scenario 1: Future Western Pit	L	H	M	L
	Future Mining Scenario 2: Future Central Pit	L	H	M	L
	Future Mining Scenario 3: Future Eastern Pit	L	H	M	L
Exposure Scenario 4: Hypothetical Agricultural Group					
	Scenario 1: Alluvium (conservative case) -12.5 km (No Dilution)	H	H	M	L
	Scenario 2: Alluvium (conservative case) -12.5 km (20% Dilution)	M	H	M	L
	Scenario 3: Alluvium (realistic case) - 12.5 km (No Dilution)	H	H	M	L
	Scenario 4: Alluvium (realistic case) - 12.5 km (20% Dilution)	L	H	M	L

		Criteria for ranking of the severity of environmental impacts	Criteria for ranking the DURATION of impacts	Criteria for ranking the SPATIAL SCALE of impacts	PROBABILITY (of exposure to impacts
Exposure Scenario 5: Background Aquatic Scenario					
	Scenario 5: Natural Background (Boreholes WW41180 - WW41182 Average Uranium concentration)	Not relevant			
Exposure Scenarios 6 Hypothetical Food Consumer					
	Scenario 1: Alluvium (conservative case) -12.5 km (No Dilution)	L	H	M	L
	Scenario 2: Alluvium (conservative case) -12.5 km (20% Dilution)	L	H	M	L
	Scenario 3: Alluvium (realistic case) - 12.5 km (No Dilution)	L	H	M	L
	Scenario 4: Alluvium (realistic case) - 12.5 km (20% Dilution)	L	H	M	L

9.3 FINAL CONCLUSION AND RECOMMENDATIONS

The outcome of the assessment indicated that, for the identified public exposure scenarios, the exposures from the relevant sources of exposure, except for the water pathway, from the current and proposed future operations are within the specified criteria limits. The water pathway, however, presented doses above the public dose limit and other criteria levels when evaluated in terms of future potential. Some recommendations are made above and in [5] for the reduction of exposures such as the construction of barrier systems to prevent the release of contaminated water from the site.

Although the doses to the public at Bloedkoppie is trivial, access to the Langer Heinrich Mining site, and especially the waste tailings facility from Bloedkoppie is possible. The implementation of some or other form of access control to these areas should be implemented by Langer Heinrich.

A Public Radiation Protection Program or routine monitoring and surveillance program must be compiled for authorized actions and the data from the Public Hazard Assessment must be used as a guideline. This needs to be site-specific because it is influenced by factors such as site location, climate, off-site environmental and population distribution.

The monitoring program must consider the source characteristics and the expected discharge rate, radionuclide composition, significance of exposure pathways, doses to individuals, radioactive effluents and the emission of radioactive dust and radon, collective doses to populations and the potential for accident releases. The program should include a structured environmental database.

The following recommendations follow in terms of such a monitoring programme:

- Continued monitoring of existing boreholes for the full nuclide specific activity concentration. This should continue until enough data has been accumulated to provide meaningful trends (twice a year for a period of three years). Thereafter only uranium concentrations could be continued with.
- Radon gas monitoring should continue but with more emphasis on monitoring the major exposure sources such as the tailings dam, open pits and waste rock stockpiles. Sampling should focus around taking radon gas measurements at specific locations upwind and downwind from the major sources. Some recommendations have been made for continued dust fall-out monitoring at specific positions on the mine site by the air dispersion specialist. It is hence proposed that radon gas monitoring be performed at the same respective positions where the dust fall-out samplers are to be deployed. The wind directions and speed should also be captured during the monitoring to enable correlation between monitoring data and meteorological conditions.
- Radon exhalation measurements should be performed for the respective exposure sources at Langer Heinrich. For the current Necsa assessment generic data was used. The results should however, be confirmed once real site data becomes available.
- Dust fall-out as well as airborne dust monitoring should be performed with specific reference to the major exposure sources. Specific locations upwind and downwind with the accompanying meteorological data, as for radon above, should have preference. The sampling can be performed at the positions as recommended by the air dispersion specialists.
- It is recommended that Langer Heinrich complete the baseline report. Ongoing background measurements are recommended and should confirm the positioning of the construction and drillers camps but will also serve the purpose of providing additional baseline information for future references.

- Sampling of solid samples from the same sources as performed for this assessment in Table 3 on a three monthly basis for a period of one year. The purpose of the sampling exercises will be to verify the nuclide specific analysis results in Table 3 as well as to collect data that will inform the future post-closure planning of Langer Heinrich. These samples should be split and analysed (full nuclide specific) for the course and fine fraction. Each sample could be a composite sample but should be collected as per approved methodologies.

The Necsa assessment was performed taking cognisance of specific critical groups. The scenarios may, however change with time. Langer Heinrich 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 ongoing basis, the validity of the identified critical group(s) and re-define these if changes are noticed. Ensure that the Contractors have left the site after 12 months as assumed in the Exposure Scenario. Also ensure that Bloedkoppie has not been developed resulting in longer occupancy than specified in the Exposure Scenario.

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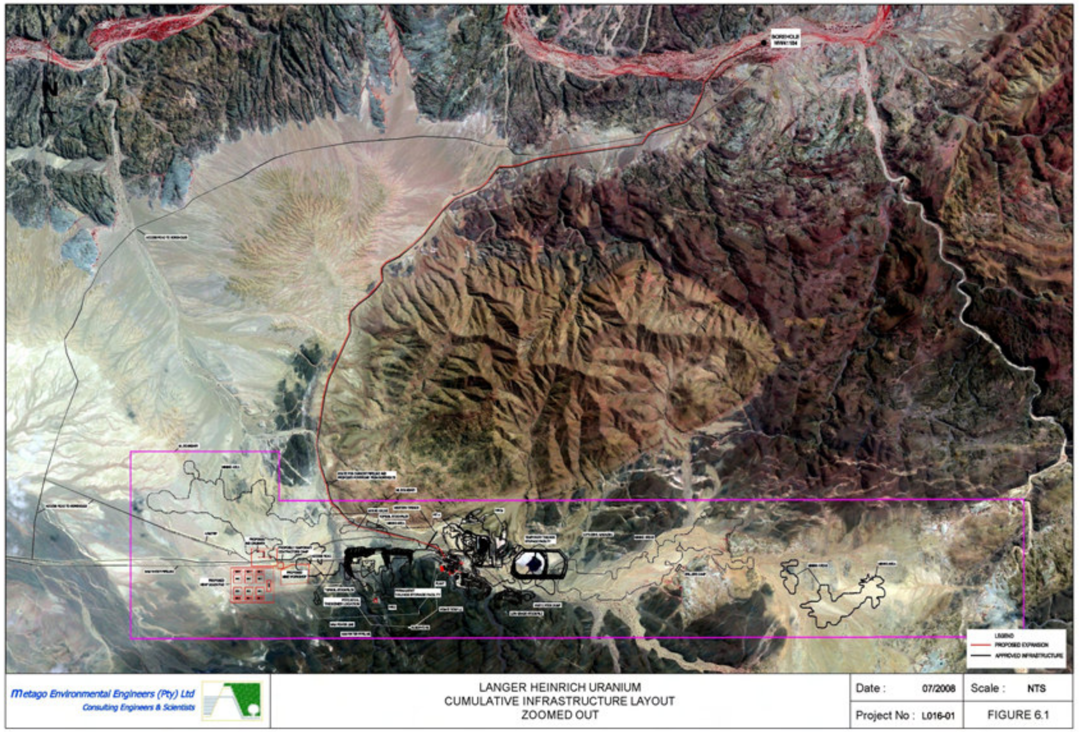
APPENDIX A: MAP OF THE LANGER HEINRICH SITE AND SURROUNDING ENVIRONMENT



APPENDIX B: DOSE ASSESSMENT PARAMETERS

Table 13: Calculation of daily-inhaled volumes for different age groups (See Tables 6 of [22]).

Type of Activity	Age = 0 – 2 a			Age = 2 - 7 a			Age = 7 - 12 a			Age = 12 - 17 a			Adults		
	T	B	T*B	T	B	T*B	T	B	T*B	T	B	T*B	T	B	T*B
Sleep	14.00	0.15	2.10	12.00	0.24	2.88	10.00	0.31	3.10	10.00	0.42	4.20	8.00	0.45	3.60
Sitting	3.33	0.22	0.73	4.00	0.32	1.28	4.67	0.38	1.77	5.50	0.48	2.64	6.00	0.54	3.24
Light exercise	6.67	0.35	2.33	8.00	0.57	4.56	9.33	1.12	10.45	7.50	1.38	10.35	9.75	1.50	14.63
Heavy exercise	-	-	-	-	-	-	-	-	-	1.00	2.92	2.92	0.25	3.00	0.75
Total per day	24		5.17	24		8.72	24		15.32	24		20.11	24		22.22
Avg. per hour	**0.22**			**0.36**			**0.64**			**0.84**			**0.93**		
T = Hours per day , B = Inhalation rate ($m^3 h^{-1}$) as per ICRP-71 Table 6															

Table 14: Dose coefficients (Sv.Bq^{-1}) to calculate inhalation doses for the public impact assessment.

Age Group	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Pa-231	Ac-227	Ra-223	Th-232	Ra-228	Th-228	Ra-224
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
Workers	5.7E-06	6.8E-06	7.2E-06	2.2E-06	1.1E-06	2.2E-06	1.7E-05	4.7E-05	5.7E-06	1.2E-05	1.7E-06	3.2E-05	2.4E-06

Table 15: Dose coefficients (Sv.Bq^{-1}) to calculate ingestion doses.

Age Group	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Pa-231	Ac-227	Ra-223	Th-232	Ra-228	Th-228	Ra-224
0 – 2	1.2E-07	1.3E-07	4.1E-07	9.6E-07	3.6E-06	8.8E-06	1.3E-06	3.1E-06	1.1E-06	4.5E-07	5.7E-06	3.7E-07	6.6E-07
2 – 7	8.0E-08	8.8E-08	3.1E-07	6.2E-07	2.2E-06	4.4E-06	1.1E-06	2.2E-06	5.7E-07	3.5E-07	3.4E-06	2.2E-07	3.5E-07
7 – 12	6.8E-08	7.4E-08	2.4E-07	8.0E-07	1.9E-06	2.6E-06	9.2E-07	1.5E-06	4.5E-07	2.9E-07	3.9E-06	1.5E-07	2.6E-07
12 – 17	6.7E-08	7.4E-08	2.2E-07	1.5E-06	1.9E-06	1.6E-06	8.0E-07	1.2E-06	3.7E-07	2.5E-07	5.3E-06	9.4E-08	2.0E-07
Adults	4.5E-08	4.9E-08	2.1E-07	2.8E-07	6.9E-07	1.2E-06	7.1E-07	1.1E-06	1.0E-07	2.3E-07	6.9E-07	7.2E-08	6.5E-08
Workers	7.6E-09	8.3E-09	8.7E-08	2.8E-07	6.8E-07	2.4E-07	7.1E-07	1.1E-06	1.0E-07	9.2E-08	6.7E-07	3.5E-08	6.5E-08

Table 16: Dose coefficients (Sv.h^{-1} per Bq.m^{-2}) to calculate the dose from external surface.

Age Group	U-238+	U-234	Th-230	Ra-226+	Pb-210+	Po-210	U-235+	Pa-231	Ac-227+	Th-232	Ra-228+	Th-228	Ra-224+
0 – 2	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
2 – 7	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
7 – 12	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
12 – 17	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
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
Workers	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
A + after the nuclide symbol indicates the inclusion of radiation from the short-lived daughters up to the next listed nuclide													

Table 17: Dose coefficients (Sv.h^{-1} per Bq.g^{-1}) to calculate the dose from external volume.

Age Group	U-238+	U-234	Th-230	Ra-226+	Pb-210+	Po-210	U-235+	Pa-231	Ac-227+	Th-232	Ra-228+	Th-228	Ra-224+
0 – 2	5.2E-09	1.3E-11	3.8E-11	3.5E-07	1.9E-10	1.6E-12	2.3E-08	5.9E-09	6.3E-08	1.6E-11	1.9E-07	2.5E-10	3.2E-07
2 – 7	5.2E-09	1.3E-11	3.8E-11	3.5E-07	1.9E-10	1.6E-12	2.3E-08	5.9E-09	6.3E-08	1.6E-11	1.9E-07	2.5E-10	3.2E-07
7 – 12	5.2E-09	1.3E-11	3.8E-11	3.5E-07	1.9E-10	1.6E-12	2.3E-08	5.9E-09	6.3E-08	1.6E-11	1.9E-07	2.5E-10	3.2E-07
12 – 17	5.2E-09	1.3E-11	3.8E-11	3.5E-07	1.9E-10	1.6E-12	2.3E-08	5.9E-09	6.3E-08	1.6E-11	1.9E-07	2.5E-10	3.2E-07
Adults	5.2E-09	1.3E-11	3.8E-11	3.5E-07	1.9E-10	1.6E-12	2.3E-08	5.9E-09	6.3E-08	1.6E-11	1.9E-07	2.5E-10	3.2E-07
Workers	5.2E-09	1.3E-11	3.8E-11	3.5E-07	1.9E-10	1.6E-12	2.3E-08	5.9E-09	6.3E-08	1.6E-11	1.9E-07	2.5E-10	3.2E-07

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

Table 18: K_d values for sandy soil and water-to-soil concentration factor in $L.kg^{-1}$

Element	K_d	Concentration factor
U	3.3E+01	3.3E+01
Th	3.0E+03	3.0E+03
Ra	4.9E+02	4.9E+02
Pb	2.7E+02	2.7E+02
Po	1.5E+02	1.5E+02
Pa	5.4E+02	5.4E+02
Ac	4.5E+02	4.5E+02

Table 19: Consumption rates of various products (as sole source) for the different age groups.

	0 – 2 Years	2 – 7 Years	7 – 12 Years	12 – 17 Years	Adults
Soil (kg.a^{-1})	0.11	0.11	0.11	0.11	0.037
Fruit (kg.a^{-1})	30	37.5	45	63.75	75
Leafy Vegetables (kg.a^{-1})	22	27.5	33	44.75	55
Root Vegetables (kg.a^{-1})	68	85	102	144.5	170
Water (L.a^{-1})	260	300	350	600	730
Fish (kg.a^{-1}) (0 for Langer Heinrich)	1	5	10	10	25
Beef + Goat (kg.a^{-1})	20	50	75	100	100
Milk (L.a^{-1})	300	300	300	300	250
Poultry (kg.a^{-1})	15	35	60	75	75
Eggs (kg.a^{-1})	6	15	25	30	30
Cereals + Grains (kg.a^{-1})	60	75	90	127.5	150

Table 20: Soil to plant concentration factors in Bq.kg^{-1} fresh weight per Bq.kg^{-1} dry soil

Element	Leafy Vegetables	Root Vegetables	Fruit	Cereal/Grain	Forage
U	8.3E-04	2.2E-03	2.2E-03	1.1E-03	2.3E-02
Th	1.8E-04	4.8E-05	4.8E-05	2.9E-05	1.1E-02
Ra	4.9E-03	7.8E-03	7.8E-03	1.0E-03	8.0E-02
Pb	1.0E-03	1.6E-03	1.6E-03	4.0E-03	1.1E-03
Po	1.1E-05	1.8E-05	1.8E-05	4.4E-04	2.0E-02
Pa	1.1E-04	1.8E-04	1.8E-04	4.4E-04	2.0E-02
Ac	1.1E-04	1.8E-04	1.8E-04	4.4E-04	2.0E-02

Table 21: Concentration factors for freshwater fish in L.kg^{-1}.

Element	Fish
U	**5.0E+01**
Th	1.0E+03
Ra	2.0E+02
Pb	2.0E+03
Po	5.0E+02
Pa	3.0E+01

Ac	3.3E+02

Table 22: Transfer coefficients to animal products in d.kg^{-1} and d.L^{-1} (milk).

Element	Beef/Goat (d.kg^{-1})	Milk (d.L^{-1})	Poultry (d.kg^{-1})	Eggs (d.kg^{-1})
U	3.0E-04	4.0E-04	3.0E-04	1.00E+00
Th	9.0E-04	1.7E-06	9.0E-04	2.00E-03
Ra	9.0E-04	1.3E-03	9.0E-04	2.00E-05
Pb	4.0E-04	2.0E-04	4.0E-04	2.00E-03
Po	5.0E-03	1.0E-03	5.0E-03	1.8E-02
Pa	5.0E-03	1.0E-03	5.0E-03	1.8E-02
Ac	5.0E-03	1.0E-03	5.0E-03	1.8E-02

Table 23: Animal consumption rates for the biosphere analysis.

	Water (L.day^{-1})	Dry Feed (kg.day^{-1})	Soil (kg.day^{-1})
Cows	75	25	1.25
Goats	15	4	0.8
Chickens	0.3	0.15	

APPENDIX C: GENERIC INTERACTION MATRIX

1.1 Tailings dam	2.1 X	3.1 X	4.1 X	5.1 X	6.1 X	7.1 Wind erosion	8.1 Exhalation	9.1 Run-off	10.1 Water erosion	11.1 Seepage	12.1 X	13.1	14.1 External exposure	15.1	16.1 External exposure	17.1 External exposure
1.2 X	2.2 Plants and stacks	X	X	X	X	7.2 Stack emissions	8.2 Stack emissions	9.2 Liquid discharges	X	X	X	X	X	X	X	17.2 X
1.3 X	X	3.3 Rock dumps	X	X	X	7.3 Weather. /Mech	8.3 Exhalation	9.3 Run-off	10.3 Water erosion	8.3 Seepage	X	X	X	X	X	17.3 External exposure
1.4 X	X	X	4.4 Open pit	X	X	X	8.4 Exhalation	X	X	X	X	X	X	X	X	17.4 External exposure
1.5 X	X	X	X	5.5 Waste sites	X	X	8.5 Exhalation	9.5 Run-off	X	8.5 Seepage	X	X	X	X	X	17.5 External exposure
1.6 X	X	X	X	X	6.6 Stock piles	7.6 Wind erosion	8.6 Exhalation	9.6 Run-off	X	8.6 Seepage	X	X	X	X	X	17.6 External exposure
1.7 X	X	X	X	X	X	7.7 Dust	X	X	X	X	12.7 Deposition	X	14.7 Inhalation	X	16.7 Inhalation	17.7 Inhalation
1.8 X	X	X	X	X	X	X	8.8 Radon	X	X	X	X	X	14.8 Inhalation	X	16.8 Inhalation	17.8 Inhalation
1.9 X	X	X	X	X	X	X	X	9.9 Surface water	10.9 Settling	11.9 Infiltration	12.9 Irrigation	13.9 Uptake	14.9 Uptake	15.9 Uptake	19.9 Drinking	17.9 Drinking
1.10 x	X	X	X	X	X	X	X	9.10 Flood resuspension	10.10 Sediments	8.10 Flow and transport	X	13.10 Uptake	14.10 Uptake	15.10 Uptake	16.10 Uptake	17.10 External exposure
1.11 X	X	X	X	X	X	X	X	9.11 Decanting	X	11.11 Groundwater	12.11 Irrigation	X	X	X	16.8 Drinking	17.11 Drinking
1.12 X	X	X	X	X	X	X	X	9.12 Flood resuspension	X	X	12.12 Soil	X	X	15.12 Uptake	X	17.12 X
1.13 X	X	X	X	X	X	X	X	X	X	X	X	13.13 Aquatic plants	14.13 Consuption	X	16.13 Consumption	17.13 X
1.14 X	X	X	X	X	X	X	X	X	X	X	X	X	14.14 Aquatic animals	X	16.14 Consumption	17.14 Consumption
1.15 X	X	X	X	X	X	X	X	X	X	X	X	X	X	15.15 Terrestrial plants	16.15 Consumption	17.15 Consumption
1.16 X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16.16 Terrestrial animals	17.16 Consumption
1.17 X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	17.17 Humans

APPENDIX D: ADDRESSING EARTHLIFE AFRICA COMMENTS

In the Earthlife Africa comments report [25], the following comments relevant to this report are indicated and addressed. The comments from the Earthlife Africa report not addressed in this document are addressed in various other reports as indicated below.

Earthlife Africa Report summary:

1. Introduction, Task, Limitations and Structure.

The following aspects of the initial Environmental Assessment report were selected for screening and evaluation by Earthlife Africa.

1	*Radiological Consequences of the project for the general public.*	Addressed in the Necsa assessment.
2	*Radiological Consequences for employees.*	The Radiological consequences to employees are managed by the Safety Health and Environmental Manager at the Langer Heinrich mining site.
3	*Water Resources use and water use by the mining and milling facilities*	Addressed in EIA
4	*Consequences of Uranium mining and milling and of the disposal of associated wastes for the Groundwater*	Addressed in [5]
5	*Management of disposal of waste from the leaching of ores and their long-term enclosure*	Addressed in EIA

2. *Radioactive Doses to the general public*

To determine the risk for the public and for workers resulting from their exposure to radioactive pollutants, doses to the public and to workers have to be calculated. These calculations have to be based on specific parameters, for which some evidence must be given, and on computer model software, that has to be quality proofed. We looked at those two inputs; the following remarks have to be made.

Input data: Wrong Radium content of the ore and of the tailings

The most relevant input data, when calculating doses for the public and for workers, is the Radium content in the handled material. The Radium content is a central input for doses resulting from the inhalation of Radon, a radioactive daughter product of Radium. And it also determines doses from the inhalation of dust.

The EA assumes a specific activity of Radium-226 in the tailings as 5 Bq/g (p.9-8) and states that this is a conservative value. This value is chosen as a 'typical" value for mill tailings. However, the Ra-226 concentration in the tailings actually must be expected to be 21.5 Bg/g, given the Uranium concentration in the ore used for leaching of 0.143% U^3*. This is by a factor of more than four higher than the value used for the calculation. No reason is given in the EA, why this selection was made instead using will-known site-specific data as input. Due to this selection of a generic value instead of site-specific values for Langer Heinrich Uranium Mine, all following dose calculations underestimate the doses by at least a factor of four. Consequences are discussed below.*

Addressing Comment:

The data used for Radium-226 in calculating the dose in this report are based on analytical results obtained from solid samples collected for these sources at the mine. For uranium ore the values range from 335 to 754 for the crushed ore but from 759 to 1217 for the sifted material. All these are lower than the 1430 claimed by Earth Life Africa. The Necsa assessment, however, conservatively used the sifted material for the dose calculations (Section 5.1).

Nuclide and Material	Nuclide Activity in Bq/kg					
	U-238	U-234	Th-230	Ra-226	U ppm	U_3O_8 ppm
ROM Low Grade	4900	4940	4550	4760	395	335
ROM Low Grade Sifted	11100	11200	15100	12600	895	759
ROM High Grade	10900	11000	11300	10600	879	745
ROM High Grade Sifted	17800	17900	899	16900	1435	1217

Radiological assumptions: Low breathing rate assumed

In the dose calculations, a breathing rate of 0.4 m^3*/h resp. 3.504*m^3*/a was assumed (p.9-15, table 9.3). No reference is given for that chosen value. The assumed breathing rate has a linear effect on the dose: the higher the breathing rate, the higher the dose. This is true for Radon inhalation as well as for dust inhalation.*

The assumed breathing rate is by a factor of more than two below internationally accepted rates. The US-NRC use 0.91 m^3*/h resp. 8,000*m^3*/a. The German radiation protection ordinance uses a* *rate of 0.92* m^3/h *resp. 8.100*m^3/a *for persons over 17 years old. This is by a factor of 2.3 higher than the rate used in the environmental assessment.*

Addressing Comment:
The breathing rate used in the calculation of dose to the various Exposure Scenarios is 0.93 m^3/h as per ICRP [22], and referenced in Table 13.

Dose calculation: Incomplete nuclide spectrum
In the dose calculation for dust, only Radium-226 and Thorium-230 has been calculated. Calculations of that type have to include the whole Uranium decay series in equilibrium. If the source of the dust is the tailings only the Uranium activity in the decay chain might be reduced. The calculated dose must then sum up all doses from all radio-nuclides of the decay chain. The differences between selecting only Ra-226 and Th-230 and by calculating the whole decay chain are slightly higher dose values.

Addressing Comment:
The complete Uranium decay series have been included in the calculations as per Table 3: Results of the Radioactivity Analysis for Solid Samples (Bq.kg^{-1})

Consequences of the two inappropriate values chosen
The two values chosen (specific Radium activity, breathing rate) lead to an underestimation of doses by a factor of approximately 10. Assumed that the other assumptions and the calculations would be correct, all concentrations for Radium and Radon are by a factor of four higher and doses to be expected can be up to a factor of ten higher.

The calculated dose from inhalation of dust at Bloedkoppie, approximately 1.5 to 2.5 km away from the mine, has to be corrected in the above named way.

On the location at Bloedkoppie, chosen in the EA as the relevant location for dose modelling, Radon from tailings exhalation was modelled to be between 1 and 6 Bq/m^3*. Multiplication by roughly an additional 1* mSv.a^{-1}*, adding to a similar dose from dust inhalation at that location.*

It should be noted that Bloedkoppie is an area with public access and a site with some tourist attractions within the National Naukluft Park

Addressing Comment:
Exposure Scenario 1 : The exposure scenario for a tourist at Bloedkoppie assumed a conservative occupation of 168 hour (1 week) with a breathing rate of 0.93 m^3/h. Doses were calculated for the position of Bloedkoppie and shown to be very low (Section 7.6.4).

Missing: A clear concept for dose limitation

Radon gas and radioactive dust present the major hazards from Uranium mill tailings via the aerial pathway. While the dust has a more local impact, radon is unique in that it can be carried over large distances. It was mainly the hazard from radon release that led U.S. Congress to adopt the Uranium Mill Tailings Radiation Control Act in 1978, setting for the first time standards for the management of Uranium mill tailings. Interestingly, the ore grades of the Uranium ores processed in the U.S at that time (0.1 – 0.2% U) were comparable to those of the ore fraction to be used for leaching at the Langer Heinrich mill (0.173% U), the nature of the hazard therefore being similar.

Other than for some of the U.S Uranium mills, there are currently no permanent residents living near the proposed Langer Heinrich mill – but, land use in the surrounding area may be subject to change, while the hazards persist for millennia. The hazard from radon and dust emission should therefore be carefully assessed, anyway. In the U.S, the same standards for tailings management have been applied for tailings located in remote areas as for those located in densely populated areas, therefore.

Defining and assessing dose limits for the public makes sense, if it is clear, where those limits have to be applied. Usually, and the USA or Germany are examples for that, this is the, usually fenced area around a nuclear facility. Inside the fence, the operator has the duty to control doses, and he also has the power to control this. So inside the facility's enclosure usually an exposure time over 2,000 h/a has to be assumed, which is a reasonable assumption for workers at the facility. Outside the fence, the operator has no administrational power to control or limit exposure times and no control over habits, neither actually nor in the future. In this area an exposure time over 8760 h/a has to be assumed, and a standardised set of usual habits, land-and water-use, foot growing, etc, is defined, that can lead to exposures on the different pathways. The applicant for a permit has to show that under all these circumstances, be they actually real or not, that the sum of the doses over all pathways remains below the dose limit.

The EA neither clearly defines in which places or over which area the dose limits for the public are applicable nor is the dose as sum over all different pathways calculated. It is clear from the values provided in the EA, that the dose limit is clearly exceeded outside of Langer Heinrich Uranium Mine's facility area. But it remains unclear, how far reaching this is the case. As has been shown above, the area of Bloedkoppie is surely included. This uncertainty over the area extend, where the dose limits are exceeded, is unacceptable. It is not state-of-the-art and not in line with commonly accepted radiation protection principles and standards to leave this extend unclear.

On this basis of an unclear area extend of emission spreading and of exceeding radiation protection limits for the public in places where unlimited access is possible, a permit cannot be issued.

Additional aspects in the dose calculations for the public
Not conservative: Using Radon average concentrations
The radon dispersion model calculates average Radon concentration, averaged over the whole year. It is well known that this can cause large error margins for the resulting doses:

- *Radon exhalation rates from the mine and from tailings are to a large extent depending on a number of additional conditions. They fluctuate over the year in a very wide range. Times with high peak concentrations of Radon contribute much more to the total integrated dose than average or below-average doses. Using average values does cut those peak concentrations, underestimating the resulting doses. This effect has to be carefully assessed when exposures over shorter times that a year are estimated.*

- *Extreme peak concentrations of Radon are reached in times of the year, where the wind speed is low or totally calm. This is especially relevant for areas in valleys, surrounded by mountains or rises in one or more directions. The times, where the wind is calm, are short, but they contribute much more than the average to the total dose. Wind measurements for Radon modelling therefore have to carefully register days with very small or no wind at all. The data base, as described in the EA (p.6-8), does neither register smaller wind speeds nor does it register the time over which the wind speed is too low to measure. Radon concentration modelling and dose calculations that do not take this effect into account are therefore systematically underestimating doses.*

- *The gauss plume model that was used in the EA to model Radon and calculate its concentration, is systematically not able to model low wind speeds. So the effect of these times over the year is simply not included in the dose calculation. The dose calculation is not conservative; average Radon concentration could be higher than those in the EA.*

The extent of these effects cannot be estimated due to site-specific data. It could well reach another factor of ten, if certain conditions are given. The monitoring of the facility should be designed to later evaluate the models used for prediction. The monitoring is subject to a respective plan, to be enacted later on.

Unclear basis of model calculations.
The calculation of Radon spreading and the calculation for dust dispersal use similar models and, presumably, use the same site-specific wind data as input. When comparing the output for Radon concentration (p.9-11, figure 9.2) and for dust dispersion (p. 9013, figure 9.3), the result is

very different. The directions, where the pollutants are spreading, are different and the concentration profiles on the main plume directions.

This difference is not plausible. No mention is given in the report, where this difference stems from. The description of the two models is no detailed enough to be able to identify these reasons.

Addressing Comment:

The criteria on which the doses have been evaluated, takes into consideration a public dose constraint of 300 µSv.a^{-1}. This means that this dose constraint should not be exceeded outside the mine site licensed area.

For the assessment all relevant exposure pathways for each identified scenario were considered. Not all exposure pathways were applicable to each scenario. (Section 6.3.2).

The assessment results are indicted in Section 0.

The air dispersion modelling was done by Airshed and documented in [6] and the Necsa assessment used the data from [6] to perform the evaluation of the dose through the atmospheric pathways. The Airshed modelling as well as the Necsa assessment then provides for a clear identification of the affected area.

The groundwater modelling was done by Bittner Water Consultants and this assessment used the data from [5] to perform the evaluation of the dose through the aquatic pathways.

In terms of radon the Necsa results were conservatively evaluated in terms of a dose limit of 300 µSv.a^{-1}. For this purposes an average annual radon concentration value was used. If a maximum radon concentration value is used, it should be evaluated against the recommended action levels of between 4 mSv and 10 mSv per annum.

3. Radioactive doses for mine workers

The Radiological consequences to employees are managed by the Safety Health and Environmental manager at the Langer Heinrich mining site.

4. Water use and water resources

Addressed in the EIA performed by Metago.

5. Tailings management and disposal

Various management recommendations have been made in the EIA. A formal post-closure assessment that will be performed in the future will address the various issues.

6. Ground water protection

Addressed in the EIA performed by Metago.

7. Summary of findings

Addressed accordingly in each section.