APPENDIX O

Radiological impact study
(VO Consulting)

RADIOLOGICAL IMPACT STUDY
FOR THE PROPOSED
OMAHOLA PROJECT,
REPTILE URANIUM NAMIBIA (PTY) LTD

November 2010

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Declaration	VO Consulting is an independent technical and management consulting firm registered in Namibia, with expertise in energy, environment and radiation protection. VO Consulting has no financial or other interest in the Project other than to fulfil the contract between the Client and us. The study is based on deliverables which are described in Terms of Reference, issued by the Client specifically for the Project.
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Executive Summary

Reptile Uranium Namibia (Pty) Ltd intends to apply for mining licenses in the exclusive prospecting license area EPL 3496, situated in Namibia's Namib Naukluft Park. The ***'Omahola Project'*** referred to in this study comprises the INCA uranium and iron deposits, and the Tubas Red Sand uranium deposit. This study assesses the prevailing radiological conditions as well as the expected radiological impact that the envisaged mining activities at the Omahola Project are expected to have. It is part of the environmental impact assessment process that mining license applicants have to follow under Namibia's Environmental Policy.

The present study has three main topics, i.e. an assessment and quantification of the natural environmental radiation in the greater Omahola Project region, and an assessment of the potential exposure to radiation as a result of mining operations at the Omahola Project. Radiation control measures to limit potential exposures to ionising radiation are also discussed.

The chapter on environmental radiation describes the contributions of the different natural background radiation components in the Erongo Region of Namibia, and compares these to world-wide population-weighted averages. It is shown that the individual population-averaged contributions to the environmental background radiation in the Erongo Region include a radiation exposure dose rate of some 0.35 $mSv.a^{-1}$ from cosmic radiation, 0.55 $mSv.a^{-1}$ from terrestrial radiation, 0.04 $mSv.a^{-1}$ from radioactive dust, and an estimated 0.46 $mSv.a^{-1}$ from radon/radon progeny. Parts of the Erongo Region are characterised by elevated radionuclide concentrations in the groundwater. For the Omahola Project area, such concentrations were assessed by ANSTO in Australia. At or close to the proposed Omahola Project area, terrestrial, dust and radon contributions to the natural background radiation may be significantly different from regional averages. Also, atmospheric radioactive dust and radon concentrations are expected to increase as more uranium mines become operational in the greater Omahola Project area.

The study identifies the most likely occupational and environmental / public exposure pathways. For the occupational setting, direct external exposure to gamma radiation and internal exposure to alpha radiation from inhaled dust and radon/radon progeny are the most significant exposure dose contributors. In regard to potential public exposures to radiation originating from the proposed Omahola Project, the atmospheric pathway, and in particular the contributions of inhalable dust and radon/radon progeny are the most likely contributors to a potential exposure dose. An atmospheric dispersion model is used to predict near-ground concentrations of inhalable dust and radon. Associated dust and radon source terms are determined using the proposed pit, tailings, waste rock, road and run of mine stockpile dimensions. A hypothetical critical group postulated to live at the north-eastern boundary of the proposed INCA mining license area is found to incur an incremental exposure dose of some 36 $\mu Sv.a^{-1}$ as a result of inhaling radioactive dust originating from operations at the proposed Omahola Project, and some 26 $\mu Sv.a^{-1}$ as a result of inhaling radon/radon progeny from on-site sources. The total incremental contribution to the exposure dose, when residing at the perimeter of the proposed Omahola Project, due to the atmospheric pathway contributions considered therefore amounts to 0.06 $mSv.a^{-1}$. Such a potential exposure dose is more than factor 15 smaller than the Namibian and IAEA public dose limit of 1 $mSv.a^{-1}$.

Radiation control measures to be undertaken at the proposed Omahola Project are to be guided by relevant Namibian and international regulatory requirements. For the Omahola Project, a Radiation Management Plan will address how the occupational and public exposure monitoring is done. Transport, waste management, emergency procedures and the safety of radioactive source materials will be addressed, and guided by the Namibian (draft) radiation protection regulations, which are discussed in the study.

Abbreviations

$\mu g.m^{-3}$	microgram per cubic meter
µm	micrometer
$\mu Sv.a^{-1}$	micro-Sievert per annum (one thousands of a $mSv.a^{-1}$)
ADMS	Atmospheric Dispersion Modelling System
ANSTO	Australian Nuclear Science and Technology Organisation
Bq	Becquerel (rate of radioactive decay expressed as disintegrations per second)
$Bq.l^{-1}$	Becquerel per liter
$Bq.m^{-3}$	Becquerel per cubic meter
DCF	dose conversion factor
EIA	environmental impact assessment
EPL	exclusive prospecting license
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IEC	International Electrotechnical Commission
ILO	International Labour Organisation
ISO	International Organisation for Standardisation
km	kilometer
ml	milliliter, one thousands of a liter
mSv	milli-Sievert (unit of exposure to ionising radiation; one thousands of a Sv)
$mSv.a^{-1}$	milli-Sievert per annum (one thousands of a $Sv.a^{-1}$)
MET	Ministry of Environment and Tourism
MME	Ministry of Mines and Energy
NEA	Nuclear Energy Agency
NRPA	National Radiation Protection Authority
PM10	particulate matter with an aerodynamic diameter of less than 10 micro-meter
ppm	parts per million
RMP	Radiation Management Plan
Rn	radon (Rn^{222})
ROM	run of mine
RSO	Radiation Safety Officer
SEA	Strategic Environmental Assessment
Sv	Sievert (unit of exposure to ionising radiation)
$Sv.a^{-1}$	Sievert per annum
TSP	total suspended particles
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organisation

1 BACKGROUND, PURPOSE, PROCESS AND RATIONALE

1.1 BACKGROUND

Reptile Uranium Namibia (Pty) Ltd intends to apply for three mining licenses located within the exclusive prospecting license area EPL 3496, refer to Figure 1, situated in the Namib Naukluft Park in Namibia's Erongo Region.

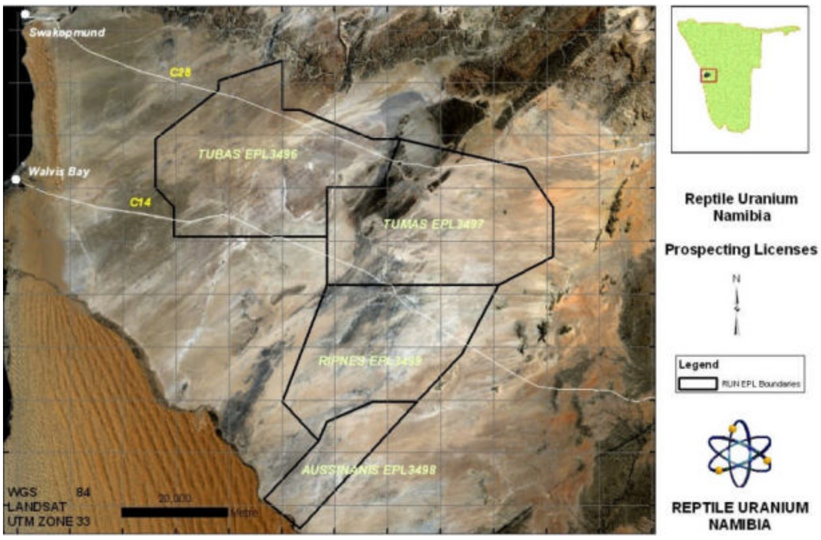

Figure 1: Location of the Tubas EPL 3496 in the Namib Naukluft Park [Reptile, 2010]

The proposed mining activities are for the extraction of mainly uranium and magnetite, and are envisaged to take place in the INCA, Tubas Red Sand and Shiyela mining license areas, as shown in Figure 2. The '**Omahola Project'** referred to in the present study comprises the INCA uranium and iron deposits and the Tubas Red Sand uranium deposit [Reptile, 2010b].

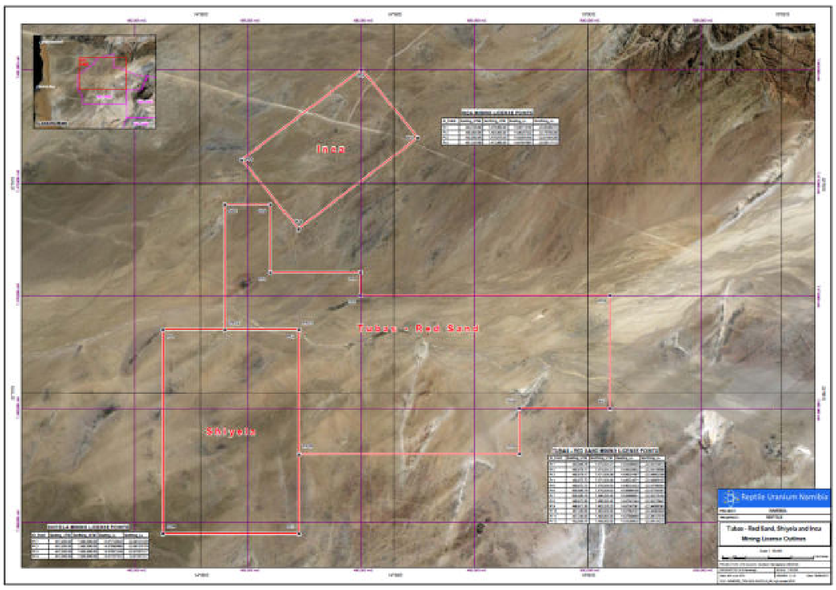

Figure 2: Location of the proposed INCA, Tubas Red Sand and Shiyela mining license areas within the Tubas EPL 3496 [Reptile, 2010]

1.2 PURPOSE

The purpose of this report is to assess and describe the potential radiological impact of the proposed Omahola Project.

1.3 PROCESS

VO Consulting was appointed by Reptile Uranium Namibia (Pty) Ltd to undertake the radiological impact study, which is to form part of the Omahola Project Environmental Impact Assessment (EIA). As such, this study is guided by the requirements of the Omahola Project EIA.

The Omahola Project EIA process is coordinated by Softchem, who are the environmental assessment practitioners appointed by Reptile Uranium Namibia (Pty) Ltd for the environmental impact assessment process, and to compile the associated scoping report [Friend, 2010].

1.4 RATIONALE

All mining license applicants in Namibia have to prepare an EIA, which is to conform to the requirements of Namibia's Environmental Policy (the country's Environmental Management Act of 2007 has yet to be fully implemented). The EIA has to be authorised by the Namibian Ministry of Environment and Tourism (MET), and will also constitute an important part of the mining license application to be submitted by Reptile Uranium Namibia (Pty) Ltd to the Namibian Ministry of Mines and Energy (MME).

As per the requirements of Namibia's Atomic Energy and Radiation Protection Act, Act No. 5 of 2005, and the requirements and recommendations of the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP), human health and the environment have to be protected against the potentially adverse effects of radiation exposure from the mining and processing of minerals containing naturally occurring radioactive materials. It is against the background of the proposed uranium mining activities at INCA and Tubas Red Sand that the present radiological impact study for the Omahola Project is undertaken.

As per the requirements of the EIA, Chapter 2 below presents an introduction and overview of the relevant aspects of environmental radiation, and Chapter 3 describes the radiation exposure and control measures for the proposed Omahola Project.

2 ENVIRONMENTAL RADIATION

2.1 INTRODUCTION

Radiation is travelling energy, and occurs in nature in the form of electromagnetic waves and sub-atomic particles [von Oertzen, 2010b]. Every day, humans benefit from the many different forms of low-energy electromagnetic radiation: its spectrum includes long-wavelength radio waves, microwaves used in kitchen appliances, as well as infrared, visible light and ultraviolet radiation. These forms of low-energy radiation are all referred to as 'non-ionising' because they lack the energy to ionise matter, i.e. remove electrons from the shells of atoms.

Ionising radiation on the other hand is associated with high-energy x-rays and gamma rays, and the various types of radiation emitted by radioactive elements. Ionising radiation has sufficient energy to strip electrons from atoms, resulting in electrically charged particles which are called ions. It has long been recognised that large doses of ionising radiation can damage human cells and tissue: free-roaming ions created at the cellular level are highly reactive and may trigger or participate in chemical reactions, some of which may bring about molecular bonds which are harmful to the cell. For example, chemical reactions that are activated by ions generated by ionising radiation can alter the chemical balance of natural processes, which may give rise to undesirable chemical products and thereby negatively affect living cells. In addition, ionising radiation can change the make-up of cells by changing the genetic building blocks of cells and in this way bring about cancerous cell multiplication and growth.

Not all atomic nuclei found in nature are stable. When unstable nuclei undergo a process of nuclear rearrangement they emit particles and radiation. The process whereby radiation is emitted from atomic nuclei as a result of nuclear instability is called radioactivity. The most common types of sub-atomic particles and radiation emitted during radioactive decays of atomic nuclei are alpha particles, beta particles and gamma radiation. Radioactivity is a natural phenomenon, and elements such as uranium, thorium and potassium are naturally occurring radioactive substances.

Radioactivity and the effects of ionising radiation on living tissue have been studied for many decades. Today it is well recognised that an exposure to large doses of ionising radiation may have potentially damaging effects on humans. To ensure that the voluntary and accidental exposure to ionising radiation is adequately regulated, the International X-ray and Radium Protection Committee was established in 1928. This body was later renamed the International Commission on Radiological Protection (ICRP). Its purpose is to establish basic principles for and issue recommendations on radiation protection, which today form the basis for international as well as national regulations governing the exposure of radiation workers and members of the public. The ICRP's recommendations have also been incorporated by the International Atomic Energy Agency (IAEA) into its Basic Safety Standards for Radiation Protection, which are published jointly with the World Health Organisation (WHO), the International Labour Organisation (ILO) and the Nuclear Energy Agency (NEA). Today, these standards are used worldwide to ensure radiation safety and protection for workers who may be occupationally exposed to ionising radiation, as well as for members of the general public.

In 1955, the General Assembly of the United Nations formed an inter-governmental body known as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). UNSCEAR is tasked to assemble, study and disseminate information on observed levels of ionising radiation and radioactivity (both natural and man-made) in the environment, and on the effects of such radiation on humans and the environment. Many of the UNSCEAR reports are regularly used to guide assessments of exposures to radiation.

Today, the basic approaches to radiation protection are consistent all over the world. The ICRP recommends that any exposure above natural background radiation should be kept as low as reasonably achievable, as well as below individual dose limits specified separately for workers and members of the public. The individual dose limit for radiation workers averaged over 5 years is 20 mSv per year, while the incremental dose limit for members of the public, i.e. the dose over and above the natural background radiation, is set at 1 mSv per year. These dose limits are based on the realisation that there is no discernible threshold dose below which there would no longer be a potentially harmful effect due to exposure to ionising radiation, and are put forward as an expression of a precautionary approach that guides the radiation sector.

Namibian regulatory requirements governing radiation protection are based on the recommendations of the ICRP and IAEA, which implies that individual doses to members of the public must be kept as low as reasonably achievable, and that consideration must also be given to the presence of other sources of ionising radiation that may cause additional exposure to radiation to the same group. Also, allowance for future sources and practices must be made, so that the total dose received by an individual member of the public does not exceed the set dose limit. This is an important stipulation, especially in a geographical area that is likely to see several uranium mines operate simultaneously, as it has direct implications for how radiation protection measures are applied during the construction, operational and decommissioning phases of each uranium mine.

2.2 NATURAL BACKGROUND RADIATION

Many areas throughout the world experience high levels of natural background radiation. Indeed, parts of the Erongo Region in Namibia in which the Omahola Project is located are known to have high levels of natural background radiation, especially of terrestrial origin [von Oertzen, 2010a]. This is not entirely unexpected, as the Erongo Region is also called the "Uranium Province of Namibia" [SEA, 2010].

Natural sources of ionising radiation include radiation of extra-terrestrial origin, i.e. cosmic radiation, and radiation emitted by soils, rocks and groundwater, i.e. terrestrial radiation, as well as radiation from radioactive dust and radioactive gases such as radon and thoron. Humans are continuously exposed to ionising radiation of natural and man-made origin. Such exposure is location- and time-dependent, and any potential effects depend on the exposure dose received by an individual person. To quantify the total exposure to ionising radiation that members of the public are exposed to one has to determine the magnitude of the exposure to the prevailing natural background radiation and add to it the incremental contribution of additional sources, such as a uranium mine.

The contribution from **cosmic radiation** to the natural background radiation levels depends on the geographic location of the receptor. Typically in Namibia, exposure doses from cosmic radiation range between 0.3 $mSv.a^{-1}$ at the coast to approximately 0.7 $mSv.a^{-1}$ in the central highlands [Wackerle, 2009a]. Since most people living in the Erongo Region live in coastal cities and towns (Walvis Bay, Swakopmund, Henties Bay), the population-weighted[1] average of the cosmic radiation for the Region is similar to the population-weighted world average of 0.38 $mSv.a^{-1}$, as reported by UNSCEAR [UNSCEAR, 1993]. Figure 3 depicts the contribution of cosmic radiation to the natural background radiation in Namibia, and is expressed in mSv per annum ($mSv.a^{-1}$).

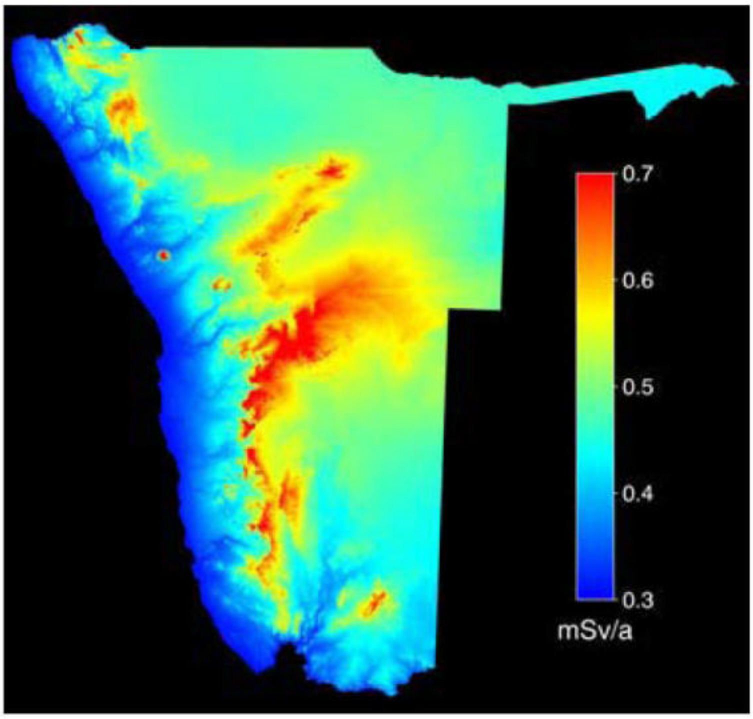

Figure 3: Contribution of cosmic radiation to natural background radiation in Namibia, shown in mSv/a ($mSv.a^{-1}$) [Wackerle, 2009a]

The contribution of **terrestrial sources** to the natural background radiation in the Erongo Region is obtained from the assessment of airborne radiometric surveys [Wackerle, 2009b]. A preliminary figure for the dose rate from natural terrestrial gamma background radiation in the

[1] The population-weighted average dose takes cognizance of the relative population sizes exposed to specific doses, and then averages over the entire population living in the area under consideration.

Erongo Region ranges between close to zero up to 7.3 $mSv.a^{-1}$, with a regional average of 0.7 $mSv.a^{-1}$ [Wackerle, 2009b]. The regional average is therefore about double the global average terrestrial radiation dose rate of 0.33 $mSv.a^{-1}$. The population-weighted average of the contribution of the natural terrestrial radiation in the Erongo Region is however lower than the average terrestrial radiation in the Region, again as a consequence of most inhabitants living in coastal towns where terrestrial radiation levels tend to be lower than the average for the Region. The population-weighted average natural terrestrial gamma radiation exposure in the Erongo Region is therefore comparable to the world average value of 0.48 $mSv.a^{-1}$, as reported by UNSCEAR [UNSCEAR, 1993]. Figure 4 depicts the contribution of terrestrial radiation to the natural background radiation in Namibia, and is expressed in $mSv.a^{-1}$.

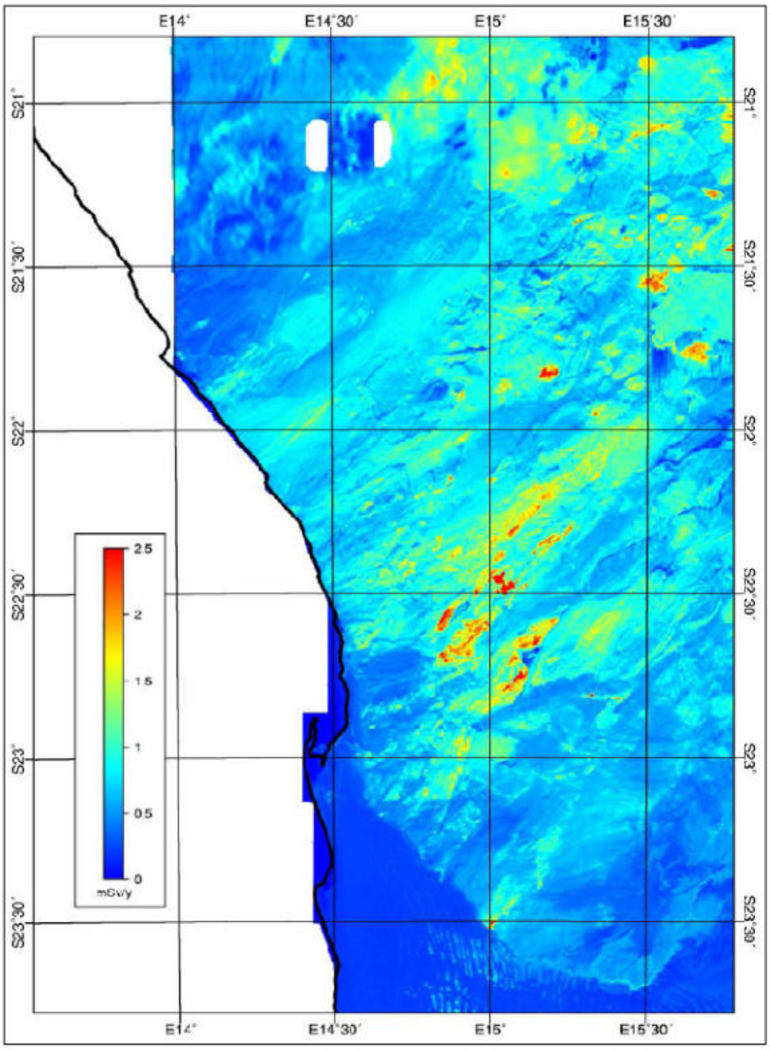

Figure 4: Contribution of terrestrial radiation to the natural background radiation in Namibia, expressed in mSv/y ($mSv.a^{-1}$) [Wackerle, 2009b]

Other forms of background radiation in the Erongo Region originate from **radioactive dust**, and from radon with its radioactive decay products. The contribution of radioactive dust to the natural background radiation is important in the context of an environmental assessment for a uranium mine in the central Namib. Dust is generated in copious amounts in the mining processes, and can be inhaled, and dust remains airborne for considerable periods in the generally dry in-land air characteristic of much of the Erongo Region.

The contribution of radioactive dust to the natural background radiation was recently measured as part of the Strategic Environmental Assessment, and the Erongo Regional average is some ten times the world average of 0.006 $mSv.a^{-1}$ [SEA, 2010]. Figure 5 depicts the contribution of radioactive dust to the natural background radiation in the Erongo Region of Namibia, in $mSv.a^{-1}$ [van Blerk *et al.*, 2010], where it is noted that the baseline contribution of dust is due to natural background sources of dust plus those produced by the existing uranium mines, most notably Rössing Uranium and Langer Heinrich Uranium.

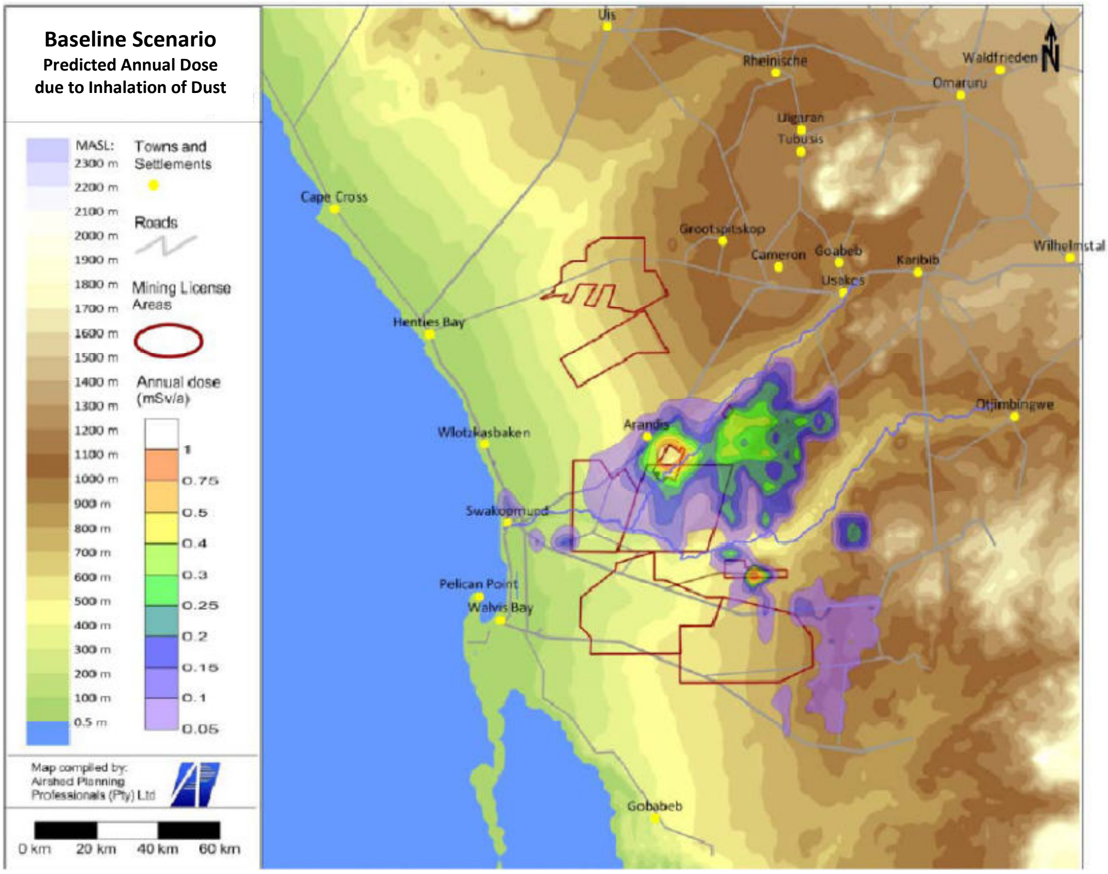

Figure 5: Contribution of radioactive dust to the natural background radiation in the Erongo Region [Based on van Blerk *et al.*, 2010]

Radon (Rn^{222} and Rn^{220}) is a gas and is formed in soils through the radioactive decay of radium (Ra^{226} and Ra^{224}). Radon and its decay products are found in variable concentrations both indoors and outdoors, and are known to exist in many mining environments. The concentration of radon in the Erongo Region was measured in a regional radon monitoring programme conducted as part of the recently completed Strategic Environmental Assessment [SEA, 2010]. It was found that the average regional radon inhalation dose measured over the 9 month period (August 2009 to April 2010) was 0.46 $mSv.a^{-1}$. It is noted that this baseline radon inhalation dose is due to natural background exhalations plus those produced by the existing uranium mines, most notably Rössing Uranium and Langer Heinrich Uranium.

As yet, little information is available for the Erongo Region to determine a baseline dose due to the **ingestion of radionuclides**, either directly through the consumption of food or via the intake of water. The population-weighted world average exposure dose as reported by UNSCEAR due to ingestion is 0.31 $mSv.a^{-1}$ [UNSCEAR, 1993], and is assumed to be very similar in the Erongo Region of Namibia.

Exposure to **man-made sources of radiation**, including medical exposures and exposures due to the use of consumer products, lifestyle choices such as smoking and flying, are well researched in the international context. Reliable baseline data however is not readily available for Namibia in general or for the Erongo Region in particular. The world average radiation dose from medical diagnostic procedures is 0.4 $mSv.a^{-1}$, but this is an average over the whole world population without any distinction between national health care levels across countries. UNSCEAR classifies Namibia as having health care level III, which corresponds to 1 physician for every 1,000 to 3,000 members of the population. The average dose to the Namibian population due to x-ray procedures is reported to be 0.02 $mSv.a^{-1}$, and nuclear medicine procedures are not reported at all. The Namibian average medical exposure dose therefore corresponds to only about 5% of the population-weighted world average figure. However, significant variations in individual exposures can be expected in Namibia, mainly because of the large differences in access to health care services between Namibians of different income levels.

Table 1 below summarises the various exposure contributions due to natural and man-made sources of ionising radiation, and allows for a comparison between such values in the Erongo Region and the population- and age-weighted world averages.

Source	Erongo Region [mSv.a^{-1}]	World Average [mSv.a^{-1}]
Cosmic radiation	0.35	0.38
Terrestrial radiation	0.55	0.48
Radioactive dust	0.04	0.006
Radon	0.46 (regional average, highly time- and position-dependent)	1.095
Ingestion	0.31 (assume to be similar to world average)	0.31
Sub-total for natural sources	**1.71**	**2.27**
Medical x-rays	0.02	0.37
Nuclear medicine	assume 0.001	0.03
Consumer products	assume 0.01	0.06
Nuclear weapons testing & production	assume 0.0046	0.0046
Nuclear fuel cycle	assume 0.0002	0.0002
Sub-total for man-made sources	**0.04**	**0.46**
GRAND TOTAL	**1.7**	**2.7**

Table 1: A comparison of the population-averaged human exposure to natural and man-made sources of radiation in the Erongo Region and the World [von Oertzen, 2010b]

2.3 ENVIRONMENTAL RADIATION IN THE OMAHOLA PROJECT AREA

2.3.1 Terrestrial gamma radiation

The natural terrestrial gamma radiation in the Omahola Project area is higher than the average values for the Erongo Region. The radiometric map of the project area (refer to Figure 6) shows where enhanced levels of terrestrial radiation, corresponding to the uranium deposit, are indicated. As expected, when one moves out of the Project area, the terrestrial gamma field returns to levels close the regional terrestrial background.

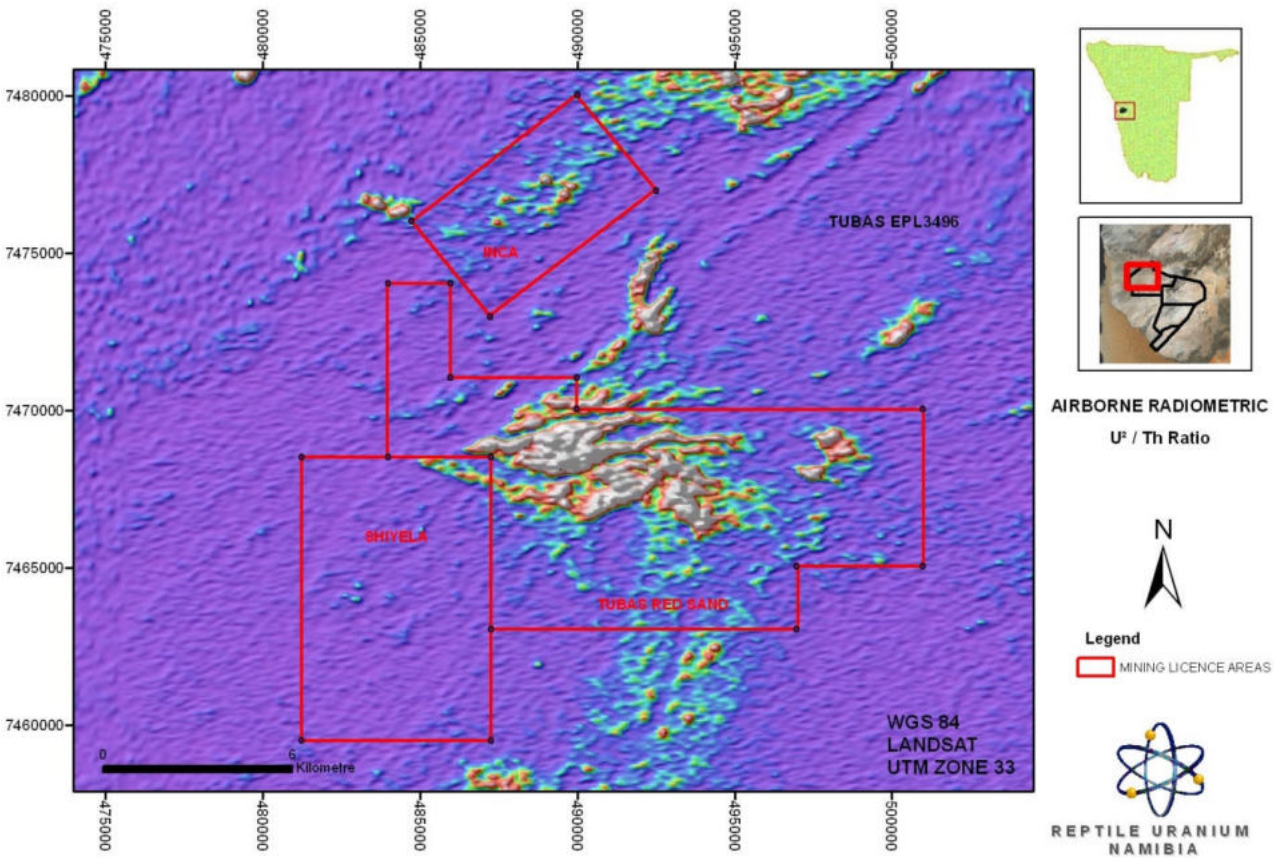

Figure 6: Radiometric map of the greater Omahola Project area [Reptile, 2010]

2.3.2 Radon

The atmospheric concentration of airborne radon, and with it the concentration of short-lived radon progeny, is highly variable. Radon emanates from the crystal lattice of the uranium- and thorium-bearing ores in which the parents were embedded, and diffuses into the pore space of the substrate material from where it moves to the surface of the material and reaches the atmosphere. This flux of radon from the soil surface, rocks and tailings facilities is the so-called radon exhalation, and is strongly dependent on the prevailing seasonal and weather conditions and the time of day. In desert environments such as in the Namib, where low-level night-time atmospheric inversion layers occur, short-term atmospheric radon concentrations may increase dramatically as radon is trapped in gullies, pits and riverines.

In response to the diurnal variations of pressure and temperature, atmospheric radon concentrations tend to decrease as the sun begins to heat the ground and convection begins. As reported above, a regional radon concentration assessment was undertaken on behalf of the Strategic Environmental Assessment in the Erongo Region. The airborne radon concentrations that were observed during the radon assessment range from 1.57 $Bq.m^{-3}$ to 62.5 $Bq.m^{-3}$, with an average activity concentration determined from measurements over the monitoring period of 20.58 $Bq.m^{-3}$ [van Blerk *et al.*, 2010].

The air quality study showed that the prevailing wind direction close to the Project area is from the north-west and the south-west, with very little airflow from the south-east [Khumalo *et al.*, 2010]. Infrequent winds are also noted from the east-northeast. On average, the winds are strong ranging between 2 $m.s^{-1}$ and 13 $m.s^{-1}$ for most of the time with winds in excess of 5 $m.s^{-1}$ occurring for 10% of the time. The strongest winds are from the east-northeast though for a limited period. During the summer months, the prevailing winds are from the north-west and to a lesser extent from the south-west with almost no flow from the easterly and southerly sectors. During autumn the wind field changes completely with a distinct shift in airflow from the south-west and noticeable winds from the east-northeast. Similar wind patterns are noted for the winter months but with very prominent occasional east-north-easterly flows. These berg-winds are also characterised by very high speeds. The prevailing wind field returns to the dominant north-westerly flow during spring, with frequent northerly winds.

The topography in the greater Omahola Project area, refer to Figure 7, promotes air movements in the north-westerly and south-westerly directions, and associated drainage of radon along these main wind corridors. Although not confirmed by measurements, the flat terrain in the Project Area, as shown in Figure 8, is expected to inhibit the formation of large-scale low-level temperature atmospheric inversions, thus limiting the duration of still-air conditions and with it the additional enhancement of radon gas concentrations close to and around the proposed Project site.

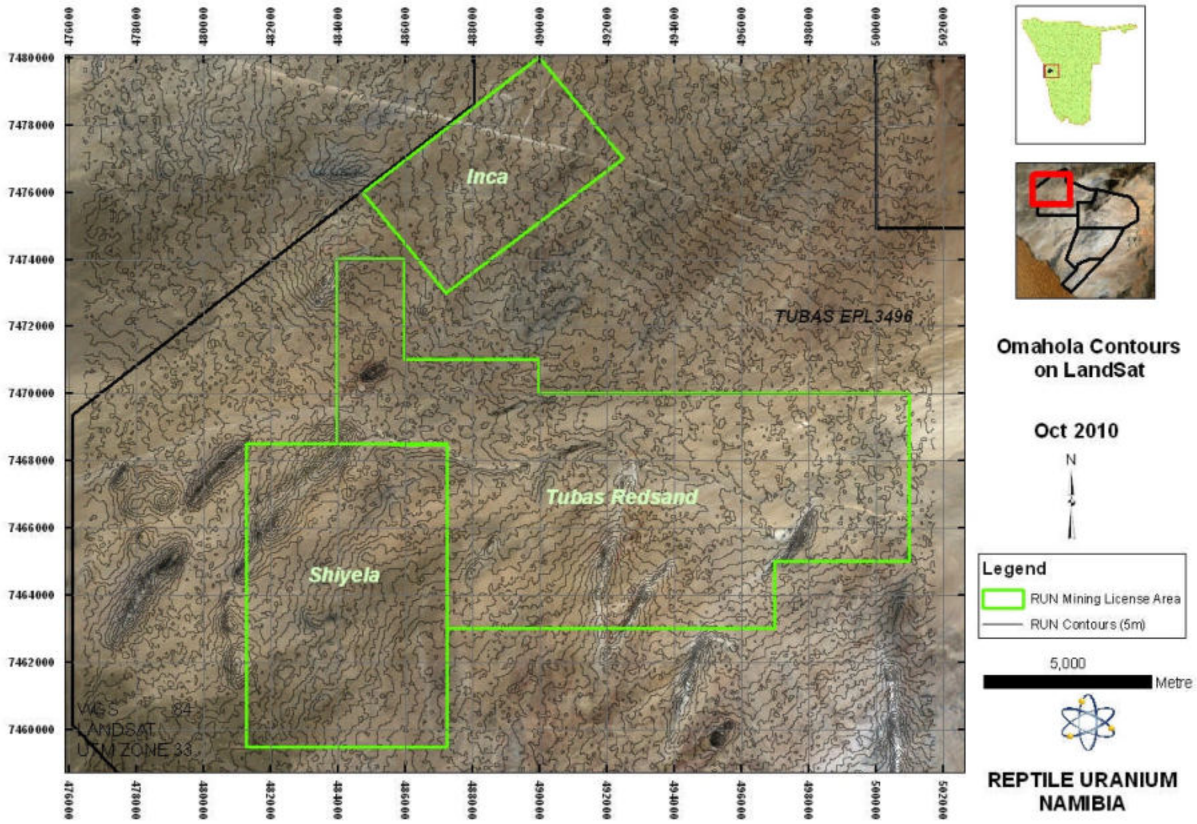

Figure 7: Topographical map of the Omahola Project area; contour interval 5 m [Reptile, 2010]

Figure 8: Drill rigs at INCA in April 2010 [Reptile, 2010b]

2.3.3 Dust

Atmospheric concentrations of airborne dust in the central Namib depend on the timing and intensity of a variety of causative agents, such as the number of cars travelling on unpaved roads, the intensity of and distance from main mining activities, and the prevailing atmospheric, seasonal and weather conditions.

The Air Quality Study which was undertaken as part of the Erongo Region Uranium Rush Strategic Environmental Assessment quantified the emissions from both the unpaved and paved roads in the Erongo Region, and windblown dust from the natural environment. The baseline assessment indicated that the main contributing source to background PM10 concentrations and dust fallout rates is windblown dust from natural sources (82% on average), while dust generated by traffic on unpaved roads is the second largest source contributing 13% to the total dust load [Liebenberg-Enslin *et al.*, 2010b].

As mentioned in section 2.3.2, the topography in the Omahola Project area experiences its main air movements in a north-westerly and south-westerly direction. This implies that the dispersion of airborne dust (inhalable fraction), as shown in Figure 9, is dominantly driven by the meteorological conditions prevailing in the Project area.

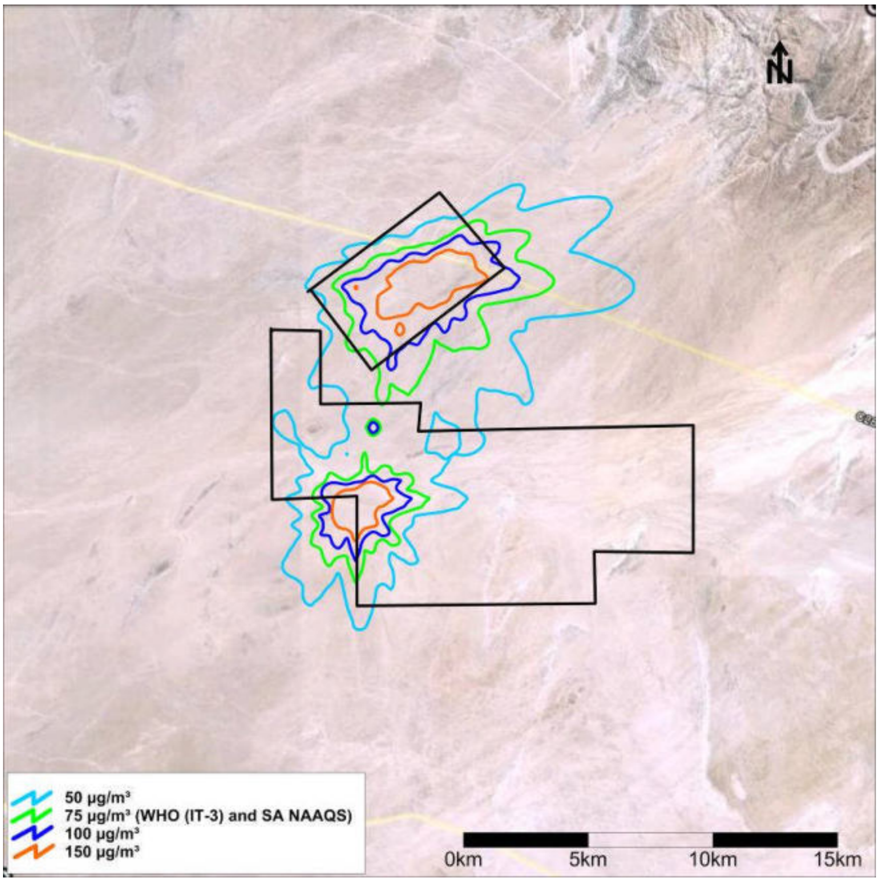

Figure 9: Highest daily average predicted PM10 ground level concentrations ($\mu g.m^{-3}$) for all sources due to unmitigated emissions from the Omahola Project area, to illustrate the worst-case near-ground level particulate concentrations [Khumalo *et al.*, 2010]

2.4 RADIONUCLIDES IN WATER

2.4.1 Introduction

The interpretation of the radiological risks posed by the presence of radionuclides in water requires some understanding of the behaviour of these nuclides when in slow-moving water resources. In closed systems, the progeny of uranium and thorium are present in concentrations that are determined by the concentrations of the uranium and thorium parent isotopes and the time since the system under consideration became closed to radionuclide transport and migration.

In nature, completely closed systems rarely exist, and predictions regarding radionuclide concentrations in water bodies invariably include considerable uncertainties. Generally, radionuclides and their decay products are found in groundwater in element-specific concentrations, dependent on complex hydro-geological processes and conditions, including dissolution rates, transport and ion-exchange processes as well as redox potentials and pH-conditions of the aqueous system. Such hydro-geological processes result in non-equilibrium conditions between parent nuclides, and their progeny.

In the oxidised zone of the earth's near-surface environment, uranium and thorium may both be mobilised, although in different ways. Uranium may either move in a detrital, resistate phase, or in solution as a complex ion. Thorium on the other hand has an extremely low solubility in natural water and there is a close correlation of thorium concentrations and the detrital content of water. Thorium is almost entirely transported in particulate form, and is either bound in insoluble resistate minerals or is adsorbed on the surface of clay minerals. Even when thorium, such as for example Th^{230}, is generated in solution by the radioactive decay of U^{234}, it rapidly hydrolyses and adsorbs onto the nearest solid surface. Both uranium and thorium appear in the 4+ oxidation state in primary igneous rocks and minerals, but uranium, unlike thorium, can be oxidised to 5+ and 6+ states in the near-surface environment. The 6+ oxidation state forms soluble uranyl complex ions, which play the most important role in uranium transport during weathering.

Waters in the natural environment are variable in uranium content, depending mainly on factors such as contact time with uranium-bearing rock, uranium content of the contact rock, the amount of evaporation, and availability of complexing ions. Groundwater is somewhat enriched in respect of uranium when compared to surface waters, especially in highly mineralised areas.

2.4.2 Uranium in regional water bodies

The Strategic Environmental Assessment has commissioned several studies to obtain a comprehensive picture of the groundwater resources in the Erongo Region, and the ambient water quality [SEA, 2010]. These studies have generated significant new insights into the characteristics of groundwater flows in the alluvial aquifers, the modes of recharge, and water quality in the Erongo Region. However, the potential radiological dose from groundwater has not yet been calculated. As groundwater resources are scarce in the hyper-arid environment of the Namib, it is imperative that the risk of pollution from mining operations on groundwater resources is well understood, and that preventative measures are in place to ensure that groundwater extraction rates remain within the known sustainable extraction limits. As yet however, the potential risks of radiological contamination of groundwater resources cannot be comprehensively quantified, although there is some consensus that current mining operations have not added measurable quantities of radionuclides to the groundwater.

Part of the difficulty in characterising radionuclides in groundwater is that uranium found in the aquatic environment cannot always be assigned clearly to a particular source. The identification of sources however, is important in order to distinguish between natural background concentrations resulting from natural leaching, dispersion and transport of uranium, and potential sources of contamination from mining activities or specific pollution events. Potential sources of uranium in groundwater are primary uranium deposits (bedrock), uranium originating from paleo-channels (saline aquatic environment), secondary uranium precipitates in calcrete (carnotite), treated uranium (sodium bicarbonate/sulphuric acid process), and uranium and other radionuclides leached from tailings.

In order to overcome this difficulty, the Strategic Environmental Assessment used naturally occurring radioactive and stable isotopes as environmental tracers for the localisation and the assessment of the presence of natural or mine-induced radionuclides in groundwater. Samples of groundwater, sediment and mine tailings were taken to determine whether the radionuclides in groundwater were from natural or mine-induced sources.

One study undertaken as part of the Strategic Environmental Assessment found that uranium is a common trace element in all 78 water samples collected along the length of the Khan and Swakop rivers [Kringel *et al.*, 2010]. Furthermore, the study found that the natural background concentration of uranium ranges between 2 $\mu g.l^{-1}$ and 528 $\mu g.l^{-1}$ in the alluvial groundwater, with a mean of 39 $\mu g.l^{-1}$. It is to be noted that these values are well above the World Health Organisation Provisional Guideline Value for Drinking Water, which is 15 $\mu g.l^{-1}$ [WHO, 2003]. However, the Namibian Group A water quality limit of 1,000 $\mu g.l^{-1}$ was not exceeded. It was also found that saline water samples from lower Swakop River catchment generally exhibited higher uranium concentrations than the respective samples found in the headwater regions.

The Strategic Environmental Assessment concluded that groundwater in the headwater region of the Swakop River valley and in the valley upstream of the Langer Heinrich Uranium Mine shows low uranium concentrations, with values below the WHO guideline, while uranium concentrations in the Khan River valley are generally higher than in the Swakop River alluvial valley. The uranium concentrations in freshwater samples from the upper Khan River valley are generally above the WHO guideline value. Also, saline water in the lower part of the Khan River valley and the Swakop River valley downstream from the confluence has uranium concentrations of up to 230 $\mu g.l^{-1}$. Altogether six groundwater samples have uranium concentrations exceeding 230 $\mu g.l^{-1}$. Three of the sampling points are located in the vicinity of

Rössing Uranium Mine, one near Langer Heinrich Uranium Mine, and two samples are from wells in the Swakop river valley downstream of the confluence of the Swakop and Khan rivers.

Process and seepage water samples from the Langer Heinrich Uranium Mine are alkaline sodium-carbonate waters, with very high concentrations of uranium, arsenic and fluoride. The samples from the Rössing Uranium Mine premises are acidic solutions with elevated concentrations of uranium, manganese and a number of trace elements like lithium, niobium and cobalt. At both sites, samples from observation wells show no clear indication of contamination by process waters.

In another study undertaken as part of the Strategic Environmental Assessment, the authors investigated radon concentrations in groundwater [Schubert *et al.*, 2010]. It is known that radon (Rn^{222}) is a good environmental tracer, mainly due to its chemically inert behaviour (appearing as a dissolved noble gas), its ubiquitous occurrence in the environment, and its straightforward detectability. In addition, because radon is a direct progeny of radium (Ra^{226}), it is a useful indicator of natural radionuclide contaminations emanating from the uranium (U^{238}) decay chain. The study analysed forty water samples for Rn^{222}, and radon concentrations of between 0.5 and 28 $Bq.l^{-1}$ were found. Given that the Ra^{226} background activity concentration detected in the sediment of the Swakop River valley was found to be about 25 $Bq.kg^{-1}$, the study states that none of the radon concentrations detected in the tested groundwater exceeded the natural background level. It is interesting to note that upstream radon data revealed background concentrations of up to 20 $Bq.l^{-1}$ (20 km north-east of Rössing on the Khan River), while water taken from wells close to the Rössing Uranium Mine showed concentrations of around 13 $Bq.l^{-1}$. The highest radon concentration was found in a well located some 9 km downstream of the Langer Heinrich uranium mine at the confluence of the Gawib and Swakop rivers, at a value of 28 $Bq.l^{-1}$. However, the study also concluded that this sample did not show any mine-induced chemical peculiarities.

A preliminary conclusion of the groundwater studies undertaken as part of the Strategic Environmental Assessment indicates that there is a very low risk of radiological exposure from contaminated groundwater in the lower Swakop River for three main reasons [SEA, 2010]:

1. the Swakop and Khan Rivers are not homogeneous aquifers, but separated into compartments. These compartments are mostly dominated by vertical flow components which manifest themselves as evapo-transpiration and recharge components. Stored water volumes are only replenished by occasional flood events and the resulting recharge. This implies that lateral or downstream flow of water in the alluvial aquifers is extremely slow (on timescales of the order of decades), and any pollution event would be 'caught' within an affected compartment.

2. natural uranium is ubiquitous in the catchment area of the Swakop and Khan Rivers. Concentrations of uranium in the upper and middle parts of these rivers tend to be lower than in their lower parts, with some exceptions, and uranium concentrations tend to increase towards the lowest parts of the Swakop and Khan Rivers, again with some

exceptions. This seems to suggest that the uranium found in the alluvial aquifers is of geogenic rather than anthropogenic origin.

3. the radon distribution pattern mapped in the Khan and Swakop River valleys, and the radionuclide concentrations detected in the tailings materials of Langer Heinrich uranium mine and Rössing Uranium mine do not indicate seepage of tailings water into the alluvial aquifers. Radon concentrations appear to correspond with the radium background concentration typical of the sediments in the surrounding river beds.

2.4.3 Uranium in local water bodies

The Omahola Project comprises of the INCA uranium and iron deposit, and the Tubas Red Sand uranium deposit. In a recent groundwater monitoring project, locations for suitable monitoring boreholes were determined using uranium exploration lithological log data and aerial electromagnetic survey data [Stanton, 2010].

The location of boreholes relative to proposed pits and satellite pits, the presence of water in the uranium exploration lithological log data, and the absence of mineralisation in the uranium exploration lithological log data were criteria used to select suitable borehole locations. Monitoring holes were drilled to a depth of approximately 100m, at a diameter of six inches. The borehole casing installed was five inch non-perforated and perforated PVC; slots of the perforated PVC are 2mm. A gravel pack of 5 to 10 mm was installed above the perforated casing to ensure water flow continuity. Monitoring holes were fitted with lockable caps and locks to prevent tampering.

Water samples were taken and preserved on site in order to ensure the samples are maintained in a condition representative of the in-situ state. Sampling was conducted in accordance with international standards. Sampling for standard environmental analysis is scheduled to take place on a biannual basis, while radionuclide sampling is to be completed once for the baseline report. Once the actual on-site work commences, a more regular monitoring schedule is to be developed. The first sampling campaign was completed in August 2010.

Groundwater samples were taken for two sets of analyses. Standard environmental analysis was completed at M&L Laboratory Services in South Africa. The environmental analysis has revealed that the groundwater in the Omahola Project area is unsuitable for human consumption. The total dissolved solids, calcium, sodium, chloride, sulfate, and nitrate concentrations generally far exceed the maximum limit set out by Namibian Standards [Stanton, 2010].

Twelve (12) acidified water samples were sent to the Australian Nuclear Science and Technology Organisation (ANSTO), Minerals Section, in Australia, for radionuclide analysis. In accordance with the Australian import permit conditions, the water samples were irradiated using the facilities at the Lucas Heights Research Laboratories in Sydney prior to the containment package being opened [ANSTO, 2010].

ANSTO reports that some of the samples contained significant quantities of a brown precipitate, while others appeared clear. A 20 ml aliquot of each sample was filtered through a 0.45 µm filter, and submitted for parent U^{238} and Th^{232} analysis using inductively coupled plasma mass spectrometry (ICPMS).

A representative sample of liquor plus solids was loaded into a Marenelli beaker and left for three weeks to enable the radium daughters to equilibrate. The samples were then counted using gamma spectrometry, to determine the concentrations of the uranium and thorium decay chain progeny.

It was found that the radioactivity of all samples was low, with U^{238} and Ra^{226} the only measurable radionuclides present; some Ra^{228} was also found in sample number 2.1. The results of the ANSTO analysis are summarised in Table 2 below [ANSTO, 2010].

Radionuclide Analysis
(ICPMS ± 5%; Gamma ± 10%)

Client Identification	ANSTO Identification	U-238 ICPMS ^{238}U mg/L	U-238 ICPMS ^{238}U Bq/L	U-238 Gamma ^{230}Th Bq/L	U-238 Gamma ^{226}Ra Bq/L	U-238 Gamma ^{210}Pb Bq/L	U-238 Radiochemistry ^{210}Po Bq/L	Th-232 ICPMS ^{232}Th mg/L	Th-232 ICPMS ^{232}Th Bq/L	Th-232 Gamma ^{228}Ra Bq/L	Th-232 Gamma ^{228}Th Bq/L	U-235 Gamma ^{235}U Bq/L	U-235 Gamma ^{227}Th Bq/L	Gamma ^{40}K Bq/L
1.1 - Hole 1	DYL-090910-1	0.32	3.9	< 6.4	< 0.22	< 1.7	nr	< 0.1	< 0.40	< 0.36	< 0.16	< 0.94	< 0.47	5.2
2.1 - Hole 2	DYL-090910-2	0.25	3.1	< 11	2.6	< 1.4	nr	< 0.1	< 0.40	0.65	< 0.14	< 0.81	< 0.34	5.9
3.1 - Hole 3	DYL-090910-3	0.18	2.2	< 17	1.4	< 2.7	nr	< 0.1	< 0.40	< 0.47	< 0.24	< 1.5	< 0.71	< 3.4
4.1 - Hole 4	DYL-090910-4	0.74	9.2	< 6.8	0.59	< 1.9	nr	< 0.1	< 0.40	< 0.37	< 0.17	< 1.0	< 0.40	4.1
5.1 - Hole 5	DYL-090910-5	0.78	9.7	< 6.5	< 0.18	< 1.5	nr	< 0.1	< 0.40	< 0.33	< 0.14	< 0.82	< 0.35	3.9
6.1 - Hole 6	DYL-090910-6	0.23	2.9	< 5.2	< 0.24	< 1.9	nr	< 0.1	< 0.40	< 0.41	< 0.19	< 1.2	< 0.47	< 2.6
7.1 - Hole 7	DYL-090910-7	< 0.1	< 1.2	< 1.6	< 0.23	< 3.3	nr	< 0.1	< 0.40	< 0.53	< 0.16	< 1.1	< 0.52	< 4.5
8.1 - Hole 8	DYL-090910-8	< 0.1	< 1.2	< 13	< 0.16	< 2.2	nr	< 0.1	< 0.40	< 0.37	< 0.11	< 0.81	< 0.39	< 3.2
9.1 - Hole 9	DYL-090910-9	< 0.1	< 1.2	< 23	2.3	< 5.1	nr	< 0.1	< 0.40	< 0.79	0.73	< 1.6	< 0.89	< 6.9
10.1 - Hole 10	DYL-090910-10	< 0.1	< 1.2	< 16	< 0.22	< 2.7	nr	< 0.1	< 0.40	< 0.51	< 0.16	< 0.98	< 0.52	< 4.4
11.1 - Hole 11	DYL-090910-11	< 0.1	< 1.2	< 15	< 0.18	< 2.3	nr	< 0.1	< 0.40	< 0.46	< 0.13	< 0.91	< 0.45	< 3.7
12.1 - Hole 12	DYL-090910-12	0.13	1.6	< 8.3	< 0.22	< 2.5	nr	< 0.1	< 0.40	< 0.53	< 0.16	< 1.3	< 0.56	< 4.6

nr – not requested

Table 2: Results of the radionuclide analysis of twelve water samples taken from the Omahola Project area [ANSTO, 2010]

3 RADIATION EXPOSURE AND CONTROL

3.1 INTRODUCTORY CONCEPTS

Humans have evolved in the presence of ionising radiation from natural sources, including from cosmic radiation, radioactive terrestrial sources, air, food and water. Since more than five decades now, a variety of man-made sources emitting ionising radiation have made additional contributions to this perpetual sea of background radiation.

Today, some such sources of man-made radiation are from uranium mines. Here, radioactive ores are brought to the surface and are crushed, milled and concentrated. Through ore dumps, waste rock, tailings and process facilities, radioactive materials are exposed to the environment, and also contribute to an enhancement of atmospheric radon exhalations and the addition and uptake of inhalable radioactive dust into the atmosphere.

The International Commission on Radiological Protection (ICRP) has put forward a conceptual model of the processes causing human exposures to ionising radiation [ICRP, 2007]. The model views exposure processes as a network of events and situations with each part of the network starting from a specific source of radiation. This radiation, or the radioactive source material giving rise to such radiation, passes through environmental or other pathways, and in this way exposes individuals. Such exposure to radiation or radioactive materials then leads to exposure doses to individuals.

In what is today commonly referred to as the source-pathway-receptor model of exposure to radiation, radiation protection can be achieved by taking action at the source of radiation, or at the various points along the exposure pathways, and if possible, by changing the location, behaviours and protective measures used by exposed individuals. Radiation protection includes all measures, processes and controls applied to minimise the potential exposure to radiation, and such measures are therefore most effectively implemented at the source(s), in the pathway(s) and at the receptor(s).

Although not fully fortified by empirical data for low exposure doses, it is generally assumed that there exists a proportional relationship between an increment of exposure dose and an increment of the associated risk of such an exposure. The assumption is further that there exists no low-radiation threshold for the onset of such risks. This so-called linear no-threshold assumption and the associated view that radiation risk increases linearly as the dose increases underpins the formulation of separate radiation protection measures for each source, pathway and receptor, while enabling the radiation protection officer to identify those parts of the exposure chain that are most relevant and amenable to the application of effective exposure controls. Separating the total exposure dose into its various contributing parts therefore allows targeted action for each such contributing element.

It is recognised that individuals are subject to several types and categories of exposure, each of which can be dealt with separately. For example, a worker at a uranium mine who is occupationally exposed because of the particular work that is being undertaken is also exposed to naturally occurring environmental sources of ionising radiation. Similarly, a member of the public is exposed to the ionising radiation from the natural background radiation, plus an incremental contribution due to other sources in his/her immediate environment, such as radioactive dust, radon and radon progeny entering the environment from nearby uranium mines.

Radiation protection measures are most effective when applied in the immediate environment in which risks to exposure exist. For example, the occupational exposure by a worker at a uranium mine needs to be minimised at the place of work where particular exposure dose limits apply for such an occupational settings. Similarly, the incremental dose that ordinary members of the public may be exposed to as a result of the operations of a uranium mine needs to be minimised to such a degree as to ensure that such potential exposure does not exceed the dose limit applicable for this particular group. As far as regulatory controls are concerned, each distinct exposure group, such as for example the occupational group or members of the public, are treated separately and are subject to separate regulatory provisions. And because potential occupational and public exposure categories require different control approaches, separate control measures and dose limits apply to each exposure category.

Radiation protection practices in the uranium mining industry focus on minimising the so-called stochastic effects of ionising radiation. Stochastic effects are not associated with a particular exposure threshold, in contrast to non-stochastic or deterministic effects which are certain to occur if and only if a certain exposure dose exceeds a threshold dose. Stochastic effects are probabilistic in nature, and may ensue if a cell (for example in the body of a worker) and with it the genetic make-up of the affected cell is modified rather than killed. Such modified cells may, after some delay, develop into cancer. In most cases, the body's repair and defence mechanisms active at the cellular level make it very unlikely that cells are irreparably modified when irradiated with small exposure doses, such as those that are typical in an occupational setting at a uranium mine. Nevertheless, there is no evidence that a threshold dose exists below which cancerous growth will no longer form. While the probability of occurrence of such cancers is higher for higher doses, the severity of any cancer that may result from irradiation is independent of the dose that has caused it. This implies that all potential exposures of members of the public or workers have to be kept as low as reasonably achievable, and certainly below the regulatory dose limit specified by the national regulator for the relevant exposure group.

In Namibia, the Atomic Energy and Radiation Protection Act, Act No. 5 of 2005, describes the statutory and regulatory radiation protection and control measures. By virtue of this Act, the National Radiation Protection Authority (NRPA) has been established, and is responsible for setting and overseeing the criteria applicable to radiation protection in Namibia. In October 2010, draft regulations are available from the NRPA, and are expected to become enacted soon [NRPA, 2010]. In parts, the draft regulations are based on international guidelines and the recommendations by the International Commission on Radiological Protection (ICRP) and the

International Atomic Energy Agency (IAEA). The Namibian draft regulations distinguish between occupational dose limits, and those that apply to members of the public.

The occupational exposure of any worker is to be controlled to ensure that the following limits are not exceeded [NRPA, 2010, refer to Schedule 2]:

a) an effective dose of 20 mSv per year averaged over five consecutive years;
b) an effective dose of 50 mSv in any single year;
c) an equivalent dose to the lens of the eye of 150 mSv in a year; and
d) an equivalent dose to the extremities (hands and feet) or the skin of 500 mSv in a year.

In special circumstances, a temporary change in the dose limitation requirements may be granted by the NRPA [NRPA, 2010].

For members of the public, the inferred average exposure dose of the relevant critical group(s) of members of the public may not exceed the following limits [NRPA, 2010, Schedule 2]:

a) an effective dose of 1 mSv in a year; in special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1 mSv per year;
b) an equivalent dose to the lens of the eye of 15 mSv in a year; and
c) an equivalent dose to the skin of 50 mSv in a year.

3.2 RADIOLOGICAL PROTECTION STANDARDS

The draft regulations of the Namibian National Radiation Protection Authority are largely based on the recommendations for the radiological protection standards of the International Atomic Energy Association (IAEA), as defined in the IAEA Basic Safety Standards [IAEA, 1996].

Accordingly, the Omahola Project will have to comply with the national regulatory requirements for radiological protection, which are underpinned by the following elements: justification of practices, exposure dose limits, optimisation of protection and safety, and dose constraints. These principal elements of the radiological protection standards are summarised below.

3.2.1 Justification of practices

As indicated above, the NRPA draft regulations applicable to the Omahola Project are the *"Regulations for protection against ionizing radiation and for the safety of radiation sources"* [NRPA, 2010]. In regard to the justification of practices, Chapter 3, regulation 9 of the draft regulations states (quoted verbatim from [NRPA, 2010]):

1. *"No practice or source within a practice may be licensed or registered unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation harm that it might cause, taking into account social, economic and other relevant factors.*
2. *The applicant for the license or registration must provide sufficient information to the authority relating to the benefits and the harm to support the justification of the practice.*
3. *For the purposes of sub-regulation (1), the following practices are deemed not to be justified whenever they would result in an increase, by deliberate addition of radioactive substances or by activation -*
   a) practices involving food, beverages, cosmetics or any other commodity or product intended for ingestion, inhalation or percutaneous intake by, or in relation to, a human being; or
   b) practices involving the frivolous use of radiation or radioactive substances in commodities or products such as toys and personal jewellery or adornments."

3.2.2 Dose limitation

In regard to the dose limitation applicable to the Omahola Project, Chapter 3, regulation 10 of the NRPA's draft regulations state (quoted verbatim from [NRPA, 2010]):

1. *"The normal exposure of individuals must be restricted so that neither the total effective dose nor the total equivalent dose to relevant organs or tissues, caused by the possible combination of exposures from all practices, exceeds any relevant dose limit specified in Schedule 2 except in the special circumstances contemplated in Regulation 11[2].*
2. *Sub-regulation (1) does not apply to medical exposures from licensed practices."*

The dose limits referred to in the draft regulations (Schedule 2) are summarised in section 3.1 above.

3.2.3 Optimisation of protection and safety

In regard to the optimisation of protection and safety as is applicable to the Omahola Project, Chapter 3, regulation 12 of the draft regulations state (quoted verbatim from [NRPA, 2010]):

1. *"In relation to exposures from any particular source within a practice, radiation safety must be optimised in order that the magnitude of individual doses (except for the volume of interest in cases of therapeutic medical exposures) the number of people exposed and the likelihood of incurring exposures must be kept as low as reasonably achievable, economic and social factors being taken into account, within the restriction that the dose to*

[2] Regulation 11 describes special circumstances under which the regulator may grant approval for the temporary exceedance of applicable dose limitations.

individuals delivered by the source be subject to dose constraints, as specified in the license condition imposed by the Authority.

2. *The licensee must use, to the extent practicable, procedures and engineering controls based upon sound radiation safety principles to achieve this objective."*

3.2.4 Dose constraints

In regard to dose constraints as are applicable to the Omahola Project, Chapter 3, regulation 13 of the draft regulations state (quoted verbatim from [NRPA, 2010]):

1. *"Except for medical exposure, the optimisation of the radiation safety measures associated with a given practice must satisfy the condition that the resulting doses to the individuals of the critical group do not exceed dose constraints which are equal to the dose limits specified in or any lower values established by the Authority.*
2. *In case of any source that can release radioactive substances to the environment, the dose constraints must be established so that the prospective annual doses to members of the public, including people distant from the source and people of future generations, summed over all exposure pathways, including contributions by other practices and sources, are unlikely to exceed the dose limits specified in Schedule 2 or any lower values established by the Authority."*

The dose limits referred to in the draft regulations are given in section 3.1 above.

3.3 Occupational Exposure to Ionising Radiation

The International Commission on Radiological Protection (ICRP) defines occupational exposure "as all radiation exposure of workers incurred as a result of their work", and limits the use of the term occupational exposure to "radiation exposures incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating management" [ICRP, 2007].

3.3.1 Sources of radiation exposure

In the uranium mining sector one distinguishes between three main pathways for the delivery of radiation doses to the human body [von Oertzen, 2010b], i.e.

1. external irradiation by gamma radiation originating from radioactive materials found and/or used in the mining and concentration processes,
2. internal radiation by way of inhalation of radon and radon decay products (radon progeny), and of long-lived radionuclides contained in airborne dust, and

3. internal radiation by way of ingestion of radionuclides, e.g. when coming in contact with contaminated surfaces, applying poor hygiene standards, consuming contaminated food or water, or otherwise causing radionuclides to enter the body's digestive tract.

3.3.1.1 Gamma radiation

A uranium mine concentrates naturally occurring radioactive source materials through a process of uranium extraction. In such an occupational setting, the main sources of gamma radiation are mainly due to exposure to the

- uranium ore body,
- uranium-bearing materials contained in ore stockpiles, waste rock dumps, pulps and sludge, and tailings facilities,
- final product, i.e. uranium oxide,
- radioactive deposits and contaminants building up in pipes and process equipment, and
- sealed sources containing specific radionuclides, for example those frequently used in density and flow meters.

3.3.1.2 Radon and radon progeny

Radon (Rn^{222} and Rn^{220}, which is also called thoron) are radioactive gases arising in the decay of radium (Ra^{226} and Ra^{224} respectively). Radon emanates from the crystal lattice in which the parent radionuclide radium was embedded, and travels into the pore space of the substrate material from where it diffuses to the surface of the ore to escape into the atmosphere. The flux of radon from the soil surface, rocks and tailings facilities is called radon exhalation. The crushing and milling operations undertaken in most uranium mining environments enhances the natural exhalation of radon, and ore stockpiles, tailings facilities, the pit area and waste rock dumps containing radium are the main sources of such radon and thoron.

Radon is a decay product of the uranium decay chain, whereas thoron is a decay product of the thorium chain. The presence of thoron therefore depends on the abundance of thorium in the soil and ores. In addition, the very short half-life of thoron (55 seconds) limits the ambient concentrations of thoron – on average therefore, radon concentrations are about 10 times higher than the thoron concentration, and hence thoron is often disregarded relative to radon. The present assessment does not take thoron into account.

The exposure to radon and radon daughters in an open pit uranium mine depends on prevailing weather conditions. Low-lying atmospheric inversion layers and still-air conditions may trap radon close to where it is exhaled from the source. As temperatures increase after sunrise and natural thermal air movements commence, radon is dispersed into the surrounding atmosphere and transported away from the source.

3.3.1.3 Radioactive dust

Geophysical analyses of the ore body in the Omahola Project indicate that uranium concentrations in the ore are between 200 and 360 parts per million (ppm) [Deep Yellow, 2010]. The mining process generates atmospheric dust, which contains radionuclides, which can be inhaled and/or ingested by humans and also cause the contamination of exposed surfaces with particulates containing radionuclides. Main dust-generating activities include exploration drilling, blasting, mining, transport of ores on haul trucks, crushing, milling, conveying, general vehicle movements on unsealed roads, and the eventual storage on tailings facilities, all of which enhance the natural concentration of airborne dust.

Airborne dust originating from drilling, blasting, crushing and milling has average uranium concentrations which are very similar to the mined ores. In addition, the production of the final product, and in particular the drying and packaging process involving uranium concentrate in the form of yellow cake are other sources of radioactive dust that may be inhaled and/or ingested.

3.3.1.4 Contaminated surfaces

Airborne dust is characterised by the concentration of total suspended particulates, and the concentration of the inhalable fraction of the dust. Both types of airborne dust are eventually deposited on exposed surfaces, and will then become available for human and animal ingestion. Such ingestion can be direct, i.e. by way of a direct intake, or indirect by way of consuming food or water that is contaminated by such dust. The mining environment offers opportunities for intense surface contamination, as are typically found at drill rigs and crushers. In addition, dust which is transported away from the source will eventually settle out and is deposited on objects.

3.3.2 Managing the occupational exposure to radiation

Under the Namibian Atomic Energy and Radiation Protection Act, Act No. 5 of 2005, the National Radiation Protection Authority (NRPA) is the country's radiation protection regulator. The NRPA has issued guidelines for how practices that potentially give rise to exposure to ionising radiation are to develop and implement a Radiation Management Plans [NRPA, 2009].

Section 3.5.1 below summarises the main components that the Radiation Management Plan (RMP) for the Omahola Project will have to include. In regard to ensuring that occupational exposure doses of workers are kept as low as reasonably achievable, the RMP will be guided by the stipulations as currently contained in the draft regulations issued by the NRPA [NRPA, 2010].

Chapter 6 of the NRPA's draft regulations are of relevance to occupational exposure protection, in particular regulation 21 (2) pertaining to **general responsibilities** (quoted verbatim from [NRPA, 2010]):

"Licensees must ensure for all workers engaged in activities that involve or could involve occupational exposure, that –

a) occupational exposures are limited as specified in Schedule 2;
b) radiation safety is optimised in accordance with these regulations;
c) policies, procedures and organisational arrangements for occupational protection and safety are established to implement the relevant requirements of these regulations, and the resulting decisions on measures to be adopted for this purpose are recorded and made available to relevant persons, including workers, through their representatives where appropriate;
d) suitable and adequate facilities for radiation safety are provided, including personal protective devices and monitoring equipment, and arrangements are made for their proper use;
e) radiation safety and health surveillance services are provided through qualified experts;
f) arrangements are made to facilitate consultation and co-operation with workers, through their representatives where appropriate, about measures which are needed to achieve adequate radiation safety by effective implementation of these regulations; and
g) necessary conditions are provided and arrangements are made to promote a safety culture in the work force and achieve adequate training of workers on radiation safety matters."

In regard to monitoring the workplace, Chapter 6, regulation 29 of the draft regulations states that (quoted verbatim from [NRPA, 2010]):

1. *"Licensees, in co-operation with employers if appropriate, must establish, maintain and keep under review a programme for the monitoring of the workplace commensurate with the nature of and the risks associated with all relevant sources.*

2. *The nature and frequency of monitoring of workplaces must –*
   a. *be sufficient to enable –*
      i. *the evaluation of the radiological conditions in all workplaces;*
      ii. *the assessment of the exposure of workers in controlled areas and supervised areas; and*
      iii. *the review of the classification of controlled and supervised areas; and*
   b. *depend on the levels of ambient dose equivalent and airborne and surface activity concentration, including their expected fluctuations and the likelihood and magnitude of potential exposures.*

3. *The programmes for monitoring of the workplace must specify –*
   a. *the quantities to be measured;*
   b. *where and when the measurements are to be made and at what frequency;*
   c. *the most appropriate measurement methods and procedures; and*

d. reference levels of the measured quantities and the actions to be taken if they are exceeded.

4. *Licensees must keep appropriate records of the findings of the workplace monitoring programme, which must be made available to workers and where appropriate their representatives."*

In regard to work areas, Chapter 6, regulation 23 of the draft regulations states that (quoted verbatim from [NRPA, 2010]):

1. *"Licensees must designate as a* ***controlled area*** *any area in which specific protective measures or safety provisions are or could be necessary for –*
   a) controlling normal exposures or preventing the spread of contamination during normal working conditions; and
   b) preventing or limiting the extent of potential exposures.

2. *Licensees must –*
   a) determine the boundaries of any controlled area on the basis of the magnitude and likelihood of expected exposures and the nature and extent of the required protection and safety measures;
   b) delineate controlled areas by physical means or, where this is not reasonably practicable, by some other suitable means;
   c) where a source is brought into operation or energised only intermittently or is moved from place to place, delineate an appropriate controlled area by means that are appropriate under the prevailing circumstances and specify exposure times;
   d) display a warning symbol, recommended by the International Organisation for Standardisation (ISO) , and appropriate instructions at access points and other appropriate locations within controlled areas;
   e) establish occupational protection and safety measures, including local rules and procedures that are appropriate for controlled areas;
   f) restrict access to controlled areas by means of administrative procedures, such as the use of work permits, and by physical barriers, which could include locks or interlocks, the degree of restriction being commensurate with the magnitude and likelihood of the expected exposures; and
   g) provide at entrances and exits of controlled areas appropriate means for change of clothing, contamination monitoring and personal decontamination."

In regard to supervised work areas, Chapter 6, regulation 24 of the draft regulations states that (quoted verbatim from [NRPA, 2010]):

1. *"Licensees must designate as a supervised area any area not already designated as a controlled area, but where occupational exposure conditions need to be kept under*

review even though specific protection measures and safety provisions are not normally needed.

2. *Licensees must delineate and identify the supervised areas by appropriate means, taking into account the nature and extent of radiation hazards in those areas.*
3. *Licensees must periodically review conditions to determine the possible need to revise the protection measures or safety provisions, including the boundaries of controlled and supervised areas."*

The draft regulations also contain descriptions of the regulations for

- conditions of service of workers who are potentially exposed to ionising radiation
- local rules and supervision of workers
- personal protective equipment
- management of overexposure
- monitoring of the workplace
- health surveillance
- approval of dosimetry services, and
- records of worker exposure

which, in the interest of brevity, will not be reproduced here, but are discussed in further detail in section 3.5 below.

3.3.3 Determining the occupational exposure dose

The occupational exposure of workers is determined from the results of the occupational monitoring program. As described in section 3.3.2, the occupational exposure program will be presented in detail in the to-be-developed Radiation Management Plan, which will be prepared for the Omahola Project.

The occupational radiation exposure of workers is based on the dose attributable to gamma radiation, the dose attributable to the inhalation of radionuclides contained in dust, and the dose attributable to the inhalation of radon and radon progeny. It is noted that the ingestion pathway is ignored in the present study as this pathway is most easily managed (and thereby almost eliminated) if proper hygiene and behavioural measures are put in place. Under these assumptions, the individual occupational dose is expressed as:

Equation 1: $$E_T = H_p(d) + h_\alpha I_\alpha + h_{Rn}$$

where E_T resultant annual effective dose in $mSv.a^{-1}$,

$H_p(d)$ whole-body external exposure dose from gamma radiation,

$h_\alpha I_\alpha$ whole-body internal dose from inhaled long-lived alpha emitters in dust,

h_{Rn} whole-body internal dose from inhaled radon/radon progeny,

where the exposure dose along each pathway is expressed in $mSv.a^{-1}$.

3.3.3.1 Monitoring exposure to gamma radiation

Worker exposure to external gamma radiation will be monitored using electronic personal dosimeters or thermo-luminescent dosimeters. Such dosimeters will be individually assigned, and the duration and number of assignees per work area will depend on the expected exposure in a specific work area, the relevant exposure group, and the number of members per such exposure group.

The details of how dosimeters will be assigned will be described in the to-be-developed Radiation Management Plan, which will be prepared for the Omahola Project. For the purposes of this section it suffices to mention that the whole-body dose equivalent from external gamma radiation will be determined using individually assigned dosimeters, yielding an external exposure dose for a specific worker $H_p(d)$ measured in units of mSv per annum ($mSv.a^{-1}$).

3.3.3.2 Monitoring exposure to radioactive dust

The committed effective dose from the inhalation of long-lived alpha emitting radionuclides contained in airborne dust, $h_\alpha I_\alpha$ (in $mSv.a^{-1}$), is estimated using the following equation:

Equation 2: $$h_\alpha I_\alpha = V_{Rate} \times AC_\alpha \times DCF \times ET$$

where V_{Rate} is the hourly breathing rate for workers, which is assumed to be 1.2 $m^3.h^{-1}$ as per the recommendations by the ICRP for adult workers [ICRP, 1995],

AC_α is the average long-lived alpha activity concentration expressed in $Bq.m^{-3}$, and measured in air using a personal air sampler, or inferred from an area air sampler,

DCF is the dose conversion coefficient, which is expressed in $mSv.Bq^{-1}$, and

ET is the exposure time, which is expressed in hours per annum ($h.a^{-1}$).

Appropriate dose conversion coefficients DCF are chosen and depend on whether the airborne dust is mainly due to uranium-bearing ore dust, or the final uranium oxide product. In the present study, and as per the Namibian regulator's draft regulations, the DCFs as provided by the IAEA guidelines [IAEA, 2004, Annex, p. 79 for uranium ore dust] are used.

3.3.3.3 Monitoring exposure to radon/radon progeny

The exposure dose from inhaled radon and radon daughters, h_{Rn} (in $mSv.a^{-1}$), is estimated using the following equation:

Equation 3: $$h_{Rn} = AC_{Rn} \times CF_{Rn} \times ET$$

where AC_{Rn} is the average radon activity concentration, which is expressed in $Bq.m^{-3}$, and measured using a personal radon/radon progeny monitor, or inferred from an area radon sampler,

CF_{Rn} is the conversion factor, which is expressed in mSv / Bq.h.m^{-3}, and

ET is the exposure time, which is expressed in hours per annum (h.a^{-1}).

The present study uses the conversion factors CF_{Rn} as provided in the ICRP guidelines [ICRP, 1994].

3.4 Environmental / Public Exposure to Ionising Radiation

3.4.1 Background environmental radiation at the Omahola Project area

The chapter on Environmental Radiation, refer to chapter 2, presented the contributions to the natural background radiation in the Erongo Region and discussed the respective contributions of terrestrial radiation, dust and radon in the Project area.

As yet, the Omahola Project site has not benefited from a detailed radiological assessment, which will be commissioned prior to the commencement of mining operations to determine a representative radiological baseline. Such a baseline survey will also include the ongoing sampling and analysis of groundwater in the Project area, so as to establish a quantitative basis on which changes in the radionuclide content of groundwater resources can be determined.

The baseline survey will also establish a quantitative basis on which incremental exposure doses can be determined, i.e. exposure doses that can be attributed to the operations of the Omahola Project. The survey will also be used to establish suitable indicators for environmental rehabilitation and long-term radiological safety monitoring of the Project area.

3.4.2 Critical group(s) of members of the public

As shown in Figure 10, the Omahola Project is situated some 40 km south-east of Swakopmund, within the Namib Naukluft Park. There are no permanent human settlements in the immediate proximity to the proposed mining project. The closest permanent settlements are smallholding farms in the Swakop River, as shown in Figure 10, which are more than 10 km north and north-west from the proposed INCA mining license area.

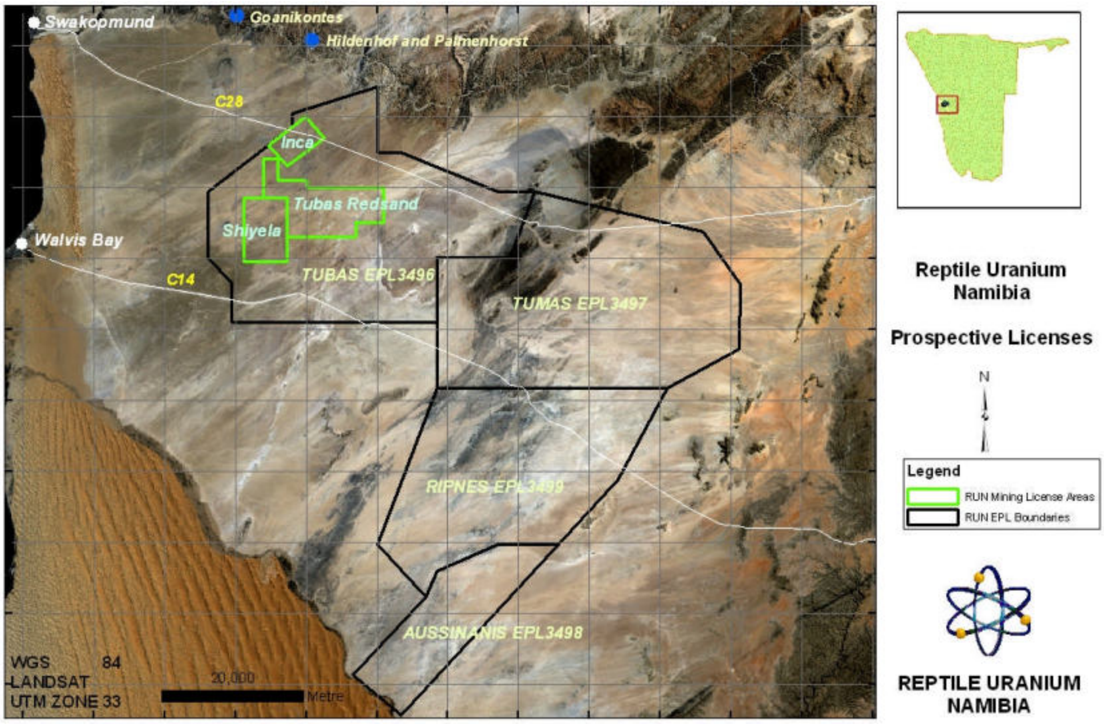

Figure 10: The Omahola Project and closest permanent smallholding farms Hildenhof, Palmenhorst and Goanikontes (blue dots), and towns of Swakopmund and Walvis Bay [Reptile, 2010]

One defines a critical group as a group of members of the public which is reasonably homogeneous with respect to its exposure for a specific radiation source and exposure pathways, and who are representative of those individuals receiving the highest exposure dose along the given exposure pathway from the sources under consideration. One selects a critical group by identifying those groups of individuals from amongst the potentially exposed population that reflect the various lifestyle and land use characteristics of the area which would result in the highest exposures under the respective scenario. The potential exposures of these groups are then assessed, based on their potential of being exposed through the exposure pathways considered.

The present study considers one hypothetical critical group, and one actual critical group. The hypothetical critical group is a group of adult individuals who are postulated to live at the most exposed part of the perimeter of the proposed mining license area. This hypothetical critical group is defined to gauge the worst-case exposures of members of the public that would be attributable to the operations taking place at the future Omahola Project. In contrast, the actual critical group are members of the smallholding community of farmers residing on farms along the Swakop River as shown in Figure 10. The radiological impact on these members of the critical group is evaluated in case the exposures to members of the hypothetical 'worst-case group' indicate that exposure doses may exceed the applicable public dose limit.

3.4.3 Exposure pathways

There are three main pathways by which radioactive materials can enter the environment from the Omahola Project, namely by way of the atmospheric pathway (dust and radon), through the aquatic pathway, and by way of direct exposure to radiation.

Based on experience with uranium mining operations internationally and in Namibia, the direct external exposure to gamma radiation originating from uranium-bearing ores, stockpiles and tailings facilities are negligible beyond the immediate mining license area. As a result, such direct exposure will therefore not be considered as part of the present environmental / public exposure dose assessment. This simplification is warranted because of the considerable physical distances between the actual sources of gamma radiation and those of the critical group of the members of the public. It is however emphasised that this simplification does not apply in case of the potential occupational exposures, as were discussed in section 3.3 above.

The remaining pathways, namely the atmospheric and the aquatic pathways, are illustrated in Figure 11 below. An atmospheric and a liquid source are found at the start of the atmospheric and aquatic pathway respectively, and are discussed separately below.

3.4.3.1 Atmospheric pathways

The atmospheric pathway is responsible for the transport of two distinct sources, i.e.

- radon and radon progeny, and
- radionuclides as contained in the inhalable fraction of atmospheric dust.

These two components of the atmospheric pathway will be assessed separately: section 3.4.4 discusses the assumptions made to estimate the contribution of radon and radon progeny to potential environmental / public exposures, while section 3.4.5 quantifies the potential contribution from radioactive dust. It is noted that the contribution of both components of this pathway gives rise to internal exposures.

In the atmospheric pathway, the dominant physical processes upon release of the source are atmospheric dispersion and eventual deposition. Dispersion may lead to the inhalation of the source by a receptor, and an exposure dose to the receptor. Deposition may lead to direct or indirect ingestion of the source by the receptor (via plants or animals), and the subsequent exposure of the receptor. In the absence of food-producing regions in the greater Omahola Project area (the closest smallholding where some foodstuff is produced is more than 10 km from the proposed Project area), ingestion of radionuclides originating at the Omahola Project is not considered probable, provided standard hygiene measures are applied. Ingestion is therefore not considered a likely exposure pathway, and will be ignored in this study; this is indicated by a dashed line in Figure 11.

While direct external irradiation exposure from radionuclides suspended in the air may occur, it is shown below that the predicted airborne concentration of radioactive dust is low at and beyond the perimeter of the proposed mining license areas. This implies that the potential external exposure as a result of 'gamma shine' from radionuclides suspended in the air will not be considered further in the present study; this is indicated by dashed lines in Figure 11.

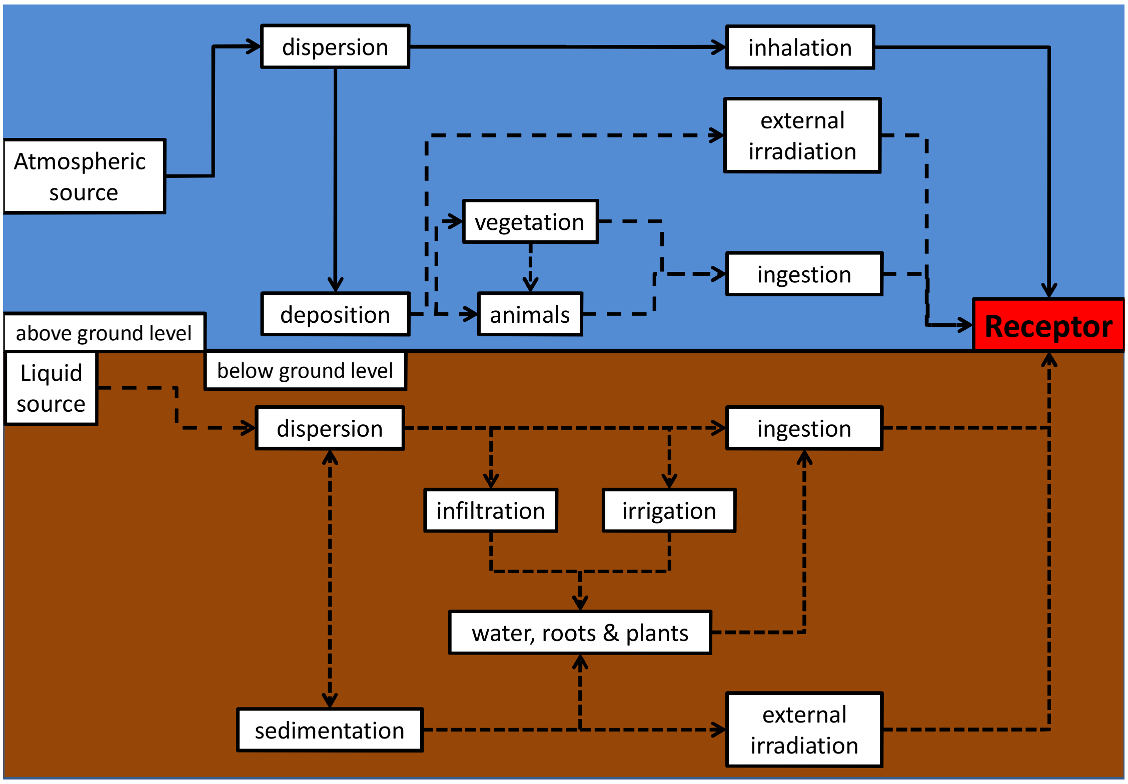

Figure 11: Potential environmental / public exposure pathways; pathways indicated by solid lines are further quantified in this study [von Oertzen, 2010b]

3.4.3.2 Aquatic pathway

The aquatic environment in which the Omahola Project is to take place is dominated by the climatic and weather drivers of the central hyper-arid Namib desert environment. Surface run-off of water is limited to times where sporadic rainfall events take place, some of which can result in considerable quantities of run-off water within a very short time. Such intermittent rainfall episodes lead to the rapid transport of water masses, both within existing drainage lines and man-made surface structures. Surface run-off water eventually collects in surface depressions, from where it infiltrates into the ground and disperses into soil and rock formations.

As discussed in the section on groundwater resources, the existing water resources in the Omahola Project area are saline, and not suited for human consumption without prior treatment. Different methods of water treatment exist, most of which would remove a significant proportion of the dissolved solids and suspended radionuclides found in the untreated resource. For the purposes of this study however, it is assumed that no groundwater from the Project area will be consumed by humans; this is indicated by dashed lines in Figure 11.

This section furthermore assumes that the potential impact zone of any release of liquids containing radionuclides will be limited to the actual mine site. Liquid contamination taking place beyond the facilities constructed for such purposes (such as tailings facilities and bunded areas within the processing plant) are expected to be contained and removed before any significant contamination of the environment / groundwater resources occur.

The aquatic pathway commences with the release of a radioactive contaminant as depicted in Figure 11, upon which radionuclides are transported and dispersed into the environment. In parts, the radionuclides will lodge themselves permanently into soil and ores surrounding the contamination site. However, because members of the public are not assumed to be within the mining license area where such potential contamination may occur, this section assumes that there will not be any potential exposure of members of the public from areas into which such contaminants are absorbed.

Other radionuclides will be transported by the carrier liquid, and dispersed by the movement of such liquids and water into soils and through sediments. Here, the contaminated liquid may eventually reach biological organisms including plants, and seep into boreholes and water points used by animals and/or members of the public. In select cases, contaminated water may be pumped and used as irrigation and/or drinking water. Radionuclides taken up by plant materials or directly consumed by a receptor may expose the receptor to ionising radiation. However, as shown in a recent groundwater study, aquatic transport processes in the region of the lower Khan and Swakop Rivers are characterised by a strong vertical transport component and very slow horizontal water movements [BIWAC, 2010]. This regional peculiarity, and in view of the distance between the proposed Omahola Project area and boreholes from which water is extracted for drinking purposes or to irrigate fields, justifies that the aquatic pathway is not considered a significant exposure pathway under the present circumstances, and will therefore not be considered further in this study; this is indicated by a dashed line in Figure 11.

The above reasoning leads to the conclusion that the aquatic pathway is not likely to contribute to the consumption of groundwater contaminated with radionuclides from the proposed operations at the Omahola Project. It is assumed that any potential contamination will be addressed using best practice tailings management, as well as clean-up and decontamination procedures at the site of contamination. Based on these assumptions it is concluded that the aquatic pathway does not constitute a significant pathway for human and environmental exposure to ionising radiation, and will be ignored when determining the exposure dose to members of the critical group.

It is concluded from the above that the atmospheric pathway, in particular the dispersion of radionuclides in air and the concentration of radon remain the only two potential sources of radiation for members of the public, and these will be discussed in the next section.

3.4.4 Radon source terms

Atmospheric concentrations of radon are based on estimates of radon exhalation rates from the general ore body, pit, unsurfaced rods, ores stockpiles, waste rock dumps and tailings. These rates can be determined from the specific activity of radium (Ra^{226}) in the source materials, noting that radon (Rn^{222}) is the direct daughter product of Ra^{226} in the U^{238} decay chain.

To determine radon exhalation rates from first principles, source-specific parameters such as the radon emanation coefficient, radon diffusion parameter, material porosity and specific density are required. An alternative method, which will be used in this study, is to use estimates based on empirical radon exhalation rates. Presently, no direct empirical data is available to substantiate the radon exhalation rates for the proposed Omahola Project.

For the purposes of this section, Table 3 summarises radon exhalation rates that were estimated for each type of source. These estimates are based on radon exhalation rates found at similar mining operations in central Namibia [Fourie *et al*., 2009; Strydom, 2006]. The exhalation rates summarised in Table 3 are to be compared with those derived from first principles under dry-soil conditions, i.e. 0.033 $Bq.m^{-2}.s^{-1}$ [UNSCEAR, 2000], and the estimated mean worldwide radon exhalation rate of 0.016 $Bq.m^{-2}.s^{-1}$ [Wilkening *et al.*, 1972].

Using the envisaged surface areas for the different planned structures yields the radon source terms for the various sources, refer to Table 3, which in turn were used as inputs to the radon dispersion model. The Atmospheric Dispersion Modelling System (ADMS) developed by Cambridge Environmental Research Consultants was used as the radon dispersion model. It predicts the concentration of radon in near-ground level air masses originating from the various radon sources as summarised in Table 3, while taking the prevailing meteorological conditions into account [Khumalo *et al.*, 2010].

Source	Radon exhalation rate [Bq.m^{-2}.s^{-1}]	Surface area [m^2]	Radon source term [Bq.s^{-1}]
Waste rock dump 1	1.50	975,000	1,462,500
Waste rock dump 2	1.50	950,625	1,425,938
Waste rock dump 3	1.50	975,000	1,462,500
Tailings facility	2.00	926,250	1,852,500
ROM stockpile	2.00	9,375	18,750
Pits at INCA & Tubas	2.00	13,500	27,000
Unpaved road 1	0.05	6,250	313
Unpaved road 2	0.05	11,260	563
Unpaved road 3	0.05	7,500	375
Unpaved road 4	0.05	14,270	714
Unpaved road 5	0.05	1,500	75
Unpaved road (Tubas)	0.05	85,000	4,250
Unpaved road (INCA)	0.05	4,280	214

Table 3: Estimated radon exhalation rates, surface areas and inferred radon source terms at the proposed Omahola Project, as used in the radon dispersion model

3.4.5 Dust source terms

Most mining activities are associated with a prolific generation of dust. Activities including drilling, blasting, loading, trucking along unpaved roads, as well as crushing and the effects of wind erosion on stockpiles and the tailings surface all generate copious amounts of airborne dust.

There is no actual operational data available for the Omahola Project. This implies that the potential airborne dust concentrations are estimated using an air dispersion model [Khumalo *et al.*, 2010]. The model predicts the concentration of total suspended particulates and inhalable dust fractions in air, originating from the various dust sources in the Project area, and the dispersion of such particulates under the prevailing meteorological conditions. The model produces several outputs: for the present assessment, the airborne concentration of the inhalable fraction of the suspended dust is of greatest interest, as such dust may contain radionuclides and therefore may pose a radiological risk if inhaled by members of the public. The present study uses the concentrations of airborne inhalable particulates at various points around the proposed mining license area to compute the resulting internal exposure dose when such radioactive dust is inhaled by members of the public.

The Atmospheric Dispersion Modelling System (ADMS) developed by Cambridge Environmental Research Consultants was used as the dust dispersion model. The details of the air quality impact assessment for the Omahola Project are contained in a separate report, and will therefore not be repeated here [Khumalo *et al.*, 2010].

This section therefore only presents those elements that are of relevance to estimating potential exposures as a result of inhaling radioactive dust. It is to be noted that while air dispersion models are most useful in estimating potential airborne concentrations of total suspended particulates and inhalable dust fractions, they do not replace an empirical assessment of actual dust deposition rates.

This implies that once the Omahola Project becomes operational, dust monitoring will have to be undertaken as part of the environmental monitoring program, and should strengthen future air dispersion models by incorporating (i) actual field data for the dust source terms, (ii) actual site-specific meteorological data, (iii) actual geometries of waste rock dumps, the pit areas and tailings facilities.

3.4.6 Exposure dose due to inhalation of radon

As can be seen from Table 3, the single largest radon source term is due to the waste rock dumps, contributing almost 70% to the total radon source term. The second largest contribution is from the tailings facility, which constitutes some 30% to the total radon source. The remaining radon exhaling structures, including from the pits, the run of mine (ROM) stockpile and unpaved roads, contribute less than 1% to the total radon source term.

Figure 12 shows the modelled annual average atmospheric radon concentrations (in Bq.m^{-3}), where the various radon sources summarised in Table 3 have been taken into account, and explicitly excludes the natural radon exhalations that occur in the Omahola Project area [Khumalo *et al.*, 2010].

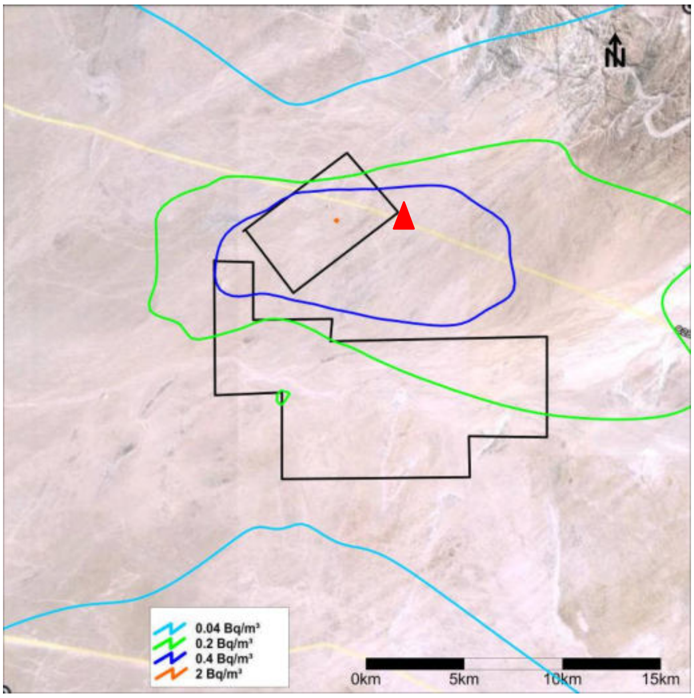

Figure 12: Predicted average radon concentrations in near-surface air, in Bq.m^{-3}, across the proposed mining license area [Khumalo *et al.*, 2010]; the red triangle indicates the location of the hypothetical critical group of members of the public

As can be seen from Figure 12, average radon concentrations are highest (at 2 Bq.m^{-3}) directly on site (INCA), where the largest radon sources (waste rock dumps and tailings) are. Atmospheric radon concentrations attributable to the mine-specific radon sources then rapidly decrease as the distance from the sources increases, and are at 1 Bq.m^{-3} at the north-eastern perimeter of the INCA mining license area, as indicated by the red triangle in Figure 12. Radon is dominantly dispersed in the east and westerly directions, which is a result of the prevailing meteorological conditions and the topographic characteristics of the Project area.

To estimate the potential exposure dose of members of the critical group as a result of inhaling radon originating from the mining activities in the Project area, the relationship between airborne radon concentrations and effective exposure dose as a result of inhalation are required. Such potential exposure depends on factors such as the equilibrium factor for radon for indoors and outdoors, the relative time spent indoors and outdoors, and the degree of ventilation [IAEA, 1996a; UNSCEAR, 2000, Appendix B]. Equation 4 is used to compute the inhalation dose due to radon, given the airborne concentration of radon and the associated dose conversion coefficient for radon inhalation.

Equation 4: $Dose_{Rn} = Conc_{Rn} \times DCF_{Rn}$

where $Dose_{Rn}$ inhalation dose due to radon, in µSv,

$Conc_{Rn}$ airborne concentration of radon, in Bq.m^{-3}, and

DCF_{Rn} dose conversion factor for radon inhalation, in µSv / Bq.m^{-3}.

The ICRP specifies the conversion coefficient for radon as 5.56 x 10^{-6} $mJ.m^{-3}/Bq.m^{-3}$ [ICRP, 1994]. Combining the equilibrium factors of 0.4 for indoors and 0.6 for outdoors, and representative times of indoor and outdoor occupancy (assuming that 7,000 hours are spent indoors and the remainder for outdoors for members of the public), yields a dose conversion factor of 1.56×10^{-2} $mJ.m^{-3}/Bq.m^{-3}$ for indoor, and 7.83×10^{-3} $mJ.m^{-3}/Bq.m^{-3}$ for outdoor. When combined with the dose conversion convention for effective dose per unit exposure to radon progeny to members of the public, i.e. 1.1 $mSv/mJ.h.m^{-3}$, as suggested by the ICRP, the annual indoor and outdoor radon inhalation doses and dose conversion factor DCF_{Rn} of indoor 1.72×10^{-2} $mSv/Bq.m^{-3}$, and outdoor 8.61×10^{-3} $mSv/Bq.m^{-3}$ is found [ICRP, 1994; IAEA, 1996]. These conversion factors are combined to yield DCF_{Rn} = 25.7 $\mu Sv/Bq.m^{-3}$, and simplify Equation 4 to:

Equation 5: $Dose_{Rn} = 25.7 \times Conc_{Rn}$

where $Dose_{Rn}$ inhalation dose due to radon, in µSv,

$Conc_{Rn}$ airborne concentration of radon, in $Bq.m^{-3}$.

Equation 5 is used to compute the exposure dose due to the inhalation of radon for members of the critical group. As described in section 3.4.2, the present study proposes a hypothetical critical group of members of the public who are postulated to live at the north-eastern perimeter of the INCA mining license area. It is emphasised that such a critical group does not exist and is postulated merely to allow for the quantification of the worst-case exposure of members of the public. Should members of such a hypothetical critical group experience exposures well below the public dose limit as specified by the NRPA, then all other members of all other critical groups who live further afield would be exposed to less than the hypothetical critical group members.

As shown in Figure 12, the highest average radon concentration outside the proposed mining license area is found at the north-eastern boundary of the INCA mining license area, at the intersection between the mining license area and the C28 public access road. If it is assumed that members of the hypothetical critical group permanently live at this point, as indicated by the red triangle in Figure 12, and using Equation 5 with $Conc_{Rn}$ = 1 $Bq.m^{-3}$, then members of such a hypothetical critical group would receive an incremental exposure dose of some 26 $\mu Sv.a^{-1}$ as a result of inhaling radon/radon progeny originating from the Omahola Project.

It is concluded that members of the critical group of farmers living on smallholdings along the Swakop River, which are more than 10 km north of the Project area, would also be exposed to radon concentrations from the Omahola Project. However, such radon concentrations would be orders of magnitude smaller than the radon concentration experienced at the location where members of the hypothetical critical group are postulated to reside.

It is recommended that ambient radon concentrations are monitored at and around the perimeter of the proposed Omahola Project, as part of the future environmental monitoring activities, and in support of the public exposure monitoring program that is a regulatory requirement in Namibia [NRPA, 2010].

3.4.7 Exposure dose due to inhalation of dust

In order to calculate the exposure dose from the inhalation of dust containing long-lived alpha emitters, actual or predicted dust concentrations at the point(s) of interest are required. As there are no mining operations in the Omahola Project area at the present time, airborne dust concentrations are modelled using an atmospheric dust dispersion model. For the purposes of this section, the results of the airborne dust dispersion model introduced in section 3.4.5 are used [Khumalo *et al.*, 2010].

The exposure dose as a result of inhaling radionuclides suspended in air is calculated using the following formula:

Equation 6: $Dose_{Dust} = Conc_{Dust} \times DCF_{Dust} \times Load_{Dust} \times t_{Public} \times VRate_{Public}$

where	$Dose_{Dust}$	inhalation dose due to radioactive dust, in $Sv.a^{-1}$
	$Conc_{Dust}$	specific activity of radionuclides in dust, in $Bq.g^{-1}$
	DCF_{Dust}	dose conversion factor for inhalation of specific radionuclides, $Sv.Bq^{-1}$
	$Load_{Dust}$	density of inhalable airborne dust load, in $g.m^{-3}$
	t_{Public}	time period of public exposure, in $h.a^{-1}$
	$VRate_{Public}$	average breathing rate of members of public, in $m^3.h^{-1}$

For the purposes of establishing an upper limit for the exposure dose due to the inhalation of radionuclides contained in inhalable dust, the following assumptions are made:

- dust from uranium-bearing ores having a uranium concentration of 350 ppm is dispersed in the Omahola Project area[3],
- the maximum specific activity of the dispersed dust is 63 $Bq.g^{-1}$ (only taking the U^{238} and U^{235} decay chains into account),
- the dose conversion factor for dust from the uranium ore is 3.5×10^{-6} $Sv.Bq^{-1}$, as per IAEA specifications (only taking the U^{238} and U^{235} decay chains into account) [IAEA, 2004, Annex, p. 79 for uranium ore dust],
- members of the hypothetical critical group are adults, who have a breathing rate of 0.93 $m^3.h^{-1}$, which is an age-dependent average breathing rate as recommended by the ICRP [ICRP, 1995], and
- members of the hypothetical critical group spend 365 days per year (i.e. 8,760 h) at the perimeter of the mining license area, at the spot marked by the red triangle in Figure 13.

Incorporating the above assumptions leads to a simplification of Equation 6 to:

[3] It is realised that not all the dust dispersed in the Project area will contain radionuclides at elevated concentrations.

Equation 7: $\mathbf{Dose_{Dust}} = 1.80 \times Load_{Dust}$

where $Dose_{Dust}$ inhalation dose due to radioactive dust, in $Sv.a^{-1}$

$Load_{Dust}$ density of inhalable airborne dust load, in $g.m^{-3}$

An air dispersion model quantifies the impact and dispersion of dust in and around the Omahola Project area, the details of which are discussed in a separate report [Khumalo *et al.*, 2010]. Amongst others, the model is used to compute the concentration of inhalable dust, i.e. the PM10 ground level concentration expressed in $\mu g.m^{-3}$ due to all dust sources within the Omahola Project. Figure 13 shows the annual average PM10 concentrations, assuming that dust emissions are unmitigated.

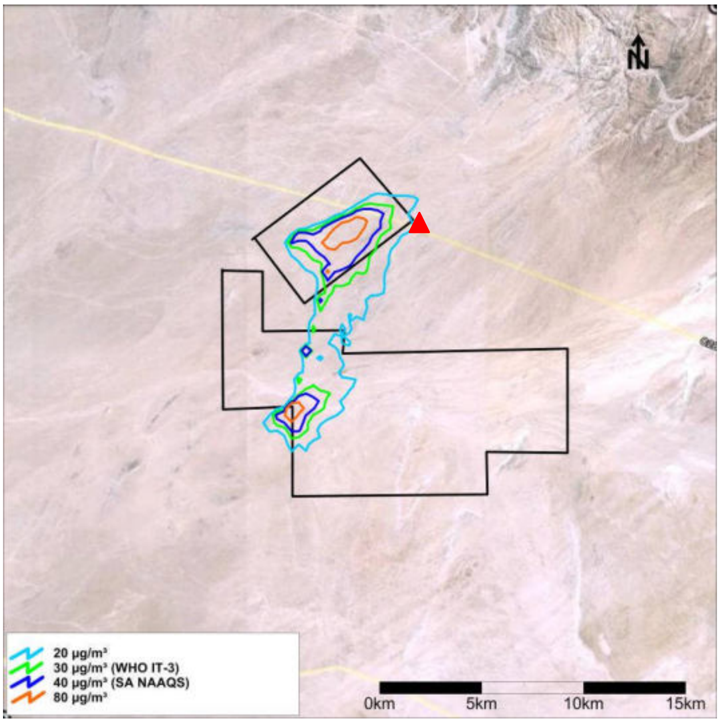

Figure 13: Annual average predicted PM10 ground level concentrations (in $\mu g.m^{-3}$) for all sources due to unmitigated dust emissions from the Omahola Project [Khumalo *et al.*, 2010]; the red triangle indicates the location of the hypothetical critical group of members of the public

An average PM 10 concentration of 20 $\mu g.m^{-3}$ is predicted at the north-eastern intersection between the C28 public access road, and the proposed INCA mining area, refer to the red triangle location shown in Figure 13. Assuming that members of the hypothetical critical group live permanently at this intersection point, and using Equation 7 with $Load_{Dust} = 20\ \mu g.m^{-3}$, one finds that members of this hypothetical critical group would receive an exposure dose of some 36 $\mu Sv.a^{-1}$ as a result of inhaling radioactive dust originating in the Omahola Project area.

It was assumed that all inhalable dust will contain the full radionuclide content at the maximum uranium concentration of ores found in the Omahola area, and that the respective members of the U^{238} and U^{235} decay chains are in full secular equilibrium. It is noted that these assumptions represent upper limits, as dust fractions will originate from various sources, some of which will have undergone considerable processing and the removal of uranium isotopes, such as will be the case for dust from the tailings facilities.

Members of the critical group of farmers living on smallholdings along the Swakop River, which are more than 10 km north of the Project area, would be exposed to inhalable dust concentrations originating at the Omahola Project. However, as can be seen in the dust dispersion prediction shown in Figure 13, dust concentrations rapidly decrease as the distance between the sources of dust and the potential receptor locality increases. This implies that dust concentrations at the Swakop River smallholdings are expected to be several orders of magnitude smaller than the dust concentrations used to compute the exposure of members of the hypothetical critical group postulated to live at the north-eastern perimeter of INCA. This implies that the inferred exposure dose to members of the smallholder farmer exposure group due to the inhalation of radioactive dust from the Omahola Project is also several orders of magnitude smaller than that of the hypothetical critical group.

To ensure that the actual total suspended dust concentrations and the inhalable dust fractions emanating from the proposed Omahola Project are used in future radiological risk and exposure assessments, it is recommended that such concentrations are continuously monitored at and around the perimeter of the proposed mining license area. In addition, radionuclide analysis is to be used to determine the actual radionuclide content of the inhalable dust fraction. Such monitoring is best undertaken as part of the future environmental monitoring activities. It would ensure that the public exposure monitoring program which is to be undertaken in partial compliance with Namibian regulatory requirements is based on empirical dust concentrations, rather than those predicted by an air dispersion model which is subject to many underlying assumptions. In addition, site-specific air quality monitoring is to be initiated at the commencement of operations, in order to identify and better quantify the main impact zones, and to plan and monitor ongoing air quality management activities and dust suppression and mitigating measures.

3.4.8 Environmental / Public exposure dose estimates

It is emphasised that ***the hypothetical critical group assumed to live at the perimeter of the proposed mining area does not actually exist***. This hypothetical group was merely postulated to estimate the exposure due to the inhalation of radioactive dust emanating from the Omahola Project area, close-by the actual sources of dust. This hypothetical group is therefore an exaggerated representative group for other members of the public.

The dispersion model for radon and inhalable dust fractions predicts concentrations under prevailing meteorological conditions. Based on the predicted concentration of radon and inhalable dust, sections 3.4.6 and 3.4.7 presented the potential exposure doses of members of a hypothetical critical group that is assumed to live at the intersection of the public access road C28 and the north-eastern perimeter of the proposed INCA mining license area. Such a critical group was deliberately chosen to quantify the worst-case exposure scenario taking the atmospheric pathway into account. It was found that members of this hypothetical critical group would be exposed to some 26 $\mu Sv.a^{-1}$ and 36 $\mu Sv.a^{-1}$, due to radon/radon progeny and dust respectively.

The total exposure due to the atmospheric pathway is therefore of the order of 0.062 $mSv.a^{-1}$, which is well-below the public dose limit of 1 $mSv.a^{-1}$, as well as the dose constraint as envisaged in the Namibian draft regulations [NRPA, 2010]. It is re-emphasised however that the hypothetical critical group used to compute the exposure dose is not representative of any real member of the public, and that the closest critical members of the public, i.e. farmers on smallholdings, are more than 10 km north of the proposed Project area. This physical distance from the proposed mining site, and future mitigation measures applied to limit on-site dust generation will reduce the potential exposure to radiation from the atmospheric pathway (by dust) as experienced by members of the critical group.

3.4.9 Environmental monitoring

Environmental monitoring at the Omahola Project is to include the two main exposure pathways discussed in section 3.4.3, i.e. the atmospheric and the aquatic pathway. As described in section 3.5.3, which summarises the stipulations of the Namibian regulations on public exposure monitoring, some elements of the environmental and public exposure monitoring can and should be combined at the Omahola Project.

As for the radiation-related environmental monitoring program to be instituted at the Omahola Project, one differentiates between those activities designed to monitor the aquatic pathway, and those that are to monitor the atmospheric pathway.

Specifically, and in order to monitor the aquatic pathway, groundwater samples in and around the proposed mining license area are to be taken at regular intervals, and monitored for changes in radionuclide composition and content. Here, the groundwater analyses as reported in section 2.4 will serve as a baseline from which deviations will be determined in future.

As for the atmospheric pathway, the environmental monitoring program is to focus on quantifying the airborne concentrations of dust, radon and radon progeny. Here, an air quality monitoring program will be designed to monitor the total suspended particulate concentration in the air, and quantify the concentration of inhalable dust fractions. This is to be achieved using a combination of passive (dust buckets) and active (pumped volumes) monitoring techniques for airborne dust. In contrast, the airborne concentration of radon and radon progeny will be monitored using active radon samplers, positioned at various locations around the main mining location.

In addition, and in order to strengthen the forecast qualities of future atmospheric modelling applications (e.g. of airborne dust and radon dispersion), ongoing meteorological data acquisition in and around the mining license area is essential. To this end, the Omahola Project will establish meteorological monitoring stations at suitable locations in and around the proposed mining license area, so as to establish a reliable meteorological data set for the Project area.

The empirical results obtained in the environmental monitoring program to be undertaken at the Omahola Project will provide the input data to enhance the statistical significance of dust and radon source terms, and with it underpin further air dispersion and radon impact modelling. These will be used to quantify the changing impact of construction and mining operations at the Omahola Project. In addition, the proposed radionuclide analyses of borehole water samples will give evidence of radionuclide seepage and contamination from tailings or other radionuclide sources into the groundwater, and serve to strengthen the engineering control measures applied at the Omahola Project.

3.5 Radiation Management

3.5.1 Introduction

Under the Namibian Atomic Energy and Radiation Protection Act, Act No. 5 of 2005, the National Radiation Protection Authority (NRPA) is the country's radiation protection regulator. Recently, the NRPA has issued draft regulations to be applicable for entities dealing with radioactive substances [NRPA, 2010], and has also made available guidelines on how organisations that potentially expose their employees and/or members of the public should develop a Radiation Management Plan (RMP) [NRPA, 2009].

This section summarises the main components that the RMP for the Omahola Project will have to include, based on the requirements stipulated in the draft regulations [NRPA, 2010]. It is to be noted however that the present summary is not intended to comprehensively address all aspects that will have to be covered in the Omahola Project RMP.

The Omahola Project RMP is to comprise of the following main elements:

a. **Background**, which is to include
- a description of the technical nature of the operation
- physical plan of the site
- expected sources of radiation
- types of radioactive materials that will be used
- overview and assessment of radiation hazards, and
- description of the principal exposure pathways.

b. **Pre-Operational Safety Assessment**, which is to include
- a summary of the main outcomes of all assessments carried out prior to operations
- description of applicable risk, remediation/rehabilitation assessments and risk management plans, and
- a summary of the radiation-related Environmental Management Plan.

c. **Organisational Arrangements**, which is to include
- a description of the main responsibilities within the organisation, and
- specification of the functions and responsibilities of the designated Radiation Safety Officer(s).

d. **Occupational Radiation Protection Program**, which is to include
- a description of the program and activities undertaken to protect workers in the occupational setting.

e. **Medical Exposure Control**, which (if applicable) is to include
- a description of all relevant medical measures taken to minimise individual doses.

f. **Public Exposure Monitoring Program**, which is to include
   - a description of the programs and methods to monitor the potential public exposure pathways, and
   - minimise any accidental exposure caused by operations.

g. **Waste Management Program**, which is to include
   - a description of how radioactive waste materials, both in form of sealed and unsealed radioactive sources, contaminated materials and effluents arising from operations will be managed.

h. **Emergency Preparedness and Response Plan**, which is to include
   - a description of the emergency management plan to be enacted after accidental exposure to radiation.

i. **Transport Plan**, which is to include
   - a description of how radioactive materials will be transported, including the labelling, packing and controlling of transport processes involving radioactive materials.

j. **Safety and Security of Radiation Sources**, which is to include
   - a description of the controls and measures to ensure the safety of sources of radiation.

The sections below summarise the key requirements of the following sections of the to-be-developed RMP:

- occupational radiation protection program (refer to section 3.5.2)
- public exposure monitoring program (refer to section 3.5.3)
- safety and security of sources (refer to section 3.5.4)
- transport requirements (refer to section 3.5.5)
- emergency intervention (refer to section 3.5.6), and
- waste management program (refer to section 3.5.7).

The sections below are guided by the stipulations of the Namibian draft regulations as have been made available in October 2010 [NRPA, 2010]. It is noted that these draft regulations, and therefore the elements described below, are only to be considered as a guide and cannot as yet be seen as being prescriptive in nature. Once the regulations have been promulgated, which is expected in late 2010 or early 2011, the sections below will have to be reviewed and updated where required.

3.5.2 Elements of the occupational radiation protection program

In regard to the occupational radiation protection program to be implemented at the Omahola Project, chapter 6 of the draft regulations include the following main elements based on the regulations which are summarised below [NRPA, 2010]:

Regulation 21: General responsibilities

This regulation stipulates that an entity that employs workers who are engaged in activities that involve or could involve occupational exposure are responsible for the protection of their workers against any such occupational exposure. The regulation then further defines the conditions for such occupational exposure control, including the required policies, procedures and organisational measures to be applied.

Regulation 22: Conditions of service

This regulation stipulates that the conditions of service of workers must be independent of the existence or the possibility of occupational exposure, and that the employer may not offer or grant any special compensatory arrangements or preferential treatment with respect to salary or otherwise as substitutes for the provision of radiation protection measures. The regulation then further stipulates that female workers must be advised to notify the employer of pregnancy, upon which the employer must adapt the working conditions to ensure that the embryo or foetus is afforded the same broad level of protection as required for general members of the public.

Regulation 23: Controlled areas

This regulation stipulates that an entity must designate work areas as a controlled area to control exposures or prevent the spread of contamination under normal working conditions. The regulation then further stipulates that an entity must also determine the boundaries of any controlled area on the basis of the magnitude and likelihood of expected exposures, and the nature and extent of the required protection measures, and delineate controlled areas by physical means and display warning symbols as per the recommendations of the International Organisation for Standardisation (ISO), and issue appropriate instructions at access points and other appropriate locations within such controlled areas.

Regulation 24: Supervised areas

This regulation stipulates that an entity must designate work areas as a supervised area where occupational exposure conditions need to be kept under review, even though specific protection measures and safety provisions are not normally needed. Such supervised areas must be suitably delineated and identified, taking the nature and extent of radiation hazards in those areas into account.

Regulation 25: Local rules and supervision

This regulation stipulates that an entity must, in consultation with workers, establish rules and procedures to ensure adequate levels of protection and safety, and ensure that any work involving occupational exposure is adequately supervised, and all reasonable steps are taken to ensure that the rules, procedures, protective measures and safety provisions are observed. The regulation then further states that employers must provide workers with adequate information on the health risks due to their occupational exposure, as well as provide instruction and training on protection and safety, and provide to female workers who are liable to enter controlled areas or supervised areas appropriate information on the risk to the embryo or foetus due to exposure. Records of the training provided to individual workers need to be kept.

Regulation 26: Personal protective equipment

This regulation stipulates that an entity must minimise the need for relying on administrative controls and personal protective equipment (PPE) for protection and safety during normal operations by providing suitable controls and working conditions, and ensure that workers are provided with suitable PPE. The regulation then further states that PPE is to be regularly tested and maintained, taking into account the medical fitness of workers to sustain physical effort while using such PPE, and additional work time, inconvenience or additional non-radiological risks associated with the use of such PPE.

Regulation 27: Exposure assessment

This regulation stipulates that an entity must arrange for the assessment of the occupational exposure of workers and must ensure that adequate arrangements are made with appropriate dosimetry services under an adequate quality assurance programme. The regulation then further states that any worker who is normally employed in a controlled area, be individually monitored, or, where not feasible, that occupational exposure of the workers is assessed on the basis of the results of workplace monitoring. For a worker who is normally employed in a supervised area or who enters a controlled area only occasionally, the occupational exposure must be assessed, where such an assessment may be on the basis of the results of monitoring of the workplace or of individual monitoring.

Regulation 28: Management of overexposure

This regulation stipulates that an entity who suspects or has been informed that a person is likely to have received an overexposure as a result of work carried out by that employer must determine whether there are circumstances that such overexposure could have occurred. The regulation then further states that in case such an overexposure has occurred, the entity must as soon as practicable possible notify the NRPA and the appointed medical practitioner of the affected person.

Regulation 29: Monitoring of workplace

This regulation stipulates that an entity must establish, maintain and keep under review a program to monitor the workplace, commensurate with the nature and risks associated with all relevant sources. The regulation then further states that the nature and frequency of monitoring of workplaces must be sufficient to enable the evaluation of the radiological conditions in all workplaces, and the assessment of the exposure of workers in controlled areas and supervised areas, while allowing for the review of the classification of controlled and supervised areas. The workplace monitoring program must specify the quantities, timing, methods and reference levels to be measured, and the entity must keep appropriate records of such workplace monitoring.

Regulation 30: Health surveillance

This regulation stipulates that an entity must make arrangements for appropriate health surveillance based on the general principles of occupational health, and designed to assess the initial and continuing fitness of workers for their intended tasks. The regulation then further states that an employer must ensure that a health record in respect of each employee is made and maintained, and that that record or a copy thereof is kept until the person to whom the record relates has or would have attained the age of 75 years, but in any event for at least 50 years from the date of the last entry made in it.

Regulation 31: Approval of dosimetry services

This regulation stipulates that the NRPA may approve a suitable dosimetry service, and may carry out a re-assessment of any approval granted.

Regulation 32: Records of worker exposure

This regulation stipulates that an entity must maintain records of exposure for each worker for whom an assessment of occupational exposures is required, and include information on the general nature of the work resulting in exposure, the doses and intakes at or above the relevant exposure levels, the data upon which the dose assessments are based, and the periods of employment with different employers and the corresponding doses and intakes in each period of such employment. The regulation then further states that an entity must provide for access by workers to information in their own exposure records, and upon request from the NRPA or other persons / organisations with a demonstrated need for such records, provide access to such worker exposure records. Exposure records for each worker must be retained by the entity (or the NRPA if the entity ceases activities) and such records must be preserved at least until the worker attains or would have attained the age of 75 years, and for not less than 30 years after the termination of the work involving occupational exposures.

3.5.3 Elements of the public exposure monitoring program

In regard to the public exposure monitoring program to be implemented at the Omahola Project, chapter 8 of the draft regulations include the following elements which are briefly summarised below [NRPA, 2010]:

Regulation 42: General responsibilities

This regulation stipulates that an entity must apply the requirements of the regulations to any public exposure delivered by a practice or source for which they are responsible, unless such exposure is excluded or exempted from the regulations. The regulation then further states that an entity is responsible for the establishment, implementation and maintenance of radiation safety policies, procedures and organisational arrangements for the control of public exposure and measures for ensuring the optimisation of the protection of members of the public whose exposure is attributable to such sources, and the limitation of the normal exposure of the relevant critical group in order that the total exposure is not higher than the relevant dose limit for members of the public. An entity is responsible to ensure that suitable and adequate facilities, equipment and services for the protection of the public are available, and that appropriate radiation safety training is undertaken, and retraining of the personnel responsible for the protection of the public is provided, and that monitoring equipment and surveillance programmes are in place to assess public exposure. Records of such surveillance and monitoring exercises are to be established.

Regulation 43: Control of visitors

This regulation stipulates that an entity must ensure that visitors to any controlled area are accompanied by a person knowledgeable about the radiation safety measures for that area. The regulation then further states that adequate information and instruction is provided to visitors before they enter a controlled area, and that adequate control over entry of visitors to a supervised area is maintained, and that appropriate signs are posted in such areas.

Regulation 44: Sources of external irradiation

This regulation stipulates that an entity must ensure that, if a source of radiation can cause exposure to the public, the floor plans and equipment arrangement for all new installations and all significant modifications to existing installations utilising such sources of radiation are reviewed and approved by the NRPA. The regulation then further states that specific dose constraints for the operation of such a source are established to the satisfaction of the NRPA, and that shielding and other protective measures are provided as appropriate for restricting public exposures.

Regulation 45: Radioactive contamination in enclosed spaces

This regulation stipulates that an entity must ensure that for sources for which they are responsible, measures that are optimised are taken to restrict public exposure in areas accessible to the public, and that specific containment provisions are established for the construction and operation of such sources in order to avoid or minimise spread of contamination in areas accessible to the public.

Regulation 46: Monitoring of public exposure

This regulation stipulates that an entity must establish and carry out a monitoring program which is sufficient to ensure that the requirements of the regulations are satisfied, and to assess the exposure of members of the public from sources of radiation and discharges of radioactive substances into the environment. The regulation then further states that appropriate records of the results of the monitoring program are to be kept by the entity, and that a summary of the monitoring results is to be provided to the NRPA at intervals as stipulated in the specific authorisation to the entity.

Regulation 47: Consumer products

This regulation stipulates that an entity must ensure that consumer products capable of causing exposure to radiation may not be supplied to members of the public unless such exposure is excluded from the regulations, or such products are authorised by the NRPA. An entity that imports such exempted consumer products for sale and distribution must include in the application to the NRPA a copy of the license or authorisation issued by the Authority in the country of manufacture or origin, which authorises distribution of the product concerned to members of the public in that country. The regulation then further states that an entity that imports consumer products for sale and distribution as exempt products must ensure that legible labels are visibly and firmly affixed to each consumer product and its package, stating that the product contains radioactive material, and the sale of the product to the public has been authorised by the NRPA. The entity is to also provide information and instructions on the precautions of use and disposal of the product.

3.5.4 Elements of safety and security of sources

In regard to the safety and security of sources program to be implemented at the Omahola Project, chapter 9 of the draft regulations include the following requirements [NRPA, 2010]:

Regulation 48: General responsibilities

This regulation stipulates that an entity must ensure the safety and security of the sources under their responsibility, from the moment of their acquisition throughout their entire operational life and up to their final disposal. The regulation then further states that for this purpose, licensees must ensure that a multilayer system of provisions for protection, safety and security of sources, commensurate with the magnitude and likelihood of the potential exposures involved, is applied to the sources under their responsibility, such that a failure at one layer is compensated for or corrected by subsequent layers, for the purposes of (a) preventing accidents that may cause exposure; (b) preventing unauthorised access or damage to, and loss of, theft of or unauthorised transfer of the source; (c) mitigate or minimise the consequences of any such accident or incident should it occur; and (d) restoring sources to safe and secure conditions after any such accidents or incidents. The regulation then also states that licensees must ensure that, as applicable and appropriate, the location, design, construction and assembly, commissioning, operation and maintenance, and decommissioning of sources are based on sound engineering practice which (a) takes into account approved codes and standards and technical and scientific developments; (b) is supported by reliable managerial and organisational features, with the aim of ensuring protection, safety and security throughout the life of the sources; (c) includes adequate safety margins in the design, construction and operation of sources, to ensure the reliable performance during normal operation, taking into account quality, redundancy and inspectability, with emphasis on preventing accidents, and mitigating their consequences and restricting any future exposures.

Regulation 49: Accountability and security of sources

This regulation stipulates that a licensee must conduct and keep verified a physical inventory of all sealed sources annually or as specified in the licence by the NRPA. The regulation then further states that the records must contain the following information: (a) the identity of each sealed source (serial number and model); (b) radionuclide and its activity on a specified date; (c) location of each sealed source; (d) receipt or transfer or disposal of the source; (e) the date of the inventory and signature of the Radiation Safety Officer. The regulation also states that licensees must make arrangements for the sources under their responsibility to be kept secure by ensuring that (a) control of a source is not relinquished without compliance with all relevant requirements specified in the license and without immediate communication to the NRPA of information regarding any decontrolled, lost, stolen or missing source; (b) a source may not be transferred unless the receiver possesses a valid authorisation; (c) records are maintained of source inventory, including records of receipt, transfer and disposal of sources; and (d) a periodic inventory of sources is conducted at intervals specified in the license to confirm that they are in their assigned locations and are secure; (e) all sources are marked with legible and durable labels, which include as a minimum serial numbers, model, activity and date of activity, warning signs, supplier and manufacturer name, name and contact details of the Radiation Safety Officer; (f) sources are appropriately secured to the site of operation so as to minimise the likelihood of unauthorised access or removal. Licensees must immediately notify the NRPA, in case of loss of control of sources, unauthorised access to, or unauthorised use of a source, malevolent acts threatening authorised activities, or failures of equipment containing sources which may have security implications, and the discovery of unaccounted sources.

Regulation 50: Design and safety of sources

This regulation stipulates that a licensee, in specific co-operation with suppliers whenever appropriate, must ensure, on procurement of new equipment containing radiation generators or sources, that such equipment and sources conform to applicable standards of the International Electrotechnical Commission (IEC) and the International Standards Organisation (ISO), or equivalent standards as may be approved by the NRPA. The regulation further states that except for IEC and ISO standards, other standards applied in the country of origin of such equipment and sources must have the specific approval of the NRPA to (a) ensure that sources and equipment are tested to demonstrate compliance with the appropriate specifications; (b) conduct a safety assessment, either generic or specific, for the sources for which they are responsible, in accordance with the requirements of regulation; (c) ensure that performance specifications and operating and maintenance instructions, including protection and safety instructions, are provided in English and in compliance with the relevant IEC and ISO standards with regard to accompanying documents; (d) ensure that, where practicable, the operating terminology and operating values are displayed on operating consoles or other control systems in English. The regulation also states that where a radioactive substance is used as a source of ionising radiation, the radiation employer must ensure that (a) whenever reasonably practicable, the substance is in the form of a sealed source; (b) the design, construction and maintenance of any article containing or embodying a radioactive substance, including its bonding, immediate container or other mechanical protection, is such as to prevent the leakage of any radioactive substance; (c) suitable tests are carried out bi-annually to detect leakage of radioactive substances from any sealed source, and retain the record of each such test for inspection.

Regulation 51: Storing and moving sealed sources

This regulation stipulates that every employer must ensure that any radioactive source under his/her control which is not for the time being in use or being moved, transported or disposed of is (a) kept in a suitable sources container; and (b) kept in a suitable storage site. The regulation then further states that every employer who causes or permits a source to be moved (otherwise than by transporting it) must ensure that, so far as is reasonably practicable, the substance is kept in a suitable source holder, and suitably labelled while it is being moved. The regulation also states that nothing of the above applies in relation to a radioactive substance while it is in or on the live body or corpse of a human being.

Regulation 52: Records

This regulation stipulates that a licensee must maintain and annually submit to the NRPA records of tests, safety assessments, inventory of sources, source certificates, as well as any other necessary information to allow retrospective assessments of the doses received by third parties.

3.5.5 Elements of the transport requirements

In regard to the transport requirements to be implemented at the Omahola Project, chapter 10 of the draft regulations includes the following [NRPA, 2010]:

Regulation 53: Transport requirements

This regulation states that no radioactive material may be offered for transportation by rail, ship, aircraft or road vehicle unless the radioactive material is packed, shielded, marked and labelled in accordance with the Regulations for the Safe Transport of Radioactive Material, as drawn up by the International Atomic Energy Agency, details of which are obtainable from the NRPA. The regulation then further states that any container of radioactive material imported from recognised foreign suppliers must be deemed to comply with provisions of the conditions relating to the packing, marking and labelling of radioactive material if it is packed, marked and labelled in accordance with the law in that connection in force in the country of origin.

3.5.6 Elements regarding emergency interventions

In regard to the emergency intervention measures to be implemented at the Omahola Project, chapter 11 of the draft regulations include the following elements which are briefly summarised below [NRPA, 2010]:

Regulation 54: Responsibilities of licensees

This regulation states that if an authorised practice or source within a practice has a potential for accidents which may provoke an unplanned exposure of any person, the licensee must ensure that an emergency plan appropriate for the source and its associated risks is prepared and is kept operational. The regulation then further states that if an authorised source is involved in an accident or incident, the licensee is responsible for taking such protective actions as may be required for the protection of occupationally exposed workers undertaking intervention, and for the protection of the public from exposure as set forth in the licence application and emergency plans approved by the NRPA, or as might otherwise be required by the NRPA to protect against, mitigate or remedy a hazardous situation involving the licensed sources.

Regulation 55: Licensee emergency response planning requirements

This regulation states that a licensee responsible for sources for which prompt intervention may be required must ensure that the emergency plan defines on-site responsibilities and takes account of off-site responsibilities of other intervening organisations appropriate for implementation of the emergency plan. The regulation then further states that such emergency plans must, as appropriate (a) characterise the content, features and extent of a potential emergency taking into account the results of any accident analysis and any lessons learned from operating experience and from accidents that have occurred with sources of a similar type; (b) identify the various operating and other conditions of the source which could lead to the need for intervention; (c) describe the methods and instruments for assessing the accident and its consequences on and off the site; (d) provide for protection and mitigation actions, and assignment of responsibilities for initiating and discharging such actions; (e) provide for rapid and continuous assessment of the accident as it proceeds and determining the need for protective actions; (f) allocate responsibilities for notifying the relevant authorities and for initiating intervention; (g) provide procedures, including communication arrangements, for contacting any relevant intervening organisation and for obtaining assistance from fire-fighting, medical, police and other relevant organisations; (h) provide training to personnel involved in implementing emergency plans and ensure that these are rehearsed at suitable intervals in conjunction with designated authorities; and (i) provide for periodic review and updating of the plan.

Regulation 56: Implementation of intervention

This regulation states that the licensee must ensure that the protective or remedial actions aimed at reducing or averting accidental exposures are only undertaken when they are justified, taking into account health, social and economic factors. The regulation then further states that the form, scale and duration of any justified intervention must be optimised so as to produce the maximum net benefit under the prevailing social and economic circumstances. The regulation then states that subject to Section 32 of the Act, licensees must promptly notify the NRPA when an accidental situation requiring intervention has arisen or is expected to arise, and must keep them informed of (a) the current situation and its expected evolution; (b) the measures taken to terminate the accident and to protect workers and members of the public; and (c) the exposures that have been incurred and that are expected to be incurred.

Regulation 57: Protection of workers undertaking intervention

This regulation states that no worker undertaking an intervention may be exposed in excess of the maximum single year dose limit for occupational exposure specified in the regulations, except for (a) the purpose of saving life or preventing serious injury; or (b) if undertaking actions to prevent the development of catastrophic conditions. The regulation then further states that when undertaking interventions under the circumstances in sub-regulation (1), all reasonable efforts must be made to keep doses to workers below twice the maximum single year dose limit, except for life saving actions, in which case every effort must be made to keep doses below ten times the maximum single year dose limit in order to avoid deterministic effects on health. The regulation also states that workers undertaking actions in which their doses may approach or exceed ten times the maximum single year dose limit must do so only when the benefits to others clearly outweigh their own risk. Workers who undertake actions in which the dose may exceed the maximum single year dose limit must be volunteers and must be clearly and comprehensively informed in advance of the associated health risk, and must, to the extent feasible, be trained in the actions that may be required. Once the emergency phase of an intervention has ended, workers undertaking recovery operations, such as repairs to equipment and buildings, waste disposal or decontamination must be subject to the full system of detailed requirements for occupational exposure specified in the regulations. All reasonable steps must be taken to provide appropriate protection during the emergency intervention and to assess and record the doses received by workers involved in the emergency intervention. When the intervention has ended, the doses received and the consequent health risk must be communicated to the workers involved. Workers may not normally be precluded from incurring further occupational exposure because of doses received in an emergency exposure situation. Qualified medical advice must be obtained before any such further exposure of a worker, if that worker has during emergency exposure receives a dose exceeding ten times the maximum single year dose limit, or if a worker who was subject to emergency exposure, at that worker's request.

Regulation 58: Responsibilities of the Authority

This regulation states that pursuant to Section 24 (1) of the Act, the NRPA may initiate any action and take any measures necessary to the public interest to prevent, eliminate and ameliorate the adverse effects on and to restore the environment. The regulation further states that the NRPA must ensure that (a) emergency plans are prepared and approved for any practice or source which could reasonably give rise to a need for emergency intervention; (b) emergency plans are periodically reviewed and updated; (c) provision is made for training personnel involved in implementing emergency plans and the plans rehearsed at suitable intervals in conjunction with designated authorities; and (d) prior information is provided to members of the public who could reasonably be expected to be affected by an accident.

Regulation 59: Clean-up and removal operations

This regulation states that the NRPA in consultation with the Board must determine (a) the procedures for clean-up and removal operations in the event of an emergency exposure; (b) the method of storage and disposal of any radioactive substance or of any object, plant, animal, or any part of the environment removed in a clean-up or removal operation or otherwise affected by an exposure.

3.5.7 Elements of the waste management program

In regard to the management of radioactive waste materials at the Omahola Project, chapter 12 of the draft regulations include the following elements which are briefly summarised below [NRPA, 2010]:

Regulation 62: Application

This regulation describes the sources, substances, materials and objects within authorised practices which are above the exemption levels specified in Schedule 1 of the regulations, and defines the users of sources of ionising radiation which include the fields of medicine, industry, teaching, research, agriculture, hydrology, geology and other fields of human activity.

Regulation 63: Radioactive waste classification

This regulation categorises radioactive waste according to its physical form and composition as (i) solid waste; (ii) liquid aqueous waste; (iii) liquid organic waste; (iv) gaseous waste; (v) sealed radiation sources; (vi) biological waste (e.g. animal carcasses which might undergo decomposition if not properly treated and stored); (vii) medical waste (e.g. syringes, bed linen and contaminated clothing from a hospital environment). The regulation then further categorises waste according to the activity concentration and half lives of radionuclides contained therein as

(i) category I, which is low level radioactive waste (e.g. the activity is less than 10 MBq), containing short-lived radionuclides only (e.g. with half-life less than 50 days) that will decay to clearance levels within one year after the time of its generation;
(ii) category II, which is low and intermediate level radioactive waste, containing the radionuclides with half-life less than 30 years and restricted long-lived radionuclide concentrations and that is not expected to decay to clearance levels within one year from the time of its generation (limitation of longer lived alpha emitting radionuclides to 4,000 Bq/g in individual waste packages and to an overall average of 400 Bq/g per waste package);
(iii) category III, which is low and intermediate level radioactive waste, containing the radionuclides with half-life greater than 30 years and concentration of alpha emitters

exceeding the limitations for category II, for which the regulation stipulates that such waste needs to be disposed of in deep geologic facilities only;

(iv) category IV, which is termed high level radioactive waste, with thermal power above 2kW/m^3 and concentration of alpha emitters exceeding the limitations for category II (e.g. spent fuel from research reactors), for which the regulation stipulates that such waste needs to be disposed of in deep geologic facilities only.

Regulation 64: General responsibilities

This regulation defines the primary responsibility for the safe management of radioactive waste as resting with the waste generator, who is to take all necessary actions to ensure the safety of radioactive waste unless the responsibility has been transferred to another person or organisation as approved by the NRPA. The regulation then further stipulates that the waste generator is responsible for on-site segregation, collection, characterisation, and temporary storage of the radioactive waste arising from activities and discharge of exempt waste. The regulation states that no person or organisation may dispose of any radioactive waste unless the disposal facility designed and constructed specifically for this purpose is available, and an authorisation has been obtained for such disposal.

Regulation 65: Licence application

This regulation states that proposals from applicants to generate radioactive waste are to specify the nature and purpose of the proposed facility and equipment that generates radioactive waste, suggested operational procedures, taking into account reduction of radioactive waste generation to the extent practicable, quantity, type and characteristics of the radioactive waste to be generated, proposed destination for the radioactive waste, assessments of the safety and environmental impact of the facility under normal and accident conditions, decommissioning procedures, availability of competent staff and provisions for its further training, systems for records keeping and reporting, proposed quality assurance programme, contingency plans in the event of an emergency, proposals for discharge and environmental monitoring as needed, supporting research and development proposals as needed, and other details as may be specified by the NRPA. The regulation also states that an applicant will pay the fees as prescribed by the NRPA to cover the cost of the authorisation procedures, and that the holder of an authorisation is to comply with all limits and conditions specified in the authorisation including the amounts and characteristics of waste which may be generated, treated, conditioned and stored, and any specific radiation protection and physical security measures.

Regulation 66: Radiation Safety Officer (RSO)

This regulation states that each waste generator must appoint a technically competent person with the appropriate independence and authority to implement the provisions of the regulations, who may be the same person as appointed for other purposes. The regulation further states that the RSO must establish, maintain and keep an up to date inventory of radioactive materials and generated waste, make and maintain contact with all on-site persons using radioactive materials, and provide an authoritative point of advice and guidance, liaise as needed with the NRPA, establish and maintain a record-keeping system in such a manner as to facilitate identification, characterisation, collection and storage of radioactive materials that become waste, ensure that on-site transfer of radioactive materials and waste is carried out in accordance with written safety procedures, ensure appropriate shielding, labelling, physical security and integrity of waste packages, ensure that any discharge of effluents is made within clearance levels or limits specified as a condition for granting an authorisation for the disposal in question, ensure that the activity or activity concentration of waste to be disposed of in a municipal landfill are below clearance levels, report on accidents and inappropriate waste management practices to the management and the NRPA, maintain up to date knowledge of the characteristics of the site sewerage system, local municipal landfills, available incinerators for non-radioactive waste and other facilities relevant to the organisation of waste management practices, and return sources to supplier.

An entity that applies to import a sealed source containing radioactive material which ten years after purchase will have an activity greater than 100 MBq must require the supplier, as a condition of any contract for purchase or as acceptance of any gift, to receive the source back after its useful lifetime within one year of the recipient requesting such return, request to return the source to the supplier not later than 15 years after purchase, submit to the NRPA a copy of relevant parts of the contract or acceptance document and obtain its written agreement prior to entering the contract in force or accepting the source, and return the source to the supplier within 15 years, or if later, ensure that the source is conditioned, stored and disposed of at the cost of the waste generator.

Regulation 67: Segregation, collection and characterisation

This regulation states that the waste generator must keep control on waste generation to the minimum level practicable, and must segregate, collect and characterise waste as far as practical at the point of origin, in accordance with the categories specified in regulation 63, in order to facilitate subsequent treatment, conditioning, storage and disposal. The regulation then further states that after separation, each waste category must be kept separately in a suitable container. Sufficient numbers of containers must be made available by the waste generator where radioactive wastes are generated. The waste containers must be easy to handle, be strong enough to withstand normal handling, and not be affected by the waste content. Waste requiring treatment and conditioning must be further segregated by the waste generator as stipulated in the licence or registration depending of the availability of treatment and conditioning facilities.

Regulation 68: Container labelling

This regulation states that a licensee must ensure that each container containing radioactive waste bears a durable, clearly visible label bearing the radiation symbol. The label must be legible for the whole period of storage and must provide the following information: (a) nature of the waste generated; (b) date of waste generation; (c) commencement date of storage; (d) major radiologically significant radionuclides; (e) external surface dose rate; waste category; (f) biological, chemical or other hazardous materials if exist; (g) name of a person responsible for the waste generation; (h) identification number; and (i) any particular information that may be required by the NRPA in the authorisation for the disposal in question. The regulation further states that a licensee must, prior to removal of empty containers to unrestricted areas, which after measuring have proved to be uncontaminated, remove or deface the label or otherwise clearly indicate that the container no longer contains radioactive waste. A licensee must prior to its disposal remove the label from containers holding waste with the activity concentrations or activity levels below the exemption levels specified in Schedule 1 of the regulations.

Regulation 69: Discharge of radioactive substances to the environment

This regulation states that a licensee must ensure that radioactive waste is not discharged or released to the environment unless (a) the waste activity or concentration is confirmed to be below exemption levels specified in Schedule 1; or (b) such discharge is within the limits specified in the licence and is carried out in a controlled fashion using authorised methods. The regulation further states that before initiating the discharge to the environment of any solid, liquid or gaseous radioactive waste considered to be within discharge limits, a licensee must, as appropriate (a) determine the characteristics and activity of the material to be discharged, and the potential points and methods of discharge; (b) determine by an appropriate pre-operational model study, all significant exposure pathways by which discharged radionuclides can deliver public exposure; (c) assess the doses to the critical groups due to the planned discharges; (d) submit this information to the Authority as an input to the establishment of authorised discharge limits and conditions for their implementation. Also, a licensee, during the operational stages of radioactive waste management, must (a) keep all radioactive discharges below discharge limits imposed as a condition for the discharge in question; (b) monitor the discharges of radionuclides with sufficient detail and accuracy to demonstrate compliance with the authorised discharge limits and to permit estimation of the exposure of critical groups; (c) record the monitoring results; (d) report the monitoring results to the NRPA annually; and (e) report promptly to the NRPA any discharges exceeding the authorised discharge limits.

Regulation 70: Discharge of cleared waste

This regulation states that waste of Category I (refer to regulation 63) that is expected to decay below clearance levels within one year from its generation, must be stored safely on site, and after confirmation by measurements or other means that the exemption levels specified in Schedule 1 have been reached, must be appropriately discharged or released by the waste generator. The regulation then further states that a licensee may discharge the cleared liquid effluents into sanitary sewerage only if the material is readily soluble or is readily dispersible in water. A licensee may release the cleared solid waste into a municipal waste incinerator or landfill. The regulation notes that nothing in the regulations is construed as relieving any person from any duty imposed by any law dealing with the disposal of hazardous waste contaminated with toxic compounds or infectious agents.

Regulation 71: Release of specific waste

This regulation states that a licensee may release the following material as if it were not radioactive: (a) 1.85 kBq, or less of Hydrogen-3 or Carbon-14 per gram of medium used for liquid scintillation counting; and (b) 1.85Bq, or less of Hydrogen-3 or Carbon-14 per gram of animal tissue, averaged over the weight of the entire animal. The regulation further states that a licensee may not dispose of tissue under sub-regulation (1) in a manner that would permit its use either as food for humans or as animal feed.

Regulation 72: Waste Storage

This regulation states that a licensee must provide for interim storage of radioactive waste prior to its clearance, discharge or disposal. The regulation then further states that the interim storage facility must be properly designed and constructed with at least one physical barrier between the radioactive waste and other material in the store. The store must be large enough to hold all generated and anticipated waste in an orderly manner and keep different categories separated. The store design must provide for (a) adequate shielding of the radioactive waste; (b) prevention of deterioration of the waste packages; (c) handling and retrievability of the waste packages; (d) adequate ventilation if volatile radioactive substances may be present in the waste; (e) conventional safety; and (f) physical protection. The regulation states that the radioactive waste store must so far as is practicable not contain or be located close to any corrosive, explosive or flammable material, and be clearly and legibly marked with the radiation symbol and details of the Radiation Safety Officer of the waste generator.

Regulation 73: Transport of Radioactive Waste

This regulation states that a licensee must ensure that radioactive waste is prepared for transport, when so required, and is regarded as a radioactive source for transport in accordance with these regulations.

Regulation 74: Treatment

This regulation states that a waste generator must treat the radioactive waste in order to reduce its volume and to facilitate further conditioning. The regulation then further states that the treatment method must be suitably selected for the radioactive waste, depending on such factors as the volume and type of the radioactive waste, the discharge requirements for liquid effluents and additional conditioning requirements.

Regulation 75: Conditioning

This regulation states that the radioactive waste for long-term storage, transportation and disposal must be properly conditioned. The regulation then further states that waste packages produced by a conditioning process must be fully characterised with regard to important physical, chemical, radiological, mechanical and biological properties. Radium sources must be conditioned for storage by encapsulating the source in a welded stainless tube, placing the tube in a lead shielding container following emplacement of the container inside a 200 liter mild steel drum filled with concrete. Provisions for the retrieval of the encapsulated radium sources from drums and transportation to a disposal facility must made.

Regulation 76: Quality assurance

This regulation states that a licensee must ensure that all radioactive waste management operations are carried out in accordance with a suitable quality assurance programme commensurate with the scope of activities and approved by the NRPA. The regulation further states that the quality assurance programme must be designed to ensure that the facilities and equipment are designed, constructed and operated in accordance with specified requirements for safe operation, all regulations and conditions in a licence or registration are complied with. Each licensee must develop and maintain an accurate and complete documentation system to cover all stages of radioactive waste management, from its generation to disposal. The quality assurance programme must provide for controlled approval, receipt, retention, distribution and disposition of all records important for safety. Records, such as letters, drawings, specifications, etc. must include all pertinent information, such as stamps, initials, and signatures. Each record must be legible throughout the specified retention period. The licensee must retain the records until the NRPA terminates each pertinent licence or registration requiring the record. The licensee must maintain adequate safeguards against tampering with and loss of records. The effectiveness of the quality assurance programme must be verified by independent audits to ensure that a radioactive waste management programme meets specific requirements, is covered by procedures, and that implementation is adequate.

Regulation 77: Physical protection

This regulation states that waste generators must ensure adequate physical protection measures to prevent any unauthorised access to the radioactive waste management facilities.

Regulation 78: Reporting to Authority

This regulation states that a licensee must prepare and maintain an inventory of existing and anticipated radioactive waste containing radionuclides with half lives above 50 days and an activity greater than 10 MBq, and submit it to the NRPA annually and whenever significant changes in radioactive waste amounts or characteristics occur. The regulation then further states that the inventory must be based on the classification system specified in regulation 67, including information on important physical, chemical and radiological characteristics in addition to the quantity of the radioactive waste. Each licensee must report to the NRPA immediately after its occurrence becomes known any lost, stolen or missing radioactive waste under such circumstances that it appears to the licensee that an exposure could result to persons in unrestricted areas. Within 30 days after such occurrence, the licensee must then issue a written report with a description of the radioactive materials involved, its probable disposition, the circumstances under which the loss or theft occurred, and actions that have been taken. Each licensee or registrant must immediately report to the NRPA any event involving radioactive waste possessed by the licensee that may have caused or threatens to cause the release of radioactive material, inside or outside of a restricted area. The licensee must submit to the NRPA annually a report that specifies details of quantities and types of (a) the cleared waste disposed of at a municipal landfill, discharged into a public sewerage system or to the atmosphere; (b) the effluents discharged into the environment within authorised release limits; (c) the conditioned radioactive waste in storage; (d) the spent radiation sources sent to suppliers.

Regulation 79: Emergency preparedness

This regulation states that a licensee must establish and implement an emergency response and preparedness plan in compliance with requirements specified in Chapter 12 (i.e. the chapter describing the waste management program).

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