Rio Tinto

Rössing Uranium Limited
Working for Namibia

Radiation Management Plan

The Rössing Uranium Mine

Uranium was discovered in the Namib Desert in 1928, but it was not until intensive exploration in the late 1950s that much interest was shown in the area. After discovering numerous uranium occurrences, Rio Tinto secured the rights to the low-grade Rössing deposits in 1966. Ten years later, Rössing Uranium, Namibia's first commercial uranium mine, began operating.

Today, Namibia has two significant uranium mines, which together provide for roughly 6 per cent of the world's uranium oxide mining output; Rössing Uranium produces about 3 per cent of the world's output. The mine has a nameplate capacity of 4,500 tonnes of uranium per year and, by the end of 2014, had supplied a total of 127,405 tonnes of uranium oxide to the world.

The mine is located 12 km from the town of Arandis, which lies 70 km inland from the coastal town of Swakopmund in Namibia's Erongo Region. Walvis Bay, Namibia's only deep-water harbour, is located 30 km south of Swakopmund.

The mining operation is in a semi-arid environment. Insolation at Rössing is high, and as a result, daytime ranges of temperatures are wide, especially during May and September, when the difference between minimum and maximum temperatures exceeds 20°C daily. The lowest temperatures are normally recorded during August, but frost is rare. The highest temperatures are recorded in the late summer, particularly March.

The mine site encompasses a mining licence and accessory works areas of about 180 km^2, of which 25 km^2 is used for mining, waste disposal and processing.

Mining is done by blasting, loading and hauling from the main open pit, referred to as the *SJ Pit*, before the uranium-bearing rock is processed to produce uranium oxide. The open pit currently measures 3 km by 1.5 km, and is 390 m deep.

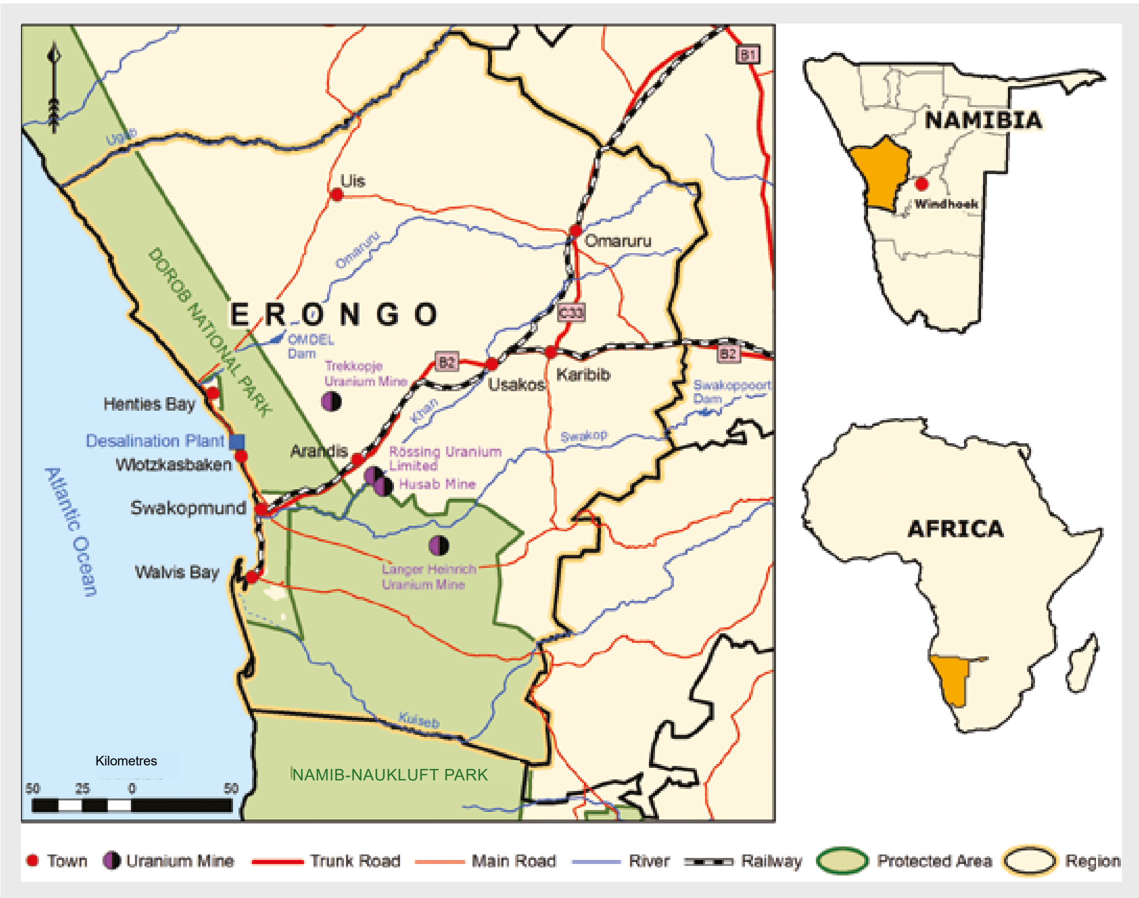

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Table of contents

Acronyms and abbreviations

Throughout this document, the following acronyms and abbreviations are used:

µg/L	micro-grams per litre, 10^{-6} g/L
µm	micro-metre, 10^{-6} m
µSv/a	micro-sieverts per annum, 10^{-6} Sv/a
a	annum (year)
AEC	Atomic Energy Corporation of South Africa
ALARA	As low as reasonably achievable
AMAD	Activity mean aerodynamic diameter
amsl	Above mean sea level
Bq	becquerel, counts per second
Bq/cm^2	Bq per square centimetre
Bq/L	Bq per litre
Bq/m^3	Bq per cubic metre
BRRP	Business Resilience and Recovery Programme (HSE MS Element 12)
CCD	Counter current decantation
CIX	Continuous ion exchange
CMP	Closure management plan
CNS	Council for Nuclear Safety
CPC	central processing control
DM&R	Disaster Management and Recovery (outdated name for HSE MS Element 12)
DPM	diesel particulate matter
EIA	Environmental impact assessment
EPD, PED	Electronic personal dosimeter
FPR	Final Product Recovery
g/L	grams per litre
g/t	grams per tonne
GBq	Giga-becquerel, 10^9 Bq
ha	hectare, 10,000 square metres
h	hour
HEF	High energy fuel (used for blasting)
HSE MS	Health, Safety and Environment Management System
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
J	Joule, energy unit
kg/t	kilogrammes per tonne, for example 0.1 kg/t = 100 ppm
LLRD	Long-lived radioactive dust
LOME	Life-of-mine extension

M	Mega, one million
m^3	cubic metre
MBq	Mega-becquerel, 10^6 Bq
MeV	Mega-electron volt, $1.6 \cdot 10^{-13}$ J
mg/m^3	milligrammes (10^{-3} g) per cubic metre
µS/cm	micro-siemens per centimetre, 10^{-6} S/cm, unit for conductivity
micron	micrometre, 10^{-6} metre
min	minute
MME	Ministry of Mines and Energy
MoHSS	Ministry of Health and Social Services
MSDS	Material safety data sheet
mSv	milli-sieverts, 10^{-3} Sv
mSv/a	milli-sieverts per annum
MyRIAM	SARAD MyRIAM radioactivity in air monitor
NORM	Naturally occurring radioactive materials
NRPA	National Radiation Protection Authority
NTSC	Northern tailings seepage control
ns	nano-seconds, 10^{-9} s
OK liquor	The chemical solution containing uranium trioxide
PM10, PM_{10}	Particulate matter smaller than 10 microns in diameter
PM2.5, $PM_{2.5}$	Particulate matter smaller than 2.5 microns in diameter
PPE	Personal protective equipment
ppm	parts per million
RMP	Radiation management plan
RSO	Radiation Safety Officer (designated)
RUL	Rössing Uranium Limited
s	second
SABS	South African Bureau of Standards
SCO	Surface contaminated object
SEG	Similar exposure group
Sv	sievert, joules of energy per kilogram of absorbing tissue
SX	Solvent Extraction
t	tonne, 10^3 kg
TDDS	Tailings dam de-watering system
TDX	Tailings dam extraction
TI	Transport index
TLD	Thermo luminescent dosimeter
TSF	Tailings Storage facility
UOC	Uranium oxide concentrate
VOC	volatile organic compound
XRF	X-ray fluorescence

Definitions

Action level	–	The level of dose rate or activity concentration above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations.
Activity	–	The strength of a radioactive source is called its activity, which is defined as the rate at which the isotope decays. Activity is measured in Bq, where 1 Bq is equivalent to 1 decay per second, or 1 disintegration per second.
Activity concentration, specific activity	–	(Radio)activity per unit mass of the stated radionuclide, measured in Bq/g.
Critical group	–	That group of people likely to be most affected by a certain impact.
Radioactively contaminated	–	Any material or area is radioactively contaminated if that material or area contains unwanted radioactive substances (whether inside or on the surface) above the levels given in section 4.4.7.1.
Controlled area	–	A controlled area is any area in which specific protection measures and safety provisions are or could be required for: - controlling normal exposures or preventing the spread of contamination during normal working conditions, and - preventing or limiting the extent of potential exposures.
Decontamination	–	The removal or reduction of contamination by a physical or chemical process.
Designated radiation worker	–	Any person who is potentially exposed to ionising radiation at a level exceeding 5 mSv/a as a result of his/her occupation, and who is assigned as such by the RSO.
Dose	–	Measures the quantity of radiation absorbed. The **absorbed** dose is a measure of the energy deposited in a medium by ionising radiation per unit mass, measured as joules per kg, called the gray (Gy). The **equivalent** dose is the absorbed dose weighted by radiation weighting factor to account for radiation type and is also measured in joules per kilogram, which is called the sievert (Sv). The **effective** dose is the equivalent dose weighted by the affected body part, also measured in Sv. If all body parts are uniformly irradiated, the effective and equivalent whole body doses are the same. In this RMP, the dose always refers to the **effective whole body dose**, and expresses the biological risk of radiation exposure independent of exposure pathway.
Exposure	–	The amount of ionisation in air produced by radiation is called the exposure, measured in coulombs per kg of material. The exposure of people refers to the amount of uptake of radiation, measured in Bq.
Exposure pathway	–	Path followed by a certain radioactive pollutant from source to receptor.
Holder of the Authority	–	The Holder of the Authority at Rössing Uranium is the legal person of the Company, ie the Managing Director.
Investigation level	–	The value of a quantity (such as effective dose, intake, or contamination per unit area or volume) at or above which an investigation should be conducted.
Ionising radiation	–	For the purposes of radiation protection, radiation capable of producing ion pairs in biological material(s).
Member of the public	–	For the purpose of this RMP, a member of the public is any person not subject to occupational exposure at Rössing Uranium.

NORM	–	Naturally occurring radioactive material. NORM refers to radioactive materials found in the environment, including ores containing radioactive elements such as uranium and thorium, and their radioactive decay products. All ores, product, and radioactive waste materials arising from Rössing Uranium's current activities are NORM.
Occupational exposure	–	All exposures of workers incurred in the course of their work, with the exception of exposures excluded from the standards, and exposures from practices or sources exempted by the standards.
Occupationally exposed	–	Anyone working in an environment that potentially exposes them to a dose from ionising beyond background and medical doses. All on-site Rössing Uranium workers are occupationally exposed persons.
Personal dosimeters	–	Means an accumulative dosimeter, from which the radiation dose equivalent is determined after a specified wearing period.
Public exposure	–	Exposure incurred by members of the public from radiation sources, excluding any occupational or medical exposure and the normal local natural background radiation but including exposure from authorised sources and practices and from intervention situations.
Radiation Safety Officer	–	Statutory appointment under Section 30(1) of the Atomic Energy Act [2], which states that "every license holder must appoint a person who is technically competent in radiation protection matters as a radiation safety officer".
Radioactive material	–	Any substance that consists of or contains any radioactive nuclide, whether natural or artificial, and whose specific activity exceeds an activity as specified in Schedule 1 in the *Radiation Protection and Waste Disposal Regulations* [37].
Radioactive nuclide	–	An unstable atomic nucleus that may spontaneously decay, with the accompanying emission of ionising radiation.
Radon	–	The isotope Rn-222 of the element of atomic number 86.
Radon progeny (radon daughters)	–	The short-lived radioactive decay products of radon, Po-218, Pb-214, Bi-214, and Po-214.
Receptor	–	Any person exposed to a source of ionising radiation.
Source register	–	A register kept in terms of Section 18 of the Atomic Energy Act [2].
Sealed source	–	A source of ionising radiation that is firmly bonded within material or sealed in a capsule of sufficient mechanical strength as to exclude the possibility of contact with the radioactive material and of the dispersion thereof into the environment under foreseeable conditions of use and wear.
Unrestricted release	–	The release of items to an uncontrolled area that is in compliance with the Standards for unrestricted release.

1 Rössing Uranium Limited's operations

1.1 Vision

The vision of Rio Tinto Rössing Uranium Limited with respect to health, safety and environment is to ensure that no one comes to harm, either by working for the mine or through secondary impacts to the environment or to members of the public.

The objective of this Radiation Management Plan (RMP) is to ensure that exposures to ionising radiation will not give rise to unacceptable levels of risk, and that the sources of such exposures are identified, quantified, controlled, and minimised.

1.2 Introduction

Rössing Uranium Limited (Rössing Uranium) is a major player in the Namibian mining industry. Its large open pit mining operation is situated 65 km inland from the coastal town of Swakopmund in the Namib Desert and has been in operation since 1976. Rio Tinto owns 69 per cent of the mine from which the primary product is uranium oxide, extracted from granitic rock known as *Alaskite*. Rössing is a significant and growing long term supplier of uranium oxide to the world's nuclear power industry, ie nuclear power utilities in Europe, North America and South-east Asia. Current Namibian output makes up about six per cent of the world production of primary produced uranium, of which Rössing Uranium contributes up to 4,000 tonnes of U_3O_8 per year[1]. The mine currently employs roughly 980 permanent employees[2]. In addition, about 500 contractors work on site.

Figure 1: Satellite image of Rössing mine site

[1] 2014 figures according to World Nuclear Association, www.world-nuclear.org. Namibia produced 3,255 tonnes of uranium in 2014, and world production was 56,252 tonnes. Rössing Uranium's production in 2014 was 1,543 tonnes of uranium oxide or 1,308 tonnes of uranium.
[2] Status: January 2016.

The operations of the Rössing Uranium mine are situated in a disturbed area of about 2,300 ha (Figure 1).

The mining sequence is a conventional drill, blast and load operation on a large scale. The open pit has been developed in a series of benches or levels interconnected by a system of haul roads. Waste rock consisting of barren country rock and sub-economic uranium ore varies in material size from large boulders to fine sand and gravel-sized particles. This material has a high buffering capacity with a low concentration of pyrites and is therefore non-acid forming. Waste rock is disposed of at several designated sites in tributaries of the Khan River.

The run of mine material is fed through primary and secondary crushers to the metallurgical Processing plant. The metallurgical process is a conventional acid leach with ion exchange solution concentration and solvent extraction purification, followed by the precipitation of ammonium diuranate (yellowcake) and subsequent roasting to uranium oxide. The facilities involved in metallurgical processing consist of: a fine crushing circuit, a Leaching plant, ten thickeners, a Continuous Ion Exchange (CIX) plant, a Solvent Extraction plant (SX), and a Final Product Recovery plant (FPR). The final product is loaded into steel drums, containerised, and dispatched to Walvis Bay harbour for export.

All tailings from the uranium extraction process are conveyed and pumped to a large tailings impoundment, referred to as the Tailing Storage facility (TSF), situated to the north west of the mine site and separated from it by a northeast trending ridge. Due to the low uranium content of the ore, the tailings material consists of virtually the entire mass of input ore plus waste process liquids. The tailings material is coarse, by industry standards. The TSF is anchored on its eastern end against a ridge of hills.

Surface seepage from the TSF occurs through the filter drain in the embankment and the foundation materials. An extensive seepage control programme and monitoring system has been established to contain subsurface seepage in Pinnacle Gorge and Panner Gorge. Windblown tailings have been accumulated to the south west of the facility over the years.

The mine infrastructure includes: buildings, gardens, tarred and un-tarred roadways, railway lines, pipelines, tanks, conveyors, power lines, a sewage plant, and waste management and borrow pit areas. Although the mine has a closed water recycling system, make-up water — necessary to counter evaporative losses, as well as provide drinking water — is required. Water is supplied to the mine along a 65 km pipeline from Swakopmund (roughly 8,500 m^3/day). The water is supplied by NamWater and piped from the Areva Desalination plant. Power is supplied from a NamPower station at Omaruru. This line supplies power to the towns of Arandis and Swakopmund, as well as to the mine. To a limited extent, water is also abstracted from the Khan River (at roughly 1,000 m^3/day). Water is recycled at the mine site at roughly 12,000 m^3/day, thereby significantly reducing the freshwater supply needed[3].

The mining and processing of ores containing uranium and thorium can give rise to exposure to ionising radiation in various forms, to both employees and to members of the general public living in the vicinity of the mine. In order to control the exposure to ionising radiation, all aspects of radiation protection and monitoring need to be addressed.

1.3 Background

1.3.1 Mining, milling and metallurgical processes

1.3.1.1 The open pit

The Rössing Uranium mining operation is one of the largest open pit uranium mines in the world. The geology that characterises the mining area consists of a close association between barren metasediments and uranium-bearing alaskite. The geophysical nature of the mineralisation and resulting grade of uranium is extremely variable and can be present as large masses or narrow intercalated bands within the barren metasediments.

The open pit is mined by means of a conventional truck/shovel operation, with mining being conducted in 15 m benches. At present, the area under excavation measures approximately 3,200 m by 1,500 m. The depth from the pit rim, 555 m above mean sea level (amsl), to the currently lowest operating bench (165 amsl) is approximately 390 m, about 150 m below the level of the Khan River alluvial aquifer situated 3 km to the south. Pit ramps are 40 m wide and established at a maximum ten per cent gradient.

The pit is roughly rectangular in shape with the longest axis orientated approximately east-west, cross-cutting a north-easterly trending ridge that is bounded to the south west by Pinnacle Gorge and to the north-west by Dome Gorge. Both gorges discharge into the Khan River to the south, which in turn merges with the Swakop River 27 km to the south-west of the mine site.

[3] Status: January 2016.

The area disturbed by the open pit and its margins is approximately 400 ha in extent. Mining activities in the lower part of the pit were abandoned towards the end of 2010 and refocused on the higher-lying benches of the next set of pushbacks, located in the south, west, and north-west of the existing excavation. As the new pit walls cut their way through severely folded geological domains, constant monitoring and assessment of pit limits and haul roads is taking place, in order to ensure that potential highwall failures won't put the operations at risk.

1.3.1.2 The waste rock dumps

The waste and low grade ore stockpile areas are mostly located around the western, southern and eastern margins of the pit, in the valleys of dry river gorges that run parallel to, or drain towards, the Khan River (see grey areas surrounding the pit in Figure 1).

Waste rock dumps 2, 5 and 6 overlie Pinnacle Gorge, while waste rock dump sites 4 and 7 fill various tributaries of the Dome Gorge system. Dumps extend up to 2 km away from the pit (Figure 2). These rock dumps and stockpiles consist of waste rock (W), low-grade (LG), and high-grade high-carbonate-content (high calc., HG) materials, which are in general competent and weathering resistant and that vary in material size from large boulders to finer sand and gravel-sized particles.

The following cut-off grades are used to classify the waste or stockpile material:

- Waste rock < 0.118 kg/t U_3O_8
- Low grade > 0.118 < 0.169 kg/t U_3O_8 at low calc. index values, and
- High calc. > 0.194 kg/t U_3O_8 at high calc. index values.

In addition to this, other materials historically placed in the waste rock dumps include Final Product Recovery material, contaminated waste, scrap metal, grease, contaminated SX cells after fire, vanadium pentoxide drums, tyres, and bags of jarosite.

The positioning of the dumps has altered the surface drainage patterns in the gorges, such that water directed either through or beneath the dumps has the potential to increase the levels of heavy metals, salts and radionuclides contributed to the groundwater.

Primary and secondary aquifers play an important role in potentially transmitting groundwater to the Khan River. The primary aquifers are the gorges that drain into the Khan River bed, which is filled with 10 to 20 m of alluvial sand. The water level within the river bed is generally 2 to 3 m beneath the ground surface. The secondary aquifers consist of rock of various geological

Figure 2: Location of rock dumps relative to the open pit. W (waste rock), LG (low-grade stockpiles) and HG (high-grade, high calc stockpile).

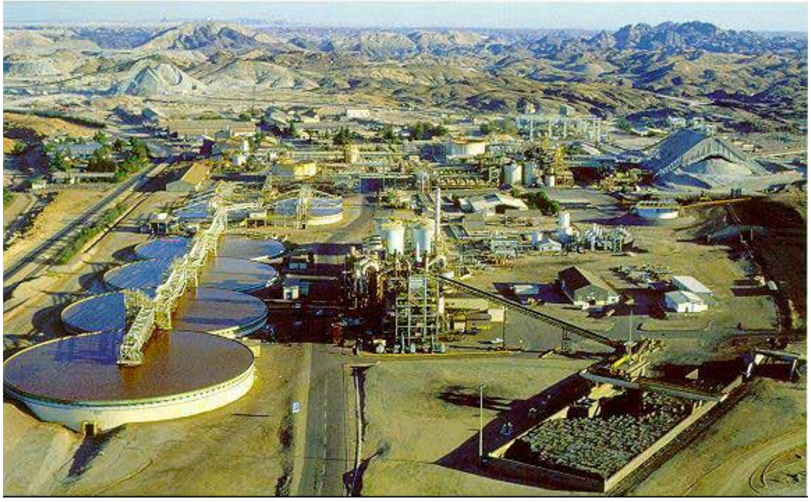


Figure 3: Panoramic view of mine site area

formations, weathered on structural features such as fractures and joints. Down-gradient water flow through these secondary features is slow, with velocities and volumes of flow being much smaller than in the sand fill of the gorges (but showing a wide range of variability depending on rock type).

In contrast to more gneissic rock types, two marble formations in the area show the highest hydraulic conductivities. These are referred to as the Rössing and Karibib marbles and their orientation is perpendicular in trend to the primary aquifers; groundwater from them is discharged into these aquifers.

1.3.1.3 Mine site area and facilities

The mine site area (Figure 3) encompasses the Processing plant, from the Primary Crusher to Final Product Recovery, summarised in flow diagram form in Figure 4. This includes the Primary Crusher, the Coarse Ore Stockpile and conveyer system, the Secondary Crushing plant, the Fine Crushing plant, the uranium Extraction section – Rodmills, Leaching section, sands washing and Counter-Current Decantation (CCD) thickeners; tails handling systems; Continuous Ion Exchange plant; Solvent Extraction; and Final Product Recovery, as well as the Engineering Workshops and Offices. It also includes the pyrite stockpile area, the acid unloading facilities, acid pipeline, and acid storage tanks.

The stages of processing and extraction are described in more detail in the sections that follow.

1.3.1.4 Mining

Ore is extracted from the hard rock by blasting. The high energy fuel explosive used, HEF 260, is made up on site with 60 per cent High Energy Fuel (ANCN Solution, old oil, diesel, Megas Emulsifier – E21 and sulphamic acid) and 40 per cent ammonium nitrate prills. Blasting takes place on average twice a week, using approximately 150 tonnes of explosives per blast. Up to 30,000 tonnes of explosives are consumed per year.

1.3.1.5 Crushing

Ore from the open pit is delivered in 140- and 180-tonne haul trucks to the Primary Crushers, where two gyratory crushers reduce the ore to particles less than 160 mm in

Figure 4: Simplified flow of metallurgical process

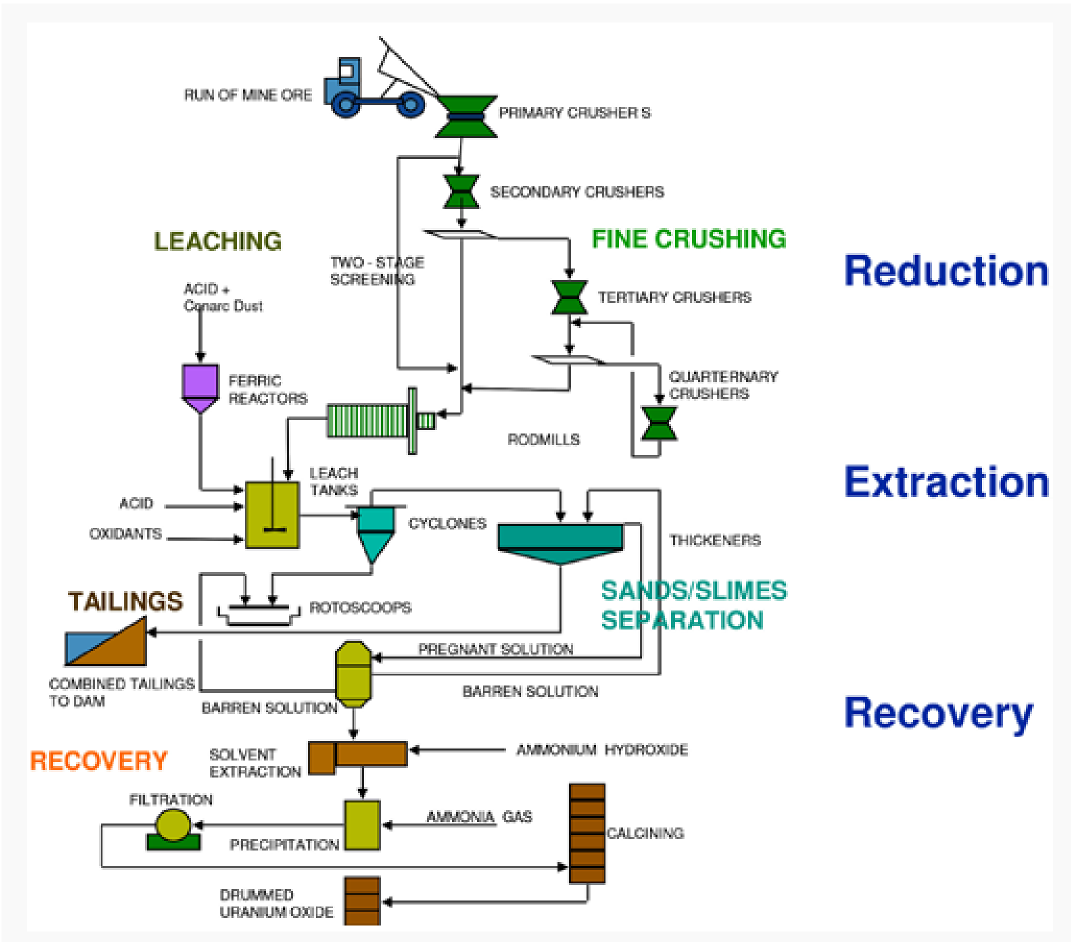


Figure 5: Coarse ore stockpile and coarse ore reclaim conveyor

size. A conveyor belt transports the crushed ore to the Coarse Ore Stockpile (Figure 5) with a live capacity of some 80,000 tonnes. Coarse ore is withdrawn from the stockpile by vibrating pan feeders below the stockpile, feeding directly onto a coarse ore reclaim conveyor. This conveyor discharges the ore to a pre-screening plant where all fines are removed and the coarse material returned to the surge bin ahead of the Secondary Crushers. The ore is further processed through secondary, tertiary and quaternary stages of crushing and screening, delivering a final product of less than 19 mm in size to the fine ore stockpile.

The crushing circuit is equipped with an appropriate system for dust extraction and collection into covered lugger bins. There are, in total, ten collection systems that provide extraction points from the reclaim tunnel to the fine ore storage bin.

1.3.1.6 Milling and leaching

The final stage of size reduction employs four Marcy Rodmills operating in parallel and comprises two modules that can be operated independently. Each module consists of two Rodmills that feed into six leach tanks respectively. Grinding in the Rodmills is a wet process, with feed water that can comprise fresh water, return dam solution from the Tailings Storage facility, or seepage water from the Seepage Dam (or a combination of these). The final particle size leaving the Rodmills is 1.1 mm in diameter on average.

The resulting slurry is pumped from the Rodmills to the leaching section where it is mixed with sulphuric acid, ferric iron and manganese dioxide in a series of six leach tanks. The first tank in the series (290 m^3 capacity) is considerably smaller than the other five (1,450 m^3 capacity each), thus ensuring adequate mixing of reagents and leach feed.

The steel leaching tanks are rubber lined and mechanically agitated. Retention time in the leaching section is eight to nine hours at a temperature of 35°C, with uranium extraction of 85 to 90 per cent. Gases and fumes generated during the leaching process are captured on top of the leach tanks by means of scrubbing units.

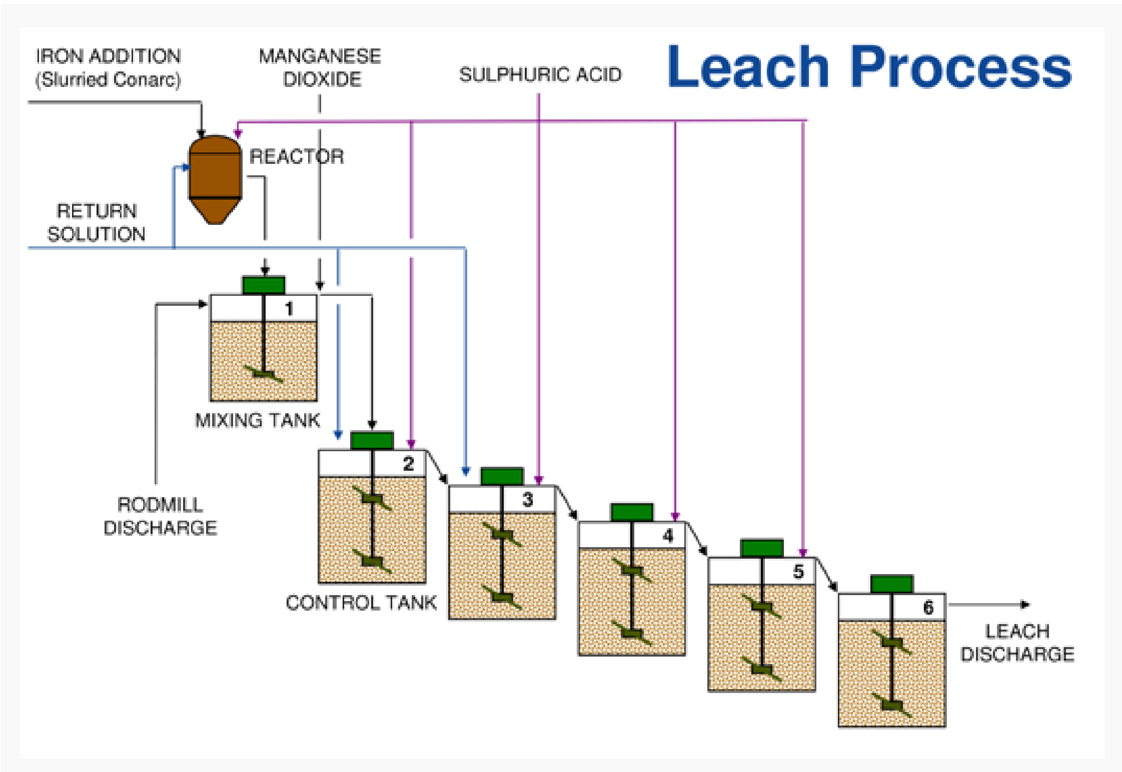
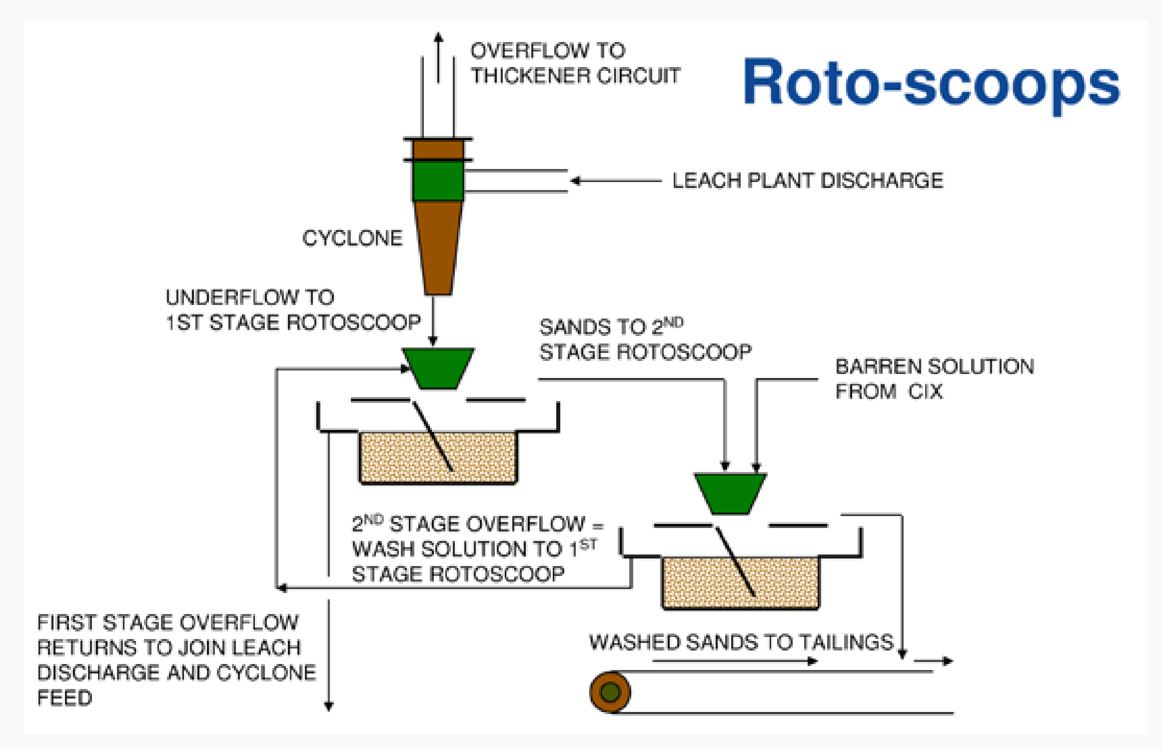


Figure 6: Leaching process

Figure 7: Washing circuits



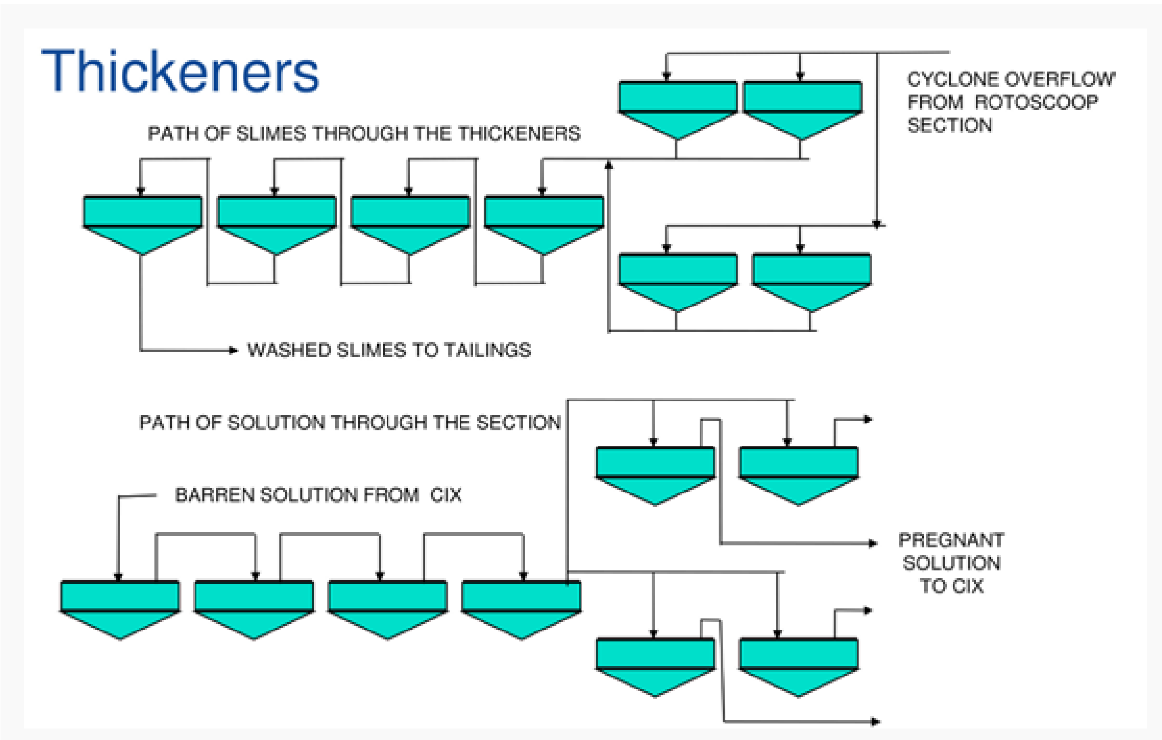
The reagents used for leaching are:

- Ferric iron, to oxidise the uranium from a tetravalent to a soluble hexavalent state. Ferric iron is obtained by reacting iron oxide with 93 per cent sulphuric acid in special Rössing Uranium-designed reactor vessels. Iron oxide (haematite) is brought in by truck in 1m³ mega bags.
- Sulphuric acid, (93 per cent) for extraction. Sulphuric acid is railed to the mine site from Tsumeb Custom Smelters, and stored in large acid tanks prior to being delivered to the leach tanks.
- Manganese dioxide, to oxidise ferric iron. Manganese dioxide ore is delivered to the Port of Walvis Bay by ship and then railed to the mine site and stored in a storage bunker. It is transported by front-end loader to a crushing, grinding and thickening plant adjacent to the leach modules, where a finely ground slurry is produced and delivered to the leach tanks as part of the extraction process.

1.3.1.7 Sand/slime split – sands washing

Pulp leaving the final leach tanks flows into a ten-way motorised pulp distributor and thence to ten hydro

Figure 8: CCD Thickeners



cyclones. A sand/slime split occurs here with the slime fraction (cyclone overflow) directed to a counter current decantation (CCD) thickener circuit. The coarse sand fraction (cyclone underflow) reports to one of ten primary rotoscoops (Figure 7). There are 20 rotoscoops in each module arranged as ten discrete pairs, a primary and secondary unit in each, providing a two-stage sands washing circuit. Barren solution from the Continuous Ion Exchange (CIX) plant is used as the wash medium on all second stage units.

Washed sands are removed from the second stage rotoscoops by a conventional conveyor belt.

1.3.1.8 Slimes washing – CCD thickeners

Slimes (cyclone overflow) washing is carried out using a five-stage CCD thickener circuit (Figure 8). The first stage consists of four identical thickeners with the slimes fraction distributed equally to two of them. The third and fourth thickeners are used as clarifiers. First stage thickener underflows are re-combined and progressively pumped through four further stages of thickening and re-pulping, thus five washing stages are achieved. CIX barren solution is introduced into the fifth washing stage. This runs counter current to the slime flow, and provides the wash medium taking up the uranium. First stage thickener overflow, called *pregnant solution*, contains uranium (uranyl sulphate) at a concentration of 0.180 g/L.

1.3.1.9 Tailings disposal

The slimes from the fifth thickening stage are pumped to the Tailings Storage facility and to the mixing and tailings pumping station there at Paddy X. The coarse material from the second stage rotoscoops is sent to the station via the sands conveyor. The slimes and sands are re-combined prior to disposal.

1.3.1.10 Tailings Storage facility

The Tailings Storage facility is the largest feature on the Rössing mine site; it covers a footprint of about 730 ha and is raised to an elevation of about 100 m above the ground surface level. The roughly 300 million tonnes of coarse and fine tailings material contain radioactive minerals and have a total specific activity of roughly 50 Bq/g. Radon emanations between 0.11 and 2.21 $Bq/m^2/s$ with a mean of 1.6 $Bq/m^2/s$ are characteristic [20]. Due to the hydraulic deposition of tailings slurry, 40 million m^3 of tailings liquid are contained in the facility. This water is expected to seep as surface and groundwater over a period of more than 30 years and therefore needs to be controlled well beyond the closure date of the mine. The site is susceptible to water and wind erosion and material could be dispersed into the environment over long periods of time. The TSF was used to dispose of contaminated materials in a number of places that are now covered by layers of tailings material. Strong winds have dispersed tailings into the environment in a westerly direction up to a distance of 8 km away from the facility.

1.3.1.11 Continuous Ion Exchange (CIX) plant

First stage CCD thickener overflow (pregnant solution) is pumped to a pregnant solution storage tank situated near the CIX plant (Figure 9).

Tank discharge is by four pumps, each delivering to one line of the CIX contactors. The Rössing CIX plant is built on the Porter System, which uses the upward flow of pregnant solution to fluidise a bed of ionic resin beads in a series of six contactor chambers per line. The flow of pregnant solution is counter current to the resin movement. There are four lines of CIX contactors with six chambers in each line. Resin transfer from one contactor to the next is carried out by air lifter units, of which there are six per contactor. Loaded resin from Contactor 1 in each line is transferred to the elution columns.

Three elution columns are provided per line of contactors; these take the form of fibreglass-lined mild steel pressure vessels. Sulphuric acid (at ten per cent concentration) is passed through the resin bed, stripping the uranium from the resin beads during its passage. Stripped resin is then returned to the contactor line and the uranium rich concentrated eluate is pumped to solvent extraction. The eluate has a uranium concentration of 4 to 5 g/L.

1.3.1.12 Solvent extraction (SX) plant

Concentrated eluate containing 4 to 5 g/L uranium is pumped to the Solvent Extraction (SX) plant as the aqueous phase of the extraction process (Figure 10).

The organic phase uses Shellsol, containing alamine 336 and isodecanol. Extraction, ie transfer of uranium from the aqueous to the organic phase, is carried out in five stages of counter current contact using Davy Powergas mixer settler units. The loaded solvent is then passed through a two-unit clean water scrubbing stage prior to a four unit stripping stage, where the loaded solvent (organic) is mixed with a seven per cent ammonium sulphate (aqueous) solution under pH control with aqueous ammonium hydroxide. Uranium is stripped into an aqueous phase and is pumped to the Final Product Recovery plant as OK liquor (concentrated uranium diuranate solution) containing 8 to 20 g/L uranium. The stripped solvent returns to the extract mixer settlers to repeat the process as described above.

Strict fire protection procedures are in force at the SX plant. These include:

- Restricting access to the area;
- Annual induction for all personnel who enter the SX plant area for any reason;
- Prohibition of matches, cigarette lighters, or any other combustible material within the designated area;
- Regulation of hand tool types, such that the possibility of creating a spark is minimised; and
- A comprehensive fire protection system attached to and serving all mechanical equipment and storage tanks. This system comprises fixed water sprays on the outside of all mixer settler units and storage tanks.

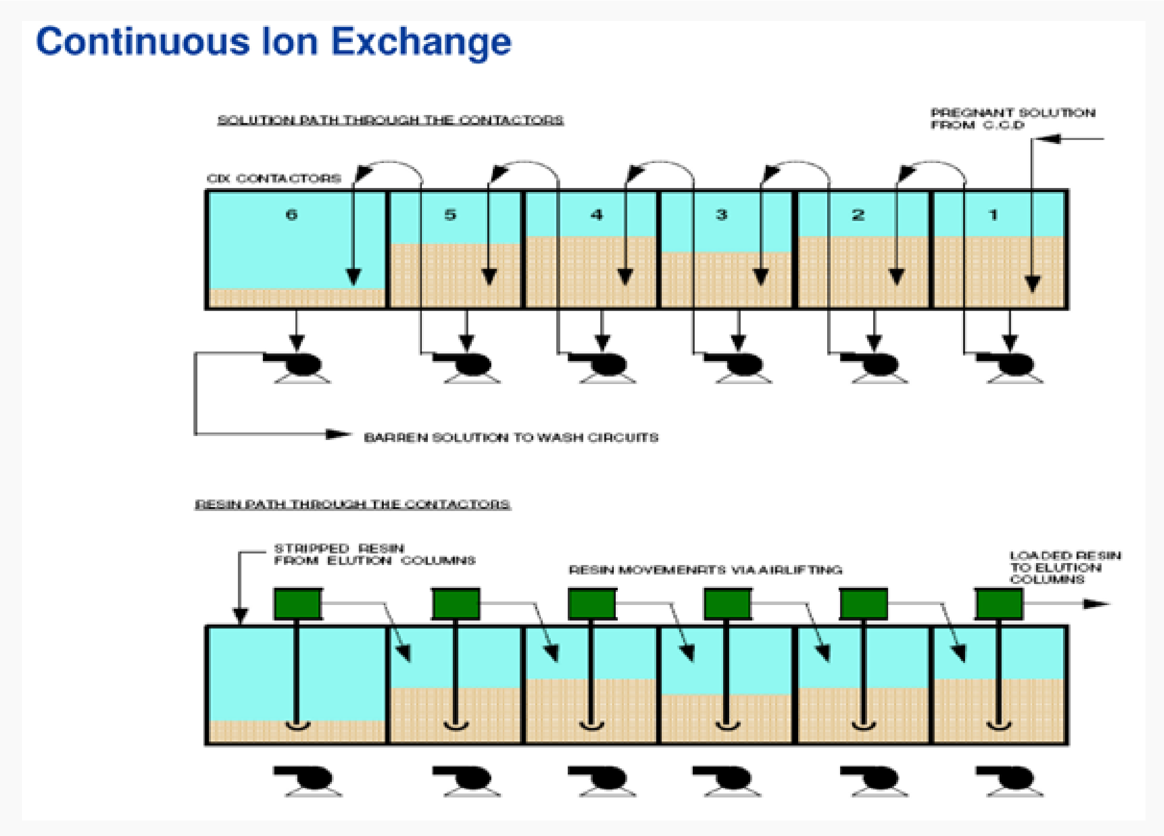


Figure 9: Continuous ion exchange

Mixer settler units are also equipped with an internal foam injection system. The system is activated manually on receiving a signal from sensing devices located inside and outside the various items of equipment. Automatic initiation of the systems will activate the water sprays only.

1.3.1.13 Final Product Recovery

OK liquor from the SX plant is pumped to the Final Product Recovery area. The first stage of final recovery is the precipitation of yellowcake from the OK liquor. This is carried out in an agitated precipitation tank. Gaseous ammonia is added to raise and maintain a pH of 7.3. Precipitation tank discharge gravitates to a yellowcake thickener. Thickener overflow (ammonium sulphate) is returned to the SX strip mixer settlers while underflow material is pumped to a two-stage washing section. Washing is carried out by two drum filters in series equipped with overhead water sprays. Filter cake from each stage of washing is re-pulped with process water and re-pulped second stage filter cake is fed into one of the two multi-hearth calcining furnaces. Each furnace has six hearths and is heated to 700°C on the final hearth. The ammonium diuranate (yellowcake) feed is calcined to uranium oxide and is discharged via a hammer mill to an automatic drum filling plant. Final product at ± 98.5 per cent U_3O_8 is dispatched in sealed drums, each drum automatically washed and dried and weighing ± 450 kg.

Gases and calcine particulates generated and emitted from the process are prevented from entering the atmosphere by means of an extraction and dust collection system and two wet venturi-type scrubbers.

A summary of the processes at Final Product Recovery is shown in Figure 11.

Figure 10: Solvent Extraction

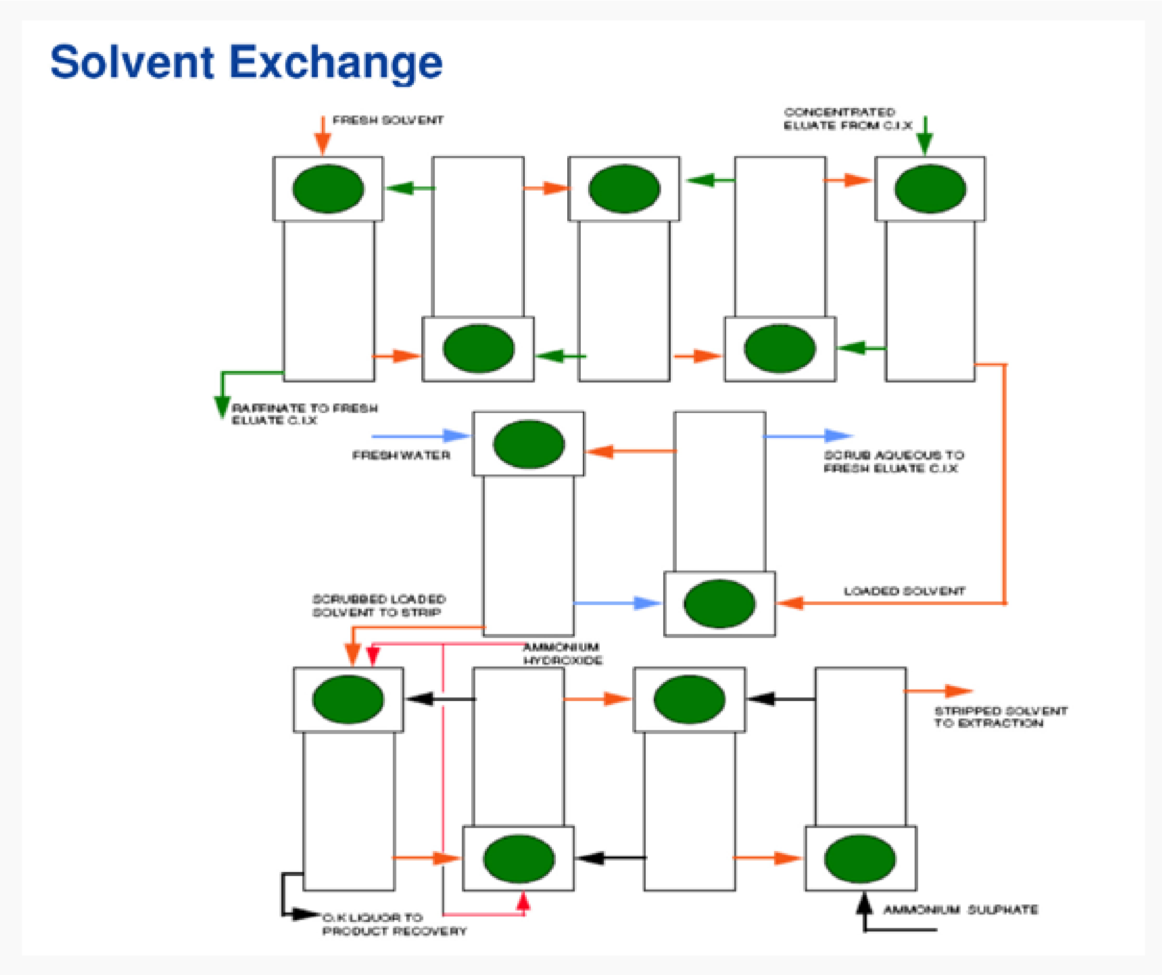
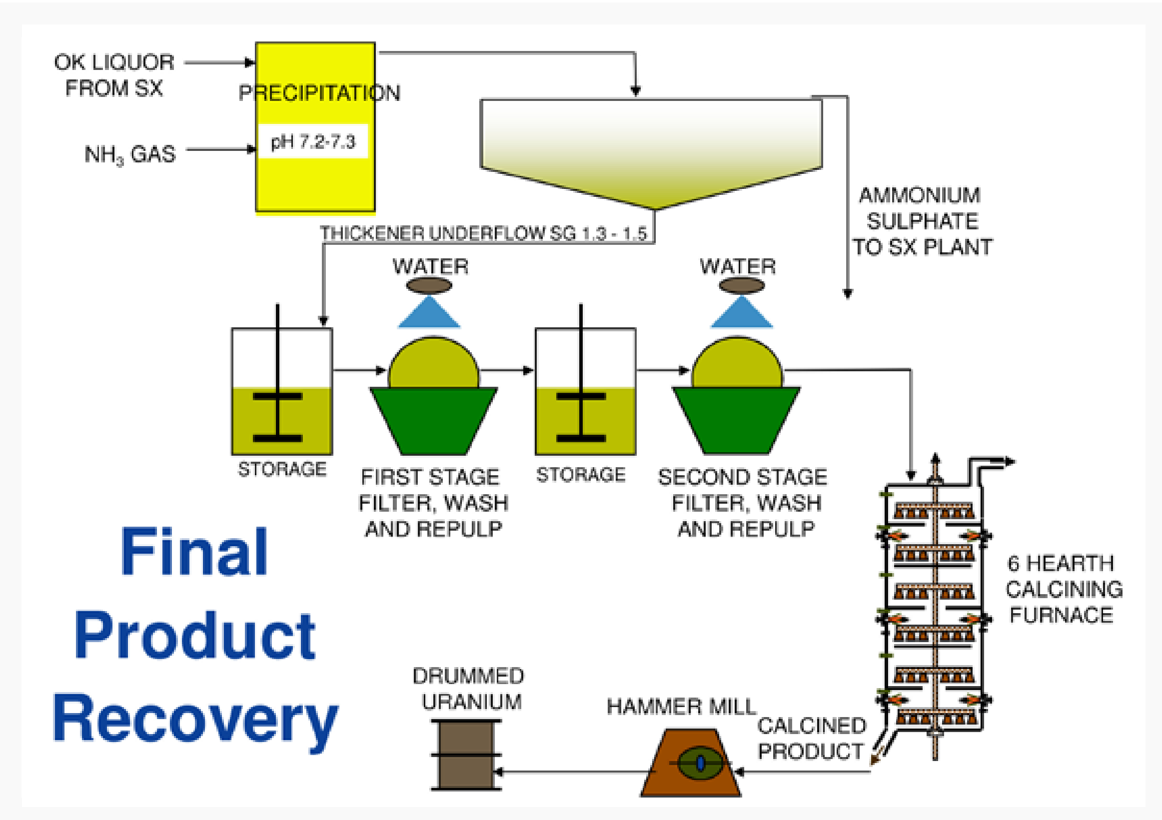


Figure 11: Final Product Recovery



1.3.2 Exploration activities

Until mid-June 2013, Rössing Uranium was engaged in exploration activities in the southern corner of the mining licence area, referred to as the *Z20 anomaly*. The duration of this exploration field work programme was short term only, from 2011 to 2013.

Work involved geological mapping and exploration drilling by percussion and diamond core drilling. Apart from the exploration drilling activities, the transport of samples for assay and final storage at Rössing Uranium's sample storage facilities was included in the work. Mineral waste generated during the drilling was transported to the Rössing Uranium mine for disposal at the TSF. (Transportation of samples and waste was carried out by the company Corporate Logistics which have been granted a permit to transport radioactive materials.) Based on X-ray fluorescence (XRF) assay data, the uranium grades ranged from a minimum close to zero to a maximum of 7,500 parts per million (ppm) U in ore, but averaged only about 120 ppm.

The exploration site operated independently and was managed by Rio Tinto Exploration. A total of up to 30 workers were employed at the site, where they were accommodated in a camp facility. The workers' exposure monitoring programme was covered by Rössing Uranium's Monitoring programme, as part of the exposure monitoring of the 'Field workers' similar exposure group (SEG).

A separate RMP was submitted for the Z20 Exploration Programme.

1.3.3 Radioactivity at the Rössing Uranium mine

The Rössing ore body contains up to 350 ppm uranium, and ambient radioactivity is low. The total radioactivity per gram of ore is typically 60 Bq. Uranium is extracted from the ore using an open pit mining, crushing, milling and metallurgical extraction process. After milling, uranium is concentrated by the metallurgical extraction process and the radioactivity along the production process therefore ranges from 60 Bq/g in the ore to 380 Bq/g in OK liquor. The majority of the radioactivity entering the Processing plant ultimately ends up in Rössing Uranium's commercial product – uranium oxide (U_3O_8) – at levels of about 21,000 Bq/g. The remaining radioactivity from the ore, which is associated with the daughter radionuclides in the uranium decay chain and those in the thorium series, is deposited at the Tailings Storage facility, along with other mineral waste. The radioactivity level in the tailings material is typically 50 Bq/g.

The processing of bulk uranium-containing materials also leads to the formation of radioactive scale on equipment within vessels and pipes. The radioactivity level of this scale can reach up to 40,000 Bq/g [34].

Radioactivity from the abovementioned materials and process chemicals can lead to exposure to workers and/or the contamination of the soil, air, or water in the vicinity, and requires remedial measures during mine operations and at mine closure. Radioactivity also occurs in dust generated by the mining and milling processes, which is dispersed by wind. Finally, the extraction and size reduction of ore results in an increase of radon concentrations in the environment, both within the borders of the mine site and beyond.

The *Radiation Protection and Waste Disposal Regulations* [37] (hereafter '*Radiation Protection Regulations*') under the Namibian Atomic Energy Act [2] stipulate as a mandatory requirement that all operations handling radioactive materials must draw up and submit a Radiation Management Plan (RMP), which needs to be approved by the National Radiation Protection Authority (NRPA). The exemption threshold for naturally-occurring uranium and thorium-bearing ores to be regarded as radioactive is an activity level of 1 Bq/g [37][4]. For uranium-bearing ores, this threshold relates to an ore grade threshold of 80 ppm, above which an RMP is required[5] and a site operation licence must be obtained. This RMP presents the required tools for complying with all the legal requirements under the Atomic Energy Act and associated Regulations.

1.3.4 Types of radiation

Radiation is classified into 'non-ionising' and 'ionising' radiation, depending on its energy. Radiation is ionising if its energy is high enough to ionise matter. The radiation that is emitted from radionuclides during radioactive decays falls into the category of ionising radiation and can be grouped into the three types:

1.3.4.1 Alpha

The alpha particle is the nucleus of the element helium and consists of two protons and two neutrons. Because of its large mass and its charge, it has a short range and is easily stopped by a sheet of paper or by human skin; external exposure to alpha radiation is therefore harmless because it is stopped by the dead outer skin layers. Its main radiation hazard arises when it is ingested or inhaled into the body, where it can come into contact with living cells. Internally, alpha radiation is the most strongly ionising type of radiation.

1.3.4.2 Beta

Beta particles are electrons or positrons that are emitted from the nucleus. These high-energy electrons have a greater range of penetration than alpha particles, but less than gamma rays. Because beta particles are more than 7,000 times less massive and only half as charged as alpha particles, beta radiation is about twenty times less ionising than alpha radiation.

1.3.4.3 Gamma

Gamma rays are high-energy electromagnetic waves, distinguished from X-rays only by their nuclear origin. Most gamma rays are higher in energy than X-rays and are therefore very penetrating. Because gamma radiation is uncharged and massless, it does not interact as easily

[4] Regulation 1.1.
[5] Regulation 8.5.

with matter as alpha and beta particles. It is therefore less ionising than alpha or beta radiation but much more penetrating.

1.3.5 Uranium

Naturally-occurring uranium has a three isotopes, the most abundant being uranium-238 (U-238, 99.3 weight percentage), followed by uranium-235 (U-235, 0.7 weight percentage) and uranium-234 (U-234, 0.005 weight percentage). All three uranium isotopes are weakly radioactive, with specific activities of 12,445 Bq/g (U-238), 80,011 Bq/g (U-235), and 231.1 MBq/g (U-234) respectively. Taking into consideration the isotope abundances, this translates into specific activities in natural uranium of 12,356 Bq/g (U-238 and U-234) and 568 Bq/g (U-235) respectively.

When uranium and thorium decay, a series of daughter nuclides results, with one element decaying into the next one until a stable isotope of lead is reached. The relevant decay chains are referred to as the 'uranium series' (starting with U-238 and containing U-234 as a daughter in the decay chain); the 'thorium series' (starting with thorium-232, Th-232); and the 'actinium series' (starting with U-235). The decay chains or series are listed in detail in Appendix A: Decay Chains[6].

Secular equilibrium occurs if the activity of a radioactive isotope remains constant because its production rate is equal to its decay rate. Uranium in the ore body is in approximate secular equilibrium with its decay products. This means the activity per gram of ore is the same for all uranium decay chain radionuclides, of which there are 14 in total. The actinium decay chain is also in approximate secular equilibrium but the total activity from the actinium chain is about 21 times less than that from the uranium chain. The activity from the thorium chain relative to that of the uranium and actinium chains depends of the ratio of uranium to thorium in the ore, which is highly variable. At the Rössing Uranium mine, the average uranium/thorium ratio is about 7.5:1 and therefore the relative radioactivity from the thorium chain is about 23 times less than that from the uranium chain.

As per the hazardous materials definition, low toxicity alpha emitters are defined as: 'natural uranium, depleted uranium, natural thorium, U-238, U-235, Th-232, Th-228 or Th-230 when contained in ores or physical or chemical concentrates or tailings, or alpha emitters with a half-life of less than 10 days' [25]. Both the mined ore and the final product (U_3O_8) at the Rössing mine therefore fall into the category of low toxicity alpha emitters.

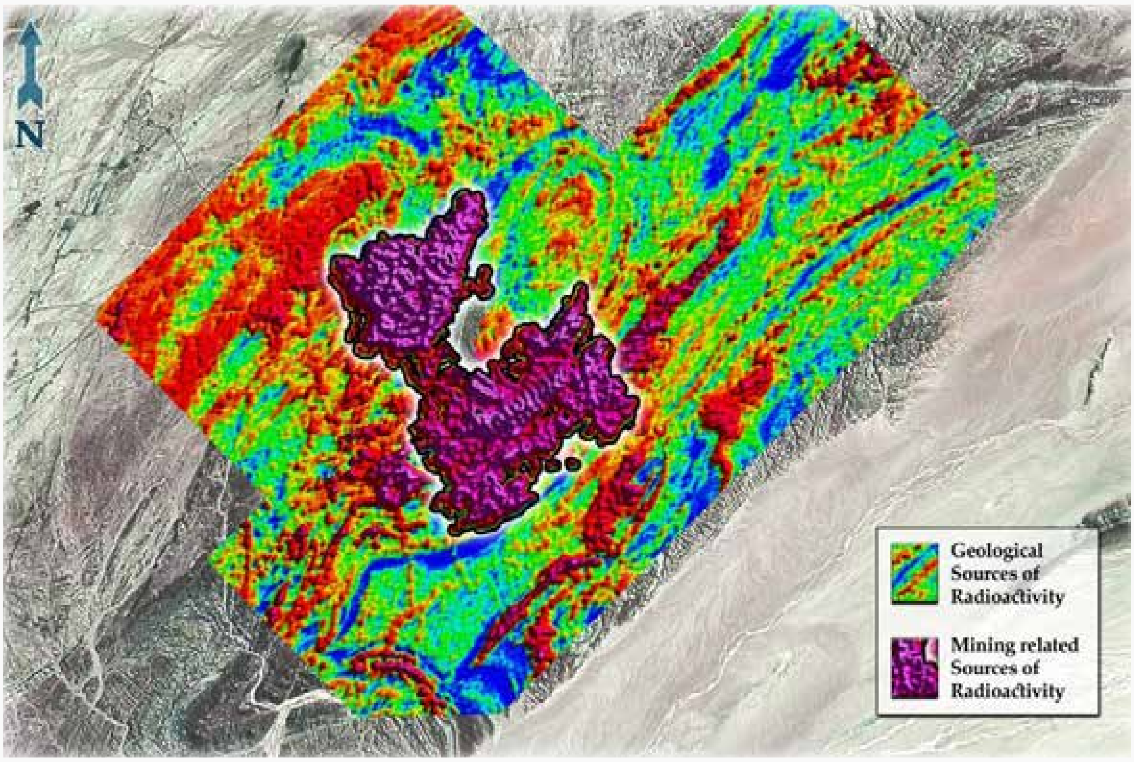
1.3.6 Sources of radiation

Most of the radiation occurring at the Rössing mine originates from the uranium, actinium and thorium decay chains (see Appendix A: Decay Chains). Because of the low ore grades, radiation levels in most areas of the mine are low, except for those areas where concentration of uranium from the ore takes place.

Radioactivity (which is in excess of the natural background radiation specific to the area) enters the environment through the redistribution of rock materials by mining out the open pit; placing material on waste rock dumps; and placing tailings into the tailings storage facility.

Figure 12 shows mining-related sources of radioactivity in the Rössing mining area in a purple colour.

Figure 12: Sources of radioactivity in the mining area



[6] The specific activity of the head of the thorium chain, Th-232, is 4,060 Bq/g.

Table 1: Areas of the mine site with representative external radiation dose rates in µSv/h

Area	Typical dose rate (µSv/h)	Area	Typical dose rate (µSv/h)
Open pit	0.5 – 1.0	FPR	0.5 – 40.0
Crushers	0.5 – 1.0	TSF	1.0 – 2.0
Processing plant (general)	0.5 – 3.0	Workshops	0.2 – 0.5
CIX plant	2.0 – 10.0	Offices	0.2 – 0.3
SX plant	0.5 – 10.0	Main gate	0.5 – 1.0

Exposure to radiation can be grouped into two categories: internal and external exposure.

1.3.6.1 External exposure

External exposure is exposure from sources external to the body, and is primarily from gamma radiation. Sources for external exposure at the mine include:

- the Rössing ore body (open pit);
- ore stockpiles (coarse ore stockpile, fine ore stockpile, waste rock dumps, low grade ore stockpiles, high calc. stockpiles);
- the Tailings Storage facility;
- the Processing plant (process tanks, pipes with process solution or scale);
- the Final Product Recovery area, product drum storage areas, container storage areas); and
- sealed radiation sources.

Representative dose rates found in some typical areas of the mine are summarised in Table 1.

1.3.6.2 Internal exposure

Internal exposure can come from all types of radioactive materials once they are inside the body, where much of the radiation energy will get absorbed into cells, tissues, and organs.

Internal exposure can be grouped according to three internal exposure pathways: The inhalation of long-lived radioactive dust, inhalation of radon and radon progeny, and ingestion of radionuclides.

1.3.6.3 Long-lived radioactive dust (LLRD)

LLRD comprises the inhalable portion of dust containing the long-lived radionuclides of the uranium, thorium and actinium decay chains. Sources of LLRD at the Rössing mine include:

- the open pit, and the mining and blasting activities that take place there (ore dust)
- dust roads, especially when covered with tailings sand (ore or tailings dust)
- the waste rock dumps (ore dust);
- coarse ore and fine ore crusher dust plumes (ore dust);
- tailings dust plume (tailings dust);
- areas of coarse- and medium-grained tailings on the TSF (tailings dust);
- areas of silt and precipitated salts on the TSF (tailings dust);
- areas of seepage precipitate between the toe of the TSF and the seepage dam (tailings dust);
- stack emissions from FPR if not adequately controlled (uranium dust); and
- FPR area (uranium dust).

The compositions of ore dust and tailings dust differ slightly: ore dust contains all of the radionuclides of the uranium, thorium and actinium decay chains, roughly in secular equilibrium. In tailings dust, between 80 and 95 per cent of the uranium from the ore has been removed, while most of the progeny from the three decay chains remain. As a large proportion of the material mined is waste rock, a significant portion of the dust on site is not strictly speaking ore dust, but can vary in composition between typical ore and waste material. The stripping ratio is about 4:1, ie for every five tonnes mined, only one is processed, with the remaining four being discarded as waste rock.

Pure uranium oxide dust, on the other hand, contains only freshly-leached uranium and none of the progeny from the uranium and actinium decay chains.

Dried out tailings may represent a major source of wind-blown dust. The position and relative sizes of the salt deposits, as well as the seepage deposits, are indicated in Figure 13.

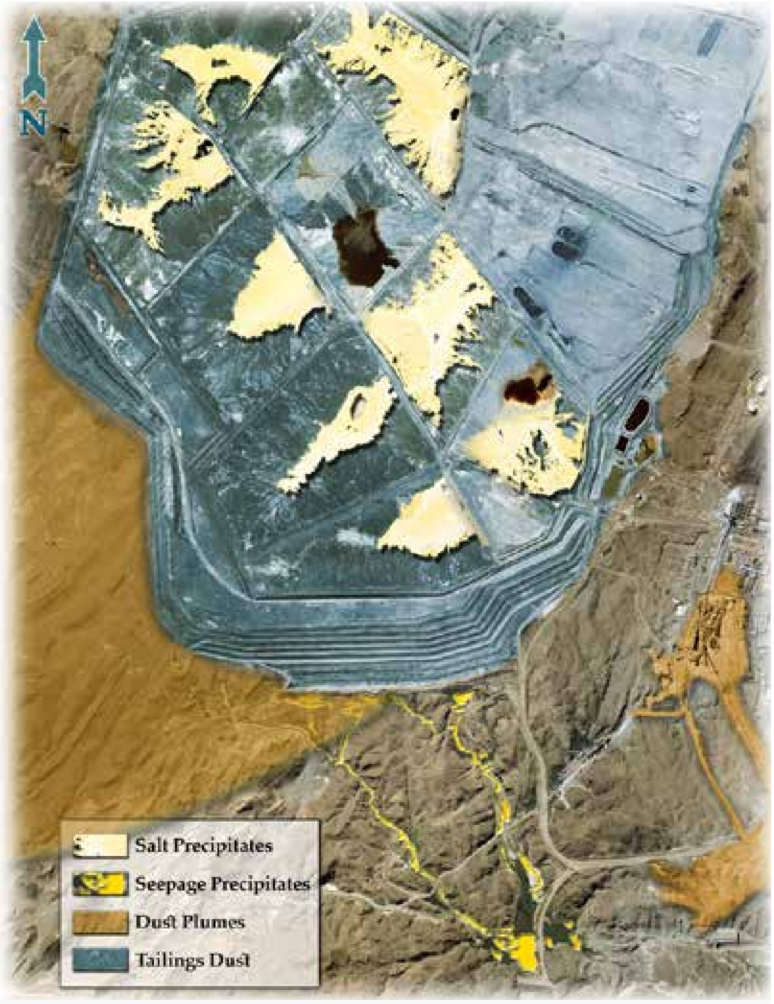


Figure 13: Areas of potential dust generation in the vicinity of the TSF.

1.3.6.4 Radon

Radon-222 is a radioactive gas which is a member of the uranium decay chain, see Appendix A: Decay Chains. It's relatively long half-life of 3.8 days allows its emanation into the atmosphere before decay. Radon is a volatile noble gas and hence does not attach easily to solids – the exposure to radon inhaled with air into the lung is therefore relatively minor, as it gets expelled from the lungs when exhaling. Radon progeny on the other hand, are solids with very short half-lives. Because of the tendency of radon progeny to attach to solids, the inhalation risk is significant, as radon progeny can be attached in the lung, hence will not be expelled on exhaling. The extent of the exposure from radon and its progeny depends crucially on the equilibrium factor, which determines how much of the radon progeny occurs together with radon. It also depends on the fraction of radon progeny attaching itself to aerosols in the air, the so-called attached fraction.

Because the major exposure to radon is from its progeny, it is good practice to measure radon progeny directly, rather than radon concentration (as is more commonly done).

Good ventilation allows a favourable equilibrium factor, ie a low concentration of radon progeny and hence low internal exposure from short-lived alphas. In addition, good ventilation allows for successful dilution of radon, thereby reducing radon concentrations. Confined spaces, on the other hand, may allow radon progeny to accumulate and thereby pose an inhalation hazard. Because of its open pit mining technique and windy conditions, good ventilation is practically always guaranteed at the Rössing mine; hence radon exposures are generally low.

Radon-220 (a member of the thorium chain) is also referred to as thoron and has a relatively short half-life of 56 seconds. This short half-life limits the mobility of thoron through the ore before it decays, making the hazard from thoron much smaller than that from radon. In addition, thorium — the parent of the thorium decay chain — is seven times less abundant at the Rössing mine than uranium, further reducing the importance of thoron as a radiation hazard. The world average environmental levels of thoron are a factor ten times less than those of radon; at Rössing Uranium, these are reduced further by the relatively low abundance of thorium in the ore. In the Monitoring Programme, thoron is generally disregarded and only radon and its progeny are monitored.

Sources of radon at the Rössing mine include:

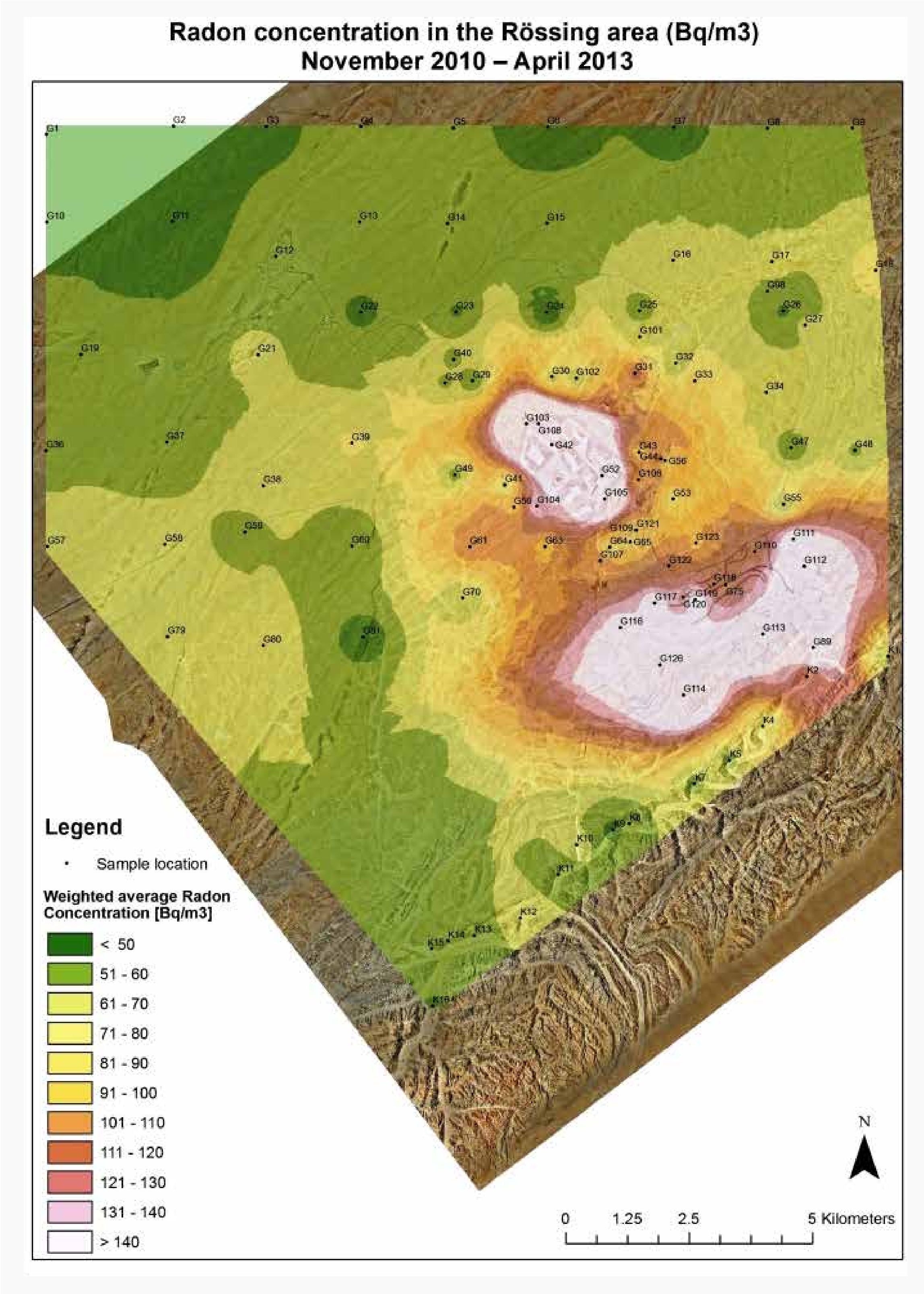
- the Rössing ore body (open pit);
- ore stockpiles (coarse ore stockpile, fine ore stockpile);
- waste rock dumps and low grade ore stockpiles;
- the Tailings Storage facility;
- empty tanks and pipes with radon scales (jarosite); and
- the crushing circuit.

Since 1989, Rössing Uranium has measured radon exhalation rates from various radon sources and a comprehensive data set of radon flux measurements has been developed. The radon sources measured include:

- the open pit shell;
- the waste rock dumps and low grade ore stockpiles;
- the crushing circuit, including the coarse and fine ore stockpiles;
- the Tailings Storage facility;
- contaminated areas around the mine site; and
- background locations in the surrounding environment, including localised areas containing enhanced natural radioactivity levels.

A comprehensive area survey of radon concentrations in the Rössing mining area was conducted in the late 1980s [3]. A grid covering an area of 16 km by 16 km was covered with track etch devices, placed between 1km (close to the pit) and 2 km (in the undisturbed areas) apart, which were exchanged every three months for a period of one year. The results from this survey were

Figure 14: Radon concentration profile at the Rössing Uranium mine site, from a survey conducted from 2011 to 2013.



used as input for the radon dispersion models used to perform public dose assessments at that time. A similar survey was repeated from 2011 to 2013, covering the same original area [50]. The new data was used for the purpose of making comparisons and to provide further input for public dose assessment calculations. The recent radon profile is consistent with the earlier survey, yielding baseline average radon concentrations of about 50 Bq/m^3, and mining-related concentrations of up to 330 Bq/m^3 on average, see Figure 14.

1.3.6.5 Ingestion

The final internal exposure is ingestion of radionuclides by eating or swallowing inhaled dust. Good hygiene practices are essential to limit ingestion but biological monitoring of urine is used to monitor the effectiveness of these practices in the Processing plant.

1.3.7 Sources not related to uranium

Fourteen sealed radioactive sources are located at the mine for density and level measurement, and for uranium analysis purposes. Only four sources are presently in use, in the Primary Crusher area of the Processing plant, all of them are Cs-137 sources.

Source activities range from 0.15 to 37 GBq. All ten unused sources are stored in the Radiation Source Bunker of the mine and will be returned to the supplier once no longer considered useful.

All sealed sources are registered and licensed with the NRPA (for a summary see Section 6.3).

Two XRF analysis machines are in operation at the Chemical Laboratory – these are registered and licensed with the NRPA.

Two calibration sources (one Th-230 and one Cs-137), originally intended for use with the portal monitor in the FPR area, are kept in the Radiation Safety Section Laboratory (in a lock-up safe); both are registered and licensed with the NRPA.

1.3.8 Exposure pathways and critical groups

The path followed by radionuclides from their source via air, soil, water, or food to humans, animals, or the environment is called the exposure pathway. The exposure of humans to radiation can occur directly from the outside (external) or internally – through ingestion or inhalation.

The relevant pathways for the exposure to ionising radiation as a result of mining activities are as follows:

1.3.8.1 Direct
Direct exposure to external gamma radiation.

1.3.8.2 Atmospheric pathway: dust
The inhalation of dust containing radionuclides.

1.3.8.3 Atmospheric pathway: radon
The inhalation of radon and radon progeny.

1.3.8.4 Aquatic pathway
Radioactivity can enter the environment via the aquatic pathway in the form of seepage water that contains dissolved radionuclide salts. Seepage emanates from the TSF as surface water flow and from groundwater flow in fractured rock aquifers and alluvial aquifers. If uncontrolled, the seepage could enter the Khan River and reach downstream users in the lower Swakop River area. Active seepage control measures are in place to prevent this from happening.

1.3.8.5 Ingestion
Radionuclides can be ingested directly, or swallowed after inhalation of dust.

The relevant exposure types, relevant pathways, and critical groups who may be exposed along these are summarised in Table 2.

Table 2: Radiation exposure pathways and critical groups at the Rössing mine site

Exposure type	Pathway	Type of radiation	Source of radionuclide	Critical group for exposure
External	Direct	Gamma	Ore, tailings, Processing plant, final product	Workers
Internal	Atmospheric: dust	Long-lived alpha	Ore, tailings, mine site, final product	Workers, members of public
Internal	Atmospheric: radon	Short-lived alpha	Radon, thoron and their decay products from ore, mine site and tailings	Workers, members of public
Internal	Ingestion	Alpha, beta, gamma	Ore, final product, process liquids, tailings	Workers
External	Direct	Gamma	Sealed sources	Workers
External	Direct	X-rays	X-ray machine	Medical personnel
Internal	Aquatic	Alpha, beta, gamma	Tailings (seepage)	Members of public (communities in the Khan and Swakop River areas)

2 Pre-operational safety assessments

2.1 Introduction

Planning to establish a mine at the Rössing Uranium site started in the early 1970s, and the operation was commissioned in 1976.

Although at that time comprehensive regulatory systems were set up in other parts of the world to control uranium mining (for example the Office of the Supervising Scientist was set up in the Northern Territories of Australia to control the new Ranger Mine), similar systems were not in place in southern Africa. Pre-operational radiation safety assessments or environmental impact assessments were therefore not carried out for the Rössing mine site prior to the mine coming into production in 1976.

The first environmental impact statement for Rössing Uranium was prepared in 1991 to allow the development of a closure strategy for the operation [14]. The first conceptual decommissioning plan was subsequently prepared in 1992 [40]. Radiation safety assessments have been conducted since the late 1970s and have contributed to subsequent environmental impact assessments (EIAs) and closure plan updates.

The sections below give a brief account of studies conducted, their purpose, results and shortcomings[7].

2.2 Radiation safety and public dose assessments

1979 to 1984: Work completed by Dames & Moore consulting engineers.

Dames & Moore conducted the initial work on the environmental transfer of radionuclide discharges through the air and groundwater pathways at the Rössing Uranium site. In September 1982, Rössing Uranium contracted this consulting firm to conduct the initial radon exhalation measurements on the TSF and other areas of the mine. Dames & Moore completed a further study on the reclamation of the Rössing Tailings Storage facility in 1984. One of its known conclusions was that radon exhalation from this source could be reduced by applying a specified thickness of alluvium or waste rock to the TSF.

These reports have not been traced to date and quantified results are therefore not available. The recommendations, which were for closure conditions, have not been implemented to date.

November 1988: Assessment of the occupational dose from the various radiation sources in the Open Pit area [6].

During 1988, the Atomic Energy Corporation of South Africa (AEC) assessed doses in the open pit from data supplied by Rössing Uranium. The total effective doses from various pathways were found to be within the range 3.4 to 4.1 mSv/a, consisting of the following components:

- external radiation: 1.4 mSv/a;
- radon exposure: 0.7 – 1.3 mSv/a; and
- inhalation of ore dust: 1.3 mSv/a.

The study recommended some adaptation of the monitoring programme applied in the open pit to assist with calculations of future doses.

November 1988: Investigation of 222Rn concentrations [20].

Environmental radon concentrations were measured at the Rössing mine site over a one-year period. Dispersion modelling was carried out for the same period and the two sets of results were compared. Measured radon concentrations varied between 25 and 1,219 Bq/m^3; the modelling exercise under-predicted these concentrations, however. The study therefore recommended that the source terms for the various possible radon sources be determined more accurately and that an in-depth investigation into the probable dose to workers and the public due to enhanced radon concentrations be conducted.

December 1989: Measurement of radon exhalation rates from identified sources [46].

This report summarised results from the identification and measurement of all possible radon sources in the mining area. A number of natural background exhalation rates outside the mining area were also measured. Results were used in the report below.

January 1990: Modelling environmental radon concentrations associated with mining activities [21].

All possible mining-related radon sources at the Rössing mine site were identified and radon exhalation measurements were used to calculate the radon source terms. The AIRDOS-EPA dispersion model was used to calculate the total environmental radon concentrations, which were verified by measured concentrations. On an annually-averaged basis, enhanced radon concentrations

[7] As required by Regulation 18 of [37].

associated with mining activities to values doubling the natural concentrations were found to be limited to a distance of approximately 5 km from the mine and there was a significant decrease with distance from the mining area: at 8 to 10 km from the mine, the percentage contribution of the mining activities to the environmental radon concentration was found to be less than 20 per cent. The average radon concentration associated with mining activities was also calculated as 14 Bq/m^3 at the town of Arandis. The maximum predicted radon concentration associated with the mining activities was found to be 307 Bq/m^3 at a location south east of the open pit. Results from this work were used as input for the study below.

Background radon emanation rates were determined to be 0.02 Bq/m^2/s on average, but were highly variable. The average radon background concentration was found to be 69 Bq/m^3.

March 1990: Estimation of the average radiation dose to the population of Arandis from radioactivity originating from natural as well as mining related sources [7].

The average radiation dose to inhabitants of Arandis was assessed using selected best estimates for the natural background exposure due to external radiation, radon, and radioactive dust concentrations, as well as from mining-related activities. The main conclusions from the study were that the average annual effective dose equivalent for an inhabitant of Arandis appeared to be about 5.4 mSv/a, with the following contributions:

- external radiation from the natural environment: 1.6 mSv/a (about 30 per cent of total);
- radon and radon daughters from the natural environment: 2.7 mSv/a (about 50 per cent of total);
- radon and radon daughters from mine-related activities: 0.5 mSv/a (about 9 per cent of total);
- radioactive dust particles from the natural environment: 0.5 mSv/a (about 10 per cent of total); and
- radioactive dust particles from mine-related activities: <0.1 mSv/a (about 1 per cent of total).

The estimated values were deduced from a limited amount of data, specifically in the case of dust due to mine-related activities. It was recommended to improve the database through the routine monitoring of radon and dust concentration measurements.

Background external radiation for Arandis was measured. For the radon background, an average indoor and outdoor concentration of 100 Bq/m^3 was assumed, and an equilibrium factor of 0.35 used for both indoor and outdoor concentrations to get a dose estimate. The reason for choosing 100 Bq/m^3 was due to the measurements carried out by Grundling et al. [20], who found the average indoor and outdoor concentrations at Arandis to be 60 and 128 Bq/m^3 respectively. However, because the indoor concentration was expected to exceed the outdoor concentration, it was decided to assume 100 Bq/m^3 for both indoor and outdoor concentrations. This was reasonably consistent with model predictions of 75 Bq/m^3, of which 14 Bq/m^3 was due to mining activities, based on the model. Best estimates for the environmental dust concentrations were deduced from measurements done at Arandis by Faanhof et al. [19]. The contribution to this from mining-related activities was assumed from the distribution of wind directions prevalent in the area.

October 1997: Assessment of the radiological impact associated with the use of tailings for maintenance of haulage roads in and around the Open Pit [8].

Rössing Uranium was using alluvium from nearby river beds for routine maintenance of the roads inside and around the open pit. Due to a possible long-term impact on the river bed, the replacement of alluvium with Rössing Uranium tailings material was contemplated for this purpose. The study assessed the possible increase in the radiological impact from the change in road maintenance practice. Based on surface contamination readings taken on existing road surfaces and on a 5-cm layer of tailings, it was concluded that the average airborne activity concentration from gamma dose rate on haulage roads should decrease or stay similar to the levels determined at the time. A similar study was conducted to assess the impacts of using seepage water for dust suppression in the open pit [9].

March 1997: Assessment of the radiological impact associated with the use of seepage water from the tailings dam for dust suppression in the Open Pit [9].

Rössing Uranium was using water from the open pit sump, from seepage collection trenches in Pinnacle Gorge and Panner Gorger, and from an aquifer in the Khan River for dust suppression in the open pit. Due to a reduction in the water available from the Khan River aquifer, the need arose to find a replacement source of water. The report assessed possible radiological impacts when supplementing these water sources with seepage water from the TSF. The conclusion was that substitution of water from the Kahn River aquifer with water from the seepage dam was not likely to cause any significant increase in radiation doses because of the limited increase in radioactivity concentrations and the small fraction of seepage water involved.

March 2001: Preliminary post closure radiological safety evaluation [34].

Rössing Uranium invited its Rio Tinto in-house consultants, Rio Tinto Technical Services, to conduct a brief study on the post-closure radiological exposures and mitigation options. In particular, an evaluation was made of the options for covering the TSF. Doses were calculated for various closure options that were included in the 1997 *Conceptual Decommissioning Plan*. In the 2001 study, post-closure doses were estimated to be well below the dose limit for members of the public, both during and after decommissioning. All doses in the Rössing mining environment for the offsite maximally-exposed persons were found to be less than 0.25 mSv/a. Therefore, radiation from the Rössing mine – and the tailings dam in particular – would not have a significant radiological impact at Arandis.

August 2001: Assessment of the dose attributable to radon at a number of receptor locations surrounding the mine [17].

Detailed data of radon exhalation values collected for all radon sources mine-wide were summarised in this report. In order to predict the concentration of radon in ambient air at locations where no radon data were available, use was made of an air quality dispersion model. The ISCST3 air dispersion model was used to estimate the radon concentrations in ambient air at each of eight receptor locations. Doses due to radon calculated for off-site receptor points ranged between 0.02 and 0.58 mSv/a.

In addition, the report summarised a comparative study between measurements made with the outdated activated charcoal method used at the Rössing mine in the past and the new diffusion tube method that has been accepted by the regulatory body in South Africa, the Council for Nuclear Safety (CNS). The results of the statistical inter-comparison of the two methods showed that the zone-averaged charcoal measurements made by Rössing Uranium since 1989 were comparable to diffusion tube flux results. The old Rössing Uranium data set therefore represents a valid, credible distribution of the radon flux situation for the radon sources measured in the vicinity of the Rössing mine site at the time.

December 2001: Assessment of the airborne and deposited dust levels attributable to dust sources at a number of receptor locations surrounding the mine [39].

This report presented a determination of the wind speed-dependent fugitive dust source terms of a number of dust sources at the Rössing mine site. The dispersion of the emitted dusts was modelled to yield concentration and deposition rates. Only those sources that would potentially release dust after mine closure were considered. The outcome of the report was the annual mean dust concentrations and deposition rates that were expected to occur at a number of specific receptor locations. The data from the report were subsequently used in radiological dose estimations at these receptor locations in addition to those dose estimates made from other sources, such as radon, as described in the August 2001 report of EnviroSolutions [17].

June 2002: Assessment of the background radon concentrations for pre-mining conditions in the present mining grant area [18].

For the purpose of determining pre-mining radon concentrations for the Rössing mine area, a once-off radon exhalation survey was completed in 2001 in areas surrounding the mine within the Mining Licence Area. Selection of sampling areas for use in the study was based on the distribution of radioactivity determined during a radiometric ground scintillometer survey carried out for exploration purposes in the pre-mining phase. The results of the scintillometer survey indicated that radiation counts varied considerably throughout the area surrounding the site of the mine at that time. This variability was considered in the design of the radon exhalation survey undertaken in 2001. To derive concentrations from exhalation rates, radon dispersion modelling was conducted assuming mining-related features were absent and by projecting exhalation measurements in areas now disturbed. The levels of exhalation rates projected were based on the distribution of radioactivity levels measured during the earlier exploration scintillometer survey. An average background radon concentration of 28 Bq/m^3 was determined for the Rössing mine area; however this was quoted with a standard deviation of 63 Bq/m^3. Shortcomings identified by the study included a statistically insufficient set of radon measurements in areas of high radioactivity associated with ore grade uranium mineralisation.

September 2002: Assessment of the post-closure radiological impact of the mine [10].

Based on the studies above, a screening assessment of the post-closure impact of the Rössing Uranium mine was carried out involving both a deterministic assessment using fixed parameters and a stochastic assessment considering uncertainties by using approximate parameter distributions. For the atmospheric pathway assessments (radon and radioactive dust inhalation), doses were assessed from dispersion modelling results while for the aquatic pathway, doses were assessed from radio analytical results from boreholes and the use of a simple mixing flow model. Post-closure additional doses assessed for critical groups in Swakopmund and the nearby smallholdings were all below 100 μSv/a, while those at Arandis were slightly higher (up to around 130 μSv/a). The report concluded that all doses were found to be below the ICRP proposed dose constraint of 300 μSv/a without any mitigatory measures and might not need further considerations (except to keep doses ALARA).

2003: Post closure public dose assessment for the Phase III expansion of the mine [11].

This September 2002 post-closure public safety assessment of the Rössing Uranium mine considered various mitigation and institutional control options, some of which related to the operational Phase I of the mine. In 2003 Rössing Uranium considered an expansion of the mine life, to be divided into expansion phases II and III. Phase III was the most likely to offer a significant upward change in respect of post-closure public dose identified, most notable of which would be an expansion of the areas of the mine tailings dam. The assessed total post-closure doses for the Phase III expansion of the mine were found to be below a dose constraint of 300 μSv/a at Arandis, the Rössing mine site, the Khan Mine, the Swakopmund smallholdings, and Swakopmund itself. At Arandis Airport, the total dose was predicted to be slightly above the constraint, at 534 μSv/a.

March 2004: Investigation into the possible increase in external radiation doses for 2004 at Final Product Recovery [1].

This study investigated the reason for the increase in external radiation to workers at Final Product Recovery in 2004 and identified the increase in numbers of filled product drums stored in the area as being responsible. A number of recommendations were implemented to reduce the workers' exposure, including limiting the time spent by workers in the drum packing area; packing drums in containers rather than storing them unshielded; and finding an alternative drum storage site further away from the drum filling area. Reference was made to a previous investigation by Isaack, [35], which recommended storing no more than 800 drums outside containers in the FPR area, and that the maximum number of containers stored in the area should be 40. The latter investigation found the maximum external radiation levels at FPR to reach 16 μSv/h when the number of drums stored outside containers reaches 800. The 2004 report conceded that actual external exposures, measured with TLDs, were far below this predicted maximum, however.

October 2006: Atmospheric dispersion modelling of radon and long-lived radioactive dust for current, Life-of-mine Extension and Post Closure mine operating scenarios [47].

This report described the atmospheric dispersion calculations done to assess the radiological impact of radon and long-lived radioactive dust (LLRD) at selected locations where critical public population groups might be found, either at the time of the report or in the future. The impact was also calculated on a contour basis to allow interpolation of results at arbitrary locations. The dispersion calculations were performed for mine operations in the existing scenario, during the life-of-mine-extension (operational period beyond 2020), and for various rehabilitation options that had been proposed for the post-closure situation. The report formed the input for the assessment below.

January 2008: Dose assessment for a Life-of-Mine Extension (LOME) [12].

The South African Nuclear Energy Corporation SOC Limited (Necsa) performed a dose assessment to compare the existing radiological impact of the mine on members of the public with the impact during the LOME and also compared the radiological impacts after mine closure. Assessed total expected public doses from radon and dust for the Operational Phase were well below the public dose limit and also below the dose constraint of 300 μSv/a for both the existing and LOME operational conditions, as well as for post-closure conditions without mitigation. However, it was reported that for the Post-closure Phase the contribution from the aquatic pathway might need a better evaluation as a simple modelling exercise might result in a total dose exceeding the dose constraint above. It was also noted that the combined impact of radon and LLRD inhalation for workers on the TSF was unlikely to be significantly affected by the LOME operations but might — for both the existing and the LOME operations — exceed 1 mSv/a for a 2,000 h/a exposure period and hence might require some time restriction or may require that persons be registered as radiation workers.

May 2011: Radiological public hazard assessment for the expansion of the mine, as a specialist study for the Phase II SEIA [13].

This radiological impact assessment consisted of the identification of public groups possibly exposed and the determination of the expected radiation doses to these groups. This was done by conversion of dust and radon concentrations modelled through dispersion modelling. The results were evaluated against international radiological criteria also applicable to Namibia.

The significance of risks from the inhalation of dust and radon combined were assessed as low and hence not in need of immediate action, ie below the dose constraint of 300 mSv/a for all critical receptor groups. The same finding applied to the planned future expansion as the assessment did not present any significant increase in the radiological risks due to dust and radon inhalation. Risks from the aquatic pathway were not assessed in this study; the 2002 dose assessment for the aquatic pathway was used as a reference instead.

2.3 Environmental impact assessments and closure management plans

1991: Environmental Impact Statement [14].

Rössing Uranium's first complete Environmental Impact Assessment (EIA) included background information and a pre-mining baseline relating to the mine site's location, topography, geological and mineral reserves, radioactivity, soils, hydrology and surface water quality, geohydrology and groundwater quality, ecological and biodiversity features, demographics, socio-economy, patterns of land use, and communications and infrastructure. It comprehensively described the (then) current mining operations, including waste disposal, dust and radiation control measures, and workforce and environmental health and safety. It evaluated the impacts due to mining operations and gave an overview of projected future mining operations. Possible impacts as a result of projected future mining operations were assessed, and decommissioning plans were proposed.

The baseline for background radiation in the area was given in the form of a very coarse contour map, with background values ranging from 2.3 mSv/a to 7.5 mSv/a in selected hot spots. The average gamma radiation at Arandis was given as 1.6–1.7 mSv/a. The values were obtained by correlating readings on the ground with pre-mining aerial surveys, and were therefore likely to have been over-estimated. The average radon exhalation from undisturbed rock in the Rössing mine vicinity was given as 0.02 $Bq/m^2/s$.

Radon exhalation values in disturbed areas were given as 0.8 (TSF) and 0.5–0.9 (open pit, waste rock dumps, ore stockpiles) $Bq/m^2/s$. Radon concentration at Arandis due to mining activities was given as 14 Bq/m^3. The total annual radon dose due to mining activities was estimated at 0.5 mSv/a. All radiation impacts estimated were based on earlier reports given in the assessments in Section 2.2, above.

Seepage control was found to be exercised through a system of de-watering trenches and wells along Pinnacle Gorge, Dome Gorge and Panner Gorge, which significantly reduced advancement of groundwater contamination into the Khan River aquifer. The efficiency of these measures to control contamination of the Khan River was reported to be confirmed with regular borehole water monitoring.

1992: Conceptual Decommissioning Plan [45].

This decommissioning plan provided background information as well as an overview of the pre-mining environment, the mining operations at the time, and projected future mining operations. It summarised existing environmental control measures and potential environmental impacts due to present and future mining activities. It put forward decommissioning objectives and measures, and provided an assessment of potential impacts after closure.

Criteria for setting up decommissioning objectives were based on accepted international radiation protection standards, namely the Environmental Protection Agency of the United States Standard EPA 40 CPR Part 192 of 1983, which provides guidelines for the decommissioning of uranium mill tailings, as well as the recommendations of the International Commission on Radiological Protection (ICRP).

Recommendations for decommissioning were:

- no facilities (buildings, structures, etc) to remain on site;
- stabilisation of the TSF by covering the area; and
- continued interception of tailings seepage via the existing controls after closure, until sufficient decline in seepage is recorded.

1997: Conceptual Decommissioning Plan update [40].

The objective of this decommissioning plan was mine closure in an environmentally acceptable manner. Actions were proposed to ameliorate the negative environmental impacts of existing and future mining activities:

- removal of all infrastructure within the open pit and access limitation through destruction of access roads and erection of berms;
- access limitation to waste rock dumps;
- all residual fuels and oils to be removed from site and sold (unless contaminated);
- any significant spillages to be cleaned up and the excavated material placed in the TSF;
- mill and mine site structures, buildings, and equipment to be dismantled, decontaminated in accordance with the criteria specified, and removed or disposed of;

- concrete foundations to be bulldozed, flattened and covered with waste rock and alluvium;
- dust plumes from the ore storage and transportation systems to be assessed for risk and removed to the TSF, if found necessary;
- erection of radon barrier on the TSF – 60 cm of rock cover; and
- continuation of tailings dam seepage de-watering and cut-off trench systems.

1998: CSIR – Assessment of the potential environmental impacts of the proposed Aquifer Recharge Scheme on the Khan River [15].

The proposal investigated the viability of a project for capturing a portion of the occasional Khan River floodwaters in a dam, settling the silt out, and then channelling clear water into the downstream alluvial aquifer. The evaluation of impacts relevant to radiation safety was not part of this assessment, and the project ended up not being implemented.

2000: CSIR – Environmental impact assessment of the proposal to expand the importation, storage and transfer of bulk sulphuric acid to the mine [16].

Environmental impacts as a result of the expanded use of sulphuric acid were discussed. The conclusion of the report was that all negative impacts could be successfully mitigated by management interventions. No radiation-specific impacts were of relevance to this activity.

2003: Sustainability Assessment for the Life of Mine Extension [44].

This sustainability assessment for the life extension of the Rössing Uranium mine incorporated an EIA. While the EIA considered social, environmental and biophysical impacts of the mine extension and aimed to ensure appropriate remedial action where needed, the sustainability assessment aimed to broaden the EIA objective by identifying actions that would create positive socio-economic outcomes for stakeholders beyond the physical and time dimensions of the mine at the time.

The proposed changes to the mine were described, ie a pushback of the (then) existing open pit to the west (referred to as Phase II), and a subsequent pushback of the pit to the south, referred to as Phase III. The outcomes of the EIA were listed, which included a public stakeholder participation programme, socio-economic impacts on the towns of Arandis, Swakopmund and elsewhere in the Erongo Region, and on- and off-site biophysical impacts.

The environmental studies showed that there were no environmental impacts that could not be addressed or minimised. The highest environmental risk associated with the mine extension was related to the expansion of the TSF. However the radiation levels were assessed to remain well below occupational and public dose limits. Some of the proposed operational changes would result in improved environmental performance, such as reduced water usage, reduced dust emissions, and reduced groundwater pollution.

The recommendation was made for further work to guarantee the stability of the Phase II tailings dam walls and the management of seepage from the extended TSF.

2005: Closure Management Plan [5].

The first complete closure management plan (CMP) collated according to the Rio Tinto Closure Standard, this document discussed two closure alternatives: closure in 2009 or 2016. The report included detailed discussions of:

- impact and risk identification;
- stakeholder consultation;
- the development of a vision for closure;
- the development of closure objectives and targets;
- a description of preferred mitigation alternatives;
- an identification of knowledge gaps and further work required; and
- an estimation of closure cost and accounting provision.

Closure measures were detailed and included:

- No backfilling of the open pit with mineral waste; use of the open pit as an evaporation area for reclaimed surface seepage as well as a containment area for contaminated infrastructure and demolition materials; covering of waste in the pit with a 10m layer of waste rock to minimise likelihood of scavenging for materials;
- Demolition of mine site facilities where infrastructure was not suited to further beneficial use; removal of contaminated materials to on-site hazardous waste facility; remediation of areas not to be used further; and

- Covering tailings facility walls and beaches with rock to control erosion; restrict access to tailings facility with fencing and signage; control systems for groundwater management to continue for 30 years after closure; continued operation of seepage control system until seepage has stopped; removal of dust plumes from around tailings dam and disposal in tailings dam; visual blending of tailings into environment with rock coverings; regular monitoring and maintenance of pumping system.

A 60 cm layer of waste rock was chosen as the preferred option for the remediation of the tailings dam, with optimal protection of members of the public from ionising radiation.

2008: Social and environmental impact assessment: proposed expansion project (Phase 1) [38].

This social and environmental impact assessment covered the impacts expected due to a proposed expansion involving an acid plant, an ore sorter, and a new satellite pit (termed 'SK4'). The impacts were evaluated according to a tabulated rating system, where each impact was described according to its extent (spatial scale), magnitude (size or degree scale), and duration (time scale), with and without mitigation. After mitigation, no risks remained that were high or critical.

(Neither the acid plant nor the ore sorter has been implemented to date, but mining in the SK4 area has started.)

2011: Social and environmental Impact assessment (Phase 2) [4].

The relevant radiation impacts were summarised in the 2011 dose assessment by de Villiers and de Beer [13] (see above).

(This social and environmental impact assessment is available on the Rössing Uranium website.)

2011: Closure Management Plan update [42]

This 2011 CMP is an update of the 2005 plan. The public dose assessments relevant for this update were all below the 300 μSv/a source constraint – even with the addition of maximum uncertainty. Mitigation options were therefore not assessed.

3 Organisational arrangements

3.1 Legal entity

The legal entity responsible for all actions relating to the mine (ie the legal persona) is Rössing Uranium Limited.

3.2 Organisation structure

Rössing Uranium Limited is managed by the Managing Director (MD). The line of reporting for the mine's Radiation Safety Officer, who is also the Principal Advisor Radiation Safety, is summarised in Figure 15 below.

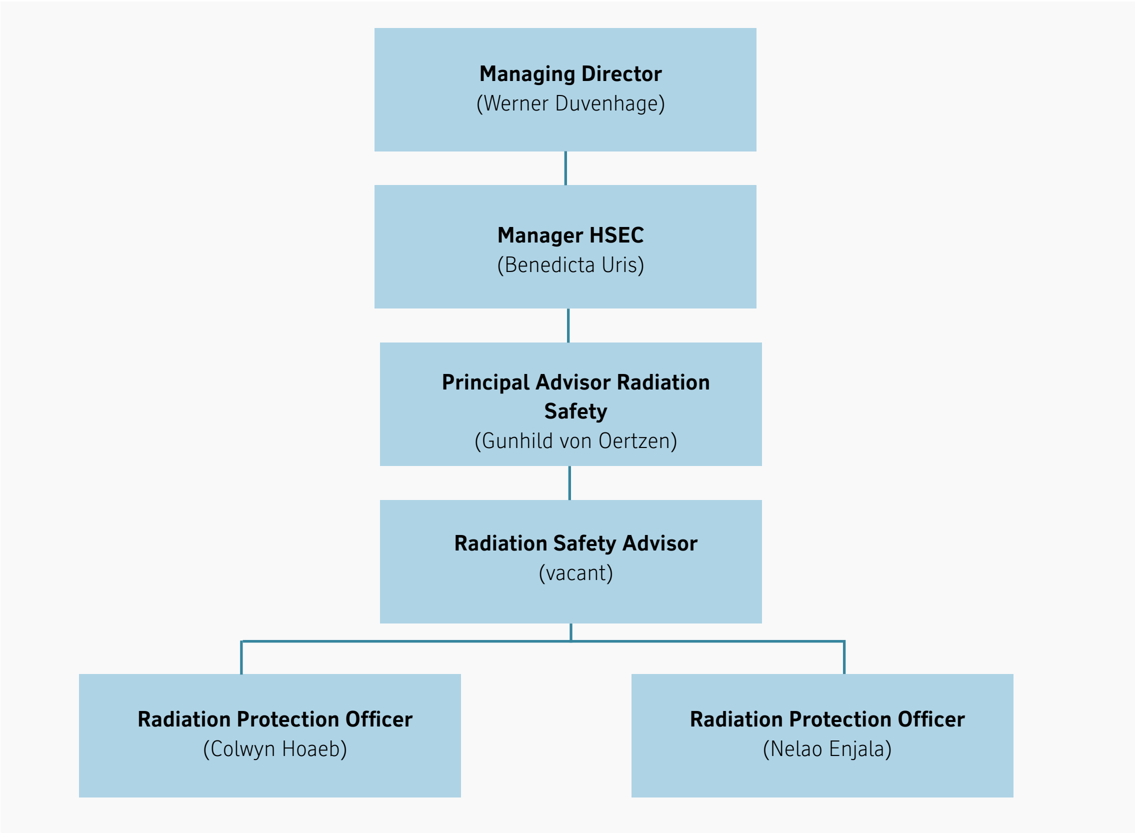


Figure 15: Organisation structure of Rössing Uranium Limited, where relevant to Radiation Safety

3.3 Radiation Safety Officer

The Principal Advisor: Radiation Safety is the designated Radiation Safety Officer (RSO) of the mine, in accordance with Section 30 of the Atomic Energy Act, 2005 [8]. The minimum qualification for the position is an MSc with a Physics Major. In addition, the incumbent is required to have five years working experience in a science-related field, at least three of which must be in a supervisory capacity, and one year's experience in radiation training. The formalisation letter for this appointment, presently filled by Dr Gunhild von Oertzen, is attached as Appendix B.

The RSO is responsible for the following tasks:

Radiation Protection programme:

- Drawing up, maintaining and implementing the site's RMP.
- Identifying the main sources of radiation and radioactive substances on and around the mine site, and assessing the risk associated with these sources.
- Ensuring that the Radiation Protection programme is consistent with the principles of justification, optimisation, and limitation.
- Ensuring radiation protection controls are introduced and implemented where required by risk assessment.
- Ensuring that all radiation protection controls are documented in safe work procedures and communicated to all relevant stakeholders.

Radiation Exposure Monitoring programme:

- Directing the routine Radiation Monitoring programme as well as special monitoring and modelling programmes.
- Assuring data quality by ensuring the checking, calibration, and maintenance of all the radiation meters and instruments used for area monitoring and personal dosimetry.
- Ensuring that exposure records are properly kept and copies are periodically sent to senior management.
- Reviewing exposure records in order to detect any unusual or anomalous results and investigating such results.

Worker engagement:

- Participating and engaging in worker training programmes and developing or approving any training material relating to radiation protection.

Legal compliance:

- Reviewing all laws and regulations pertaining to radiation so that any new legal requirements are not overlooked.
- Liaising with the NRPA regarding the implementation of radiation protection measures at the mine.
- Ensuring all reporting requirements as specified in the Radiation Protection Regulations [37] are met.

Stakeholder engagement:

- Supporting the Namibian Uranium Institute in training programmes aimed at improving skill levels in radiation safety in the mining industry and associated industries.
- Participating in stakeholder engagement sessions relating to radiation protection for people and the environment.

Product stewardship:

- Advising on matters of product stewardship, including engagement with external stakeholders such as customers, the IAEA, World Nuclear Association (WNA), and World Nuclear Transport Institute (WNTI) etc, as the need arises.

The Principal Advisor Radiation Safety is assisted by the Radiation Protection officers in the performance of his/her duties, see Figure 15.

3.4 Radiation Safety advisor

The Radiation Safety advisor supports the Principal Advisor Radiation Safety in the implementation of the RMP and supervises the Radiation Protection officers. The minimum qualification for this role is a Bachelor's degree in Science or Environmental Management and at least two years' relevant working experience.

3.5 Radiation Protection officers

The Radiation Protection officers support the Radiation Safety programmes at the mine site. The minimum qualification is Grade 12 with Mathematics and Physics. The duties may include:

[8] See also Regulation 17 of the Radiation Protection and Waste Disposal Regulations under this Act.

- hazard identification and reduction (detecting, identifying, and rectifying situations on site that can lead to exposure events);
- radiation awareness training;
- data and database management (ensuring sufficiency and integrity of monitoring data);
- quality assurance (ensuring applicable procedures are adhered to and quality work practices are maintained);
- co-ordination, communication and liaison (liaise with sections to ensure co-ordination and implementation of safety measures and monitoring programmes);
- management of pregnancy testing schedules for female radiation workers;
- equipment maintenance (management, maintenance, and operation of monitoring equipment);
- supporting and implementing all radiation monitoring programmes;
- identifying, investigating, and reporting on non-conformances or exceedances in radiation safety;
- measuring radioactivity or radioactive contamination levels of drums, containers or any equipment or material;
- co-ordinating and implementing urine sampling;
- performing routine occupational radiation exposure monitoring of employees and contractors;
- performing ad hoc monitoring programmes such as radon and external radiation surveys and contamination surveys;
- performing leak tests on sealed radiation sources;
- performing microwave leak tests;
- performing contamination checks on scrap, waste materials, and tools and equipment;
- issuing radiation clearances for items to be released for transport off site, or for transport between areas on site; and
- issuing time restrictions and work permits for areas with elevated radiation levels.

3.6 Occupational physician

The Occupational Physician is responsible for occupational medicine and the Medical Monitoring programme and he/she should be fully conversant with the environmental aspect of the Radiation Protection programme. The Occupational Physician reports directly to the Manager HSEC. At present, the Occupational Physician is contracted to the company Medixx, chaired by CEO Dr Clive Thomas.

The responsibilities of the Occupational Physician include: [9]

- carrying out pre-employment, periodic, and termination of employment medical examinations;
- issuing fit for work certificates to workers based upon the risk-based medical examinations performed;
- co-ordinating examinations of lung, kidney, and other target organ functions and if necessary consulting with various other medical specialists as appropriate;
- advising management periodically on the health status of the workers;
- giving clearance to a worker who has been temporarily withdrawn from work on medical grounds to be reinstated to normal work;
- periodically visiting work places to acquaint himself/herself with the working and environmental conditions;
- recommending the transfer of any worker he/she has examined and who is medically unfit for a specified duty. This is done by written recommendation to the Manager HSEC, who will initiate the transfer;
- obtaining radiation exposure dose records for employees and entering these into the health records of employees; and
- ensuring compliance of the occupational health programmes with the *Radiation Protection Regulations*.

3.7 Superintendent Health Management

The Superintendent Health Management, reporting to the Manager HSEC, is responsible for directing and implementing the mine occupational health monitoring programmes, such as monitoring noise levels, heat conditions, dust exposures, etc. The Superintendent Health Management is also responsible for budgeting for and managing the occupational health programmes carried out by the Occupational Physician.

[9] These responsibilities include those mandatory under *Radiation Protection Regulations* 26 (1)c and 31.

4 Occupational radiation protection programme

This section summarises the principles followed in radiation protection, the occupational exposure risks, the controls used to minimise exposures, and the monitoring programme followed to verify compliance with dose limits.

4.1 Principles of radiation protection

The objective of radiation protection of individuals exposed to radiation is the prevention of the occurrence of non-stochastic (deterministic) effects and the limitation of stochastic effects (risks) to levels deemed to be acceptable. To meet the objectives of radiation protection, Rössing Uranium has adopted the system of dose limitation recommended by the ICRP [33], comprising the following three requirements:

4.1.1 Justification

No practice will be adopted unless its introduction produces a positive benefit. Justification for a proposed practice for an operation involving exposures to radiation is ascertained by consideration of all the expected advantages and disadvantages, to ensure that there is an overall net advantage from the introduction of the practice.

4.1.2 Optimisation

All exposures are kept as low as reasonably achievable (ALARA), economic and social factors being taken into account. This means that the level of protection will be the best under the prevailing circumstances, maximising the margin of benefit over harm.

4.1.1 Individual dose limitation

The dose equivalent to individuals from all practices should be less than the appropriate dose limits. The dose limits are intended to ensure adequate protection even for the most highly-exposed individuals. In addition to the legal occupational dose limits [10] (see Section 4.2), Rio Tinto further specifies a Standard of 5 mSv/a. Every possible care is taken to avoid exposure of individuals in excess of 5 mSv/a.

The dose equivalent to individuals must not exceed the limits laid down in this RMP. Doses resulting from natural background radiation and from medical exposure (as a patient) are by definition excluded from the dose equivalent limits. However, natural background radiation is not subtracted from personal occupational radiation exposure measurements for workers. In other words, the exposures measured are recorded as occupational, without any adjustments for natural background radiation.

4.2 Occupational dose limits

Occupational exposure refers to radiation exposure incurred by all employees and contractors in the course of their work. The calculation of occupational radiation doses is based on 2,000 work hours per year [49]. Exposure to natural background radiation occurring naturally in the area is not by definition included in the occupational exposure, although at Rössing Uranium it is intentionally not excluded from personal exposure measurements. This allows for a conservative measurement and avoids the propagation of errors associated with measurements of background radiation.

The occupational dose limits are based on the 2007 ICRP recommendations [27], [33], and specified in the IAEA Safety Standards formulated for radiation protection in the mining and milling industry [22]. These limits form part of the *Radiation Protection Regulations* [37] and are as follows:

- an effective dose of 20 mSv per year averaged over five consecutive years;
- an effective dose of 50 mSv in any single year;
- an equivalent dose to the lens of the eye of 150 mSv in a year; and
- an equivalent dose to the extremities of the skin of 500 mSv in a year.

[10] Regulation 10 of [37].

4.3 Occupational Radiation Exposure Risks

4.3.1 Types of radiation risk – exposure pathways

Radiation exposure risks at Rössing Uranium include both internal and external radiation exposure. The exposure pathways are classified as follows:

- External radiation (gamma only);
- Internal radiation from radon and thoron decay products (short-lived alphas);
- Internal radiation from inhalation of dust (long-lived alphas). The type of dust differs depending on the work area: in most areas of the mine, the dust can be classified as ore dust, containing all radionuclides of the uranium, thorium and actinium chains in secular equilibrium. On the TSF the composition is slightly altered because a significant percentage of uranium has been extracted from the tailings material. In Final Product Recovery, the dust contains uranium oxide almost exclusively; and
- A further potential exposure is from the ingestion of uranium, which cannot be measured directly.

The exposure risk from ionising radiation is highest for workers in the Recovery and Final Product Recovery areas of the mine. The dominant exposure type for these worker groups is external and is due to gamma radiation. These workers are classified with the designation 'radiation workers'[11] and their external radiation exposure is monitored continuously.

For the assessment of equivalent dose, all workers are grouped into similar exposure groups (SEGs)[12], with exposure levels within a designated SEG not likely to vary significantly. The radiation exposures of workers from all SEGs — except the designated radiation workers — are monitored randomly per SEG.

The beta radiation hazard (skin dose) is only monitored for workers classified as radiation workers.

4.3.2 Potential exposure risk by area

Occupational exposures depend on the radiation levels in the area under consideration as well as on the time spent in the area and the effectiveness of controls — such as dust containment or time restrictions. Typical dose rates and potential annual exposures in some areas are listed in Table 3.

The table lists minima and maxima as they may be encountered – the maximum potential total annual dose that can realistically be expected is also given in the table. Although some maximum dose rates encountered would indicate a potential total dose exceeding 5 mSv/a in the area, these are not actually obtained in all cases. For example, the potential maximum dose from the inhalation of radon in some offices is 5 mSv/a, although this is never realised in practice. For this reason, the potential maximum dose for workers in the area is rated as being below 5 mSv/a, and workers there are not classified as radiation workers. The rationale behind this is confirmed by many years of dose records, which substantiate the general rule that the potential maximum dose as indicated by a maximum dose rate in the area is never realised as a maximum dose because workers tend to spend only limited amounts of time in maximum dose rate locations.

Table 3: Typical radiation dose rate ranges by area, and potential minimum and maximum exposures per annum

Area	Typical external dose rate (μSv/h)	Potential annual personal occupational exposures (mSv/a)			Total potential annual dose (mSv/a)
		External	Internal (dust)	Internal (radon progeny)	
Open Pit	0.2 - 1.0	0.4 - 2.0	0.05 – 0.5	0.05 – 5.0	<5
Crushers	0.5 - 1.0	1.0 – 2.0	0.2 – 2.0	0.4 - 2.0	<5
Extraction plant	0.5 - 2.0	1.0 – 4.0	0.1 – 1.0	0.1 - 2.0	<5
CIX plant	0.2 - 10	0.4 – 20	0.05 – 1.0	0.1 – 0.5	>5
SX plant	0.5 - 10	1.0 – 20	0.05 – 1.0	0.1 – 0.5	>5
FPR	0.5 - 10	1.0 – 20	0.05 – 10.0	0.1 – 0.5	>5
Mine site, general (Field workers)	0.2 - 10	0.4 - 20	1.0 – 2.0	0.1 – 2.0	>5
Tailings Storage facility	0.5 – 2.0	1.0 - 4.0	0.05 – 1.5	0.1 – 2.0	<5
Workshops	0.1 - 0.6	0.2- 1.2	0.3 – 2.0	0.5 – 2.0	<5
Offices	0.1 - 0.5	0.2 – 1.0	0.05 – 0.5	0.1 – 5.0	<5

[11] Based on the potential annual exposure, as explained in Section 4.3.3.
[12] See Section 4.3.3.

4.3.3 Worker classification into similar exposure groups (SEGs)

All workers are grouped into SEGs according to the potential health risk experienced in the area in which they work. Thus the SEG classification is not exclusively a tool for managing radiation exposure risk only but is also designed to cover other health risks such as exposure to silica dust, organic vapours, noise, or vibration. Each worker is assigned to just one of the SEGs and his/her assignment is linked to the role of the worker. The SEG assignment of workers may therefore change if the worker's role changes.

Twenty-two SEGs are categorised at present. These groups are shown in Table 4.

Offsite office workers are categorised into a separate SEG; however for the purpose of radiation protection their radiation exposure dose is regarded as nil.

Table 4: Worker classification into similar exposure groups (SEGs)

SEG name	Description of workers	Potential exposures
Pit Equipment operators	Operators of all heavy mobile equipment (haul trucks, shovels, drills, dozers, cable handling equipment, etc)	Noise, dust, silica dust, vibration, manual handling, heat stress, fatigue, shift work Possible: diesel particulate matter
Pit Field workers	Mine Electrical electricians, Pit Electronics, Shovel and Drill Maintenance electricians, Mining Shift Maintenance	Dust, silica dust, noise, heat stress, fatigue shift work
Mine Maintenance Workshop workers	Workshop welders, boilermakers, fitters, Diesel/motor mechanics, Auto electricians, Haultruck Electrical electricians, workshop foremen and artisans	Noise, dust, silica dust, welding/metal fumes, diesel particulate matter, vibration, manual handling Possible: volatile organic compounds (VOCs)
Mining Support workers	Geologists, surveyors, Pit foremen, Area Safety advisor	Dust, silica dust, noise
Blasting Crew and Grade Control workers	Drill and blast ground staff, Geology Grade Control technicians, HEF truck controllers	Dust, silica dust, noise, heat stress, UV radiation, manual handling Possible: diesel particulate matter
Reduction workers	Primary Crushers and Fine Crushing plants: foremen, sectional operators, ore supply operators, crusher controllers, plant cleaners	Noise, dust, silica dust, welding/metal fumes, vibration, manual handling, legionella, heat stress, fatigue, shift work, radioactive dust
Extraction workers	Rodmills, Leaching plant, MnO_2, Tailings Storage facility: operators and foremen, Water Treatment plant operators	Noise, dust, silica dust, diesel particulate matter, vibration, manual handling, accid mist, MnO_2, (chlorine gas - Sewerage plant), heat, legionella, radiation Possible: VOCs, CO, H_2S, fatique, shift work
Recovery workers	Recovery Operations: operators CCD, CIX and SX: foremen and operators Sub-SEG - Recovery Maintenance: Reduction Mechanical 3	Noise, welding/metal fumes, diesel particulate matter, vibration, manual handling, acid mist, radiation, radioactive dust, VOCs, ammonia gas, heat stress, legionella Possible: CO, H_2S, dust, fatigue, shift work
Final Product Recovery workers	Operators and sectional operators, quality controller drumfilling and foreman	Noise, diesel particulate matter, vibration, manual handling, radiation, ammonia gas, heat, radioactive dust Possible: fatique, shift work
Tailings Dam operators	Foreman, sectional operators & operators, Heavy equipment operators (Paddy Developers)	Noise, dust, silica dust, diesel particulate matter, vibration, manual handling, fatique, shift work

SEG name	Description of workers	Potential exposures
Processing Maintenance workers	Extraction and Water Maintenance workers, Reduction Maintenance workers, Processing Shift Maintenance workers, welders, boilermakers, fitters	Noise, dust, silica dust, welding/metal fumes, vibration, manual handling, acid mist, MnO_2, (chlorine gas - Sewerage plant), heat, asbestos (water maintenance), radiation Possible: VOCs, CO, H_2S, Fatique, Shift Work
Processing Support workers	Acid Logistics, plant electricians, instrumentation mechanics, condition monitoring technicians, metallurgists, geohydrologists, area HSE advisors	Noise, dust, silica dust, vibration, manual handling, acid mist, radiation, heat stress Possible: CO, H_2S, MnO_2, VOCs, ammonia gas, shift work
Engineering Workshop workers	Plate Shop, Vehicle Maintenance and Machine Shop: welders, boilermakers, fitters, diesel/motor mechanics, VMC/ Hiab operators, panelbeaters, foremen	Noise, dust, silica dust, welding/metal fumes, vibration, manual handling, legionella Possible: radiation, VOCs, asbestos (gaskets)
Rubberliners	Rubber liners, Fibreglass liners, Boilermakers	Noise, dust, silica dust, vibration, manual handling, acid mist, radiation, VOCs Possible: CO, H_2S, legionella
Field workers	HSE advisors, OH officers, radiation officers, Change house attendants, fire and emergency workers, protection services, mobile equipment crane operators, riggers, project engineers, electronics technicians	Noise, dust, silica dust, welding/metal fumes, vibration (whole-body and hand-arm), manual handling, acid mist, radiation, VOCs, (biologicals - emergency crew) Possible: CO, H_2S, MnO_2, legionella, heat stress, radioactive dust
Laboratory workers	Chemists, technical support, laboratory operators, FTC operators	Noise, dust, silica dust, metal fumes, H_2S, vibration, manual handling, acid mist, radiation, VOCs, legionella, fatique, shift work Possible: radon, radioactive dust, radiation
Transport workers	Bus drivers, transport controller	Ergonomics, whole body vibration, fatigue, shift work
Logistics and Warehousing workers	Warehouse officers and controlers (Central, Plant and Mining Stores), materials operators, mail dispatcher, locomotive driver, shunters	Noise, dust, manual handling, DPM Possible: silica dust, VOCs
Mining Office workers	Mining engineers, maintenance coordinators and planners, dispatchers MMC, mine manager and superindentants (Operations and Maintenance), skills trainers, administrators	Ergonomics, shift work and fatique (especially dispatchers), radon
Processing Office workers	CPC operators and shift controllers, Processing superindentants, HR advisor, personal assistants, engineers, managers	Ergonomics, shift work and fatigue (CPC operators and shift contrllers), radon
Office workers	HR staff, finance staff, procurement staff, HSE superindentants and advisors, managing directors, general managers, managers, personal assistants and administrators, janitors	Ergonomics, radon
Workers offsite	Workers based at the Windhoek and Swakopmund offices, acid offloading in Walvis Bay	Ergonomics Workers at acid offloading in Walvis Bay: manual handling, noise and acid mist

4.4 Radiation protection controls

4.4.1 Local rules and supervision

The Atomic Energy and Radiation Protection Act of 2005 [2] and any regulations or guidelines issued by the NRPA under this Act — for example the *Radiation Protection Regulations* [37] — constitute the primary authority by which radiation exposure is managed at Rössing Uranium. The Rio Tinto Standard *HO6-Radiation* [43] is also applied should this be more stringent than the national guidelines or regulations.

Audits on radiation management are conducted from time to time by the NRPA and biennial audits of performance under the Rio Tinto Standard *HO6-Radiation* are conducted by Rio Tinto.

Local procedures and rules are detailed in the relevant workplace procedures and work instructions. These are tabulated in Section 11.

4.4.2 Worker classification: radiation workers and non-designated workers

4.4.2.1 Radiation workers

A 'radiation worker' is defined as someone having to work for extended periods in areas designated by the RSO as being at risk for radiation exposures, and is assigned as such in the register of radiation workers. This is therefore any person assessed to be potentially exposed to 5 mSv or more in any one year[13], or a person working in areas where continuous exposure monitoring is regarded as necessary.

The following persons cannot be designated radiation workers:

- persons below the age of eighteen;
- persons deemed medically unfit;
- pregnant women; and
- persons who have not been trained in the hazards of the work area.

Rössing Uranium's designated radiation workers include:

- all workers classified as belonging to the SEGs 'FPR workers' or 'Recovery workers'; and
- any other workers if designated by the RSO.

A full risk assessment across the mine was conducted[14] to specify the radiation exposure risks for each role and the relevant controls required. Each position designated as a radiation worker role is listed in the risks assessment, by name and by position ID — see JK65/PRD/032-*Radiation Worker Monitoring Requirements at RUL*. The monitoring requirements include: registration as a TLD wearer, monthly urine sampling, and monthly pregnancy testing (for females under 50 years of age only). (See Procedure JK65/PRD/032 for a full list of positions classified as radiation worker roles.)

4.4.2.2 Non-designated workers

All workers not designated as radiation workers are categorised as 'non-designated workers'. The radiation exposure doses of non-designated workers are not monitored continuously; instead the average and 95 per cent confidence level of the measured dose for any SEG is assigned to all workers in this SEG. Non-designated workers are not classified as members of the public — with the exception of pregnant workers, who are protected under the rules for members of the public (see Section 5).

4.4.3 Classification of areas

In order to more effectively and consistently regulate occupational exposure to ionising radiation, workplaces are designated as either 'controlled' or 'supervised' areas, or as 'non-classified' if no additional control is required.

4.4.3.1 Controlled areas

This describes areas where personal exposures may potentially exceed 5 mSv/a (one quarter of the annual dose limit) or which require control. The limit is prescribed by Rio Tinto Radiation Standard, *HO6 – Radiation* [43], Clause 3.2.

Controlled areas include:

- Final Product Recovery, including the Solvent Exchange (SX) plant;
- the container storage yard;
- the Radiation Source bunker;
- sealed sources in use; and
- the Decontamination facility.

The mine site layout map (Figure 17) shows the location of the container storage area, the Decontamination facility, the FPR area and the Radiation Source Bunker.

Areas where sealed radioactive sources are installed are regarded as controlled areas and radiation warning signs are displayed in prominent positions. The four sources in use in the crushing area are located in locked rooms, with access restricted to instrumentation and radiation protection workers. A fifth source was in use in the FPR area, which is in itself a controlled area. The use, handling, conveyance, permit to work, and lockout procedures are described in detail in Procedure JK65/PRD/001-*Using Sealed Radioactive Sources.*

Controlled areas are fenced wherever possible and entry gates to the areas are locked. Access is restricted to personnel having to work in the areas, who undergo an area-specific induction programme before being granted access to the area. Access to the FPR area is by electronic access control using fingerprint identification.

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[13] This potential annual dose level is prescribed as the cut-off for designation as a 'radiation worker' in the Rio Tinto Health Standard *HO6 - Radiation.*

[14] The most recent update of the risk assessment per role was conducted in 2015.

Figure 16: Sign marking a radiation controlled area

Access to the Decontamination facility, container storage yard and Radiation Source Bunker is by lock and key, and access to the SX area is by electronic card access control.

Controlled areas are signposted with warning signs displaying the radiation symbol and the text: 'Restricted Access. Radiation Controlled Area' (see Figure 16).

4.4.3.2 Supervised areas

These are areas where exposures are above the general background of the area and may potentially exceed 1 mSv/a above natural background levels. Areas specifically defined are:

- the open pit;
- the crushing, milling, coarse ore and fine ore stockpiles;
- the Leaching, Rotoscoops and Thickeners areas;
- the Continuous Ion Exchange (CIX) plant;
- the Tailings Storage facility;
- the Gritblasting yard; and
- the Chemical Laboratory (X-ray & FPR analysis rooms).

Access to these areas is restricted by local departmental standard procedures. Where necessary, these areas (open pit, labs, TSF) are fitted with electronic access control activated by personal electronic access cards, restricting access to those persons authorised to work in the area.

4.4.3.3 Non-classified areas

Non-classified areas include those areas not listed under 'controlled' or 'supervised' area designations. Radiation dose monitoring for all workers who are not classified radiation workers follows the same random sampling routine described in Section 4.5 below, regardless of their assignment to supervised or non-classified areas. However, non-classified areas are those areas with radiation dose levels similar to background radiation, and these are the areas to which pregnant women are assigned for the duration of their pregnancies. Non-classified areas include the office areas and laboratories (except those areas specified as 'supervised', above).

4.4.4 Protection of pregnant workers

Unborn babies are regarded as members of the public and are therefore subject to the 1 mSv/a maximum exposure limit (see Section 5.1). In some areas, in particular those classified as controlled areas, this 1 mSv/a limit may be exceeded, making it necessary for pregnant employees to be moved out of these areas for the duration of their pregnancies.

Figure 17: Plant layout showing the controlled areas: 14 – SX plant, 16 – FPR, Decontamination facility (red circle within mine site area), Radiation Source Bunker (full red circle on top of map).

Once an employee is aware that she is pregnant she needs to inform the Medical Service Provider, her line manager, or the Wellness Co-ordinator immediately. A comprehensive hazard and risk assessment will then be completed in order to compile an Occupational Risk Exposure Profile (OREP) for that particular worker. This will be done by the Health Management Section together with the Occupational Physician. If required, alternative work will be assigned for the employee during her pregnancy.

Women who are classified as designated radiation workers are required to undergo monthly pregnancy testing, in accordance with procedure JK65/PRD/021-*Monthly Pregnancy Test*. If a pregnancy is confirmed, workers are removed to a low radiation area for the duration of the pregnancy (preferably an office environment). The total occupational radiation exposure during the pregnancy should not exceed 1mSv. This may be monitored using an electronic personal dosimeter (EPD) and by checking the dust and radon progeny exposures of the work area.

4.4.5 Medical surveillance

The medical *Fitness for Work* programme includes regular medical examinations of workers, the frequency of which depends on the exposure risks in the workplace. All workers undergo a fit for work examination at least once a year. For designated radiation workers, there is an additional examination at six-monthly intervals.

4.4.6 Access/egress to Final Product Recovery area

The Final Product Recovery (FPR) area has double fencing around the area with a gap of five metres between the two fences. A security officer is stationed within FPR and another at the access gate on the road leading to the FPR area.

Access to FPR can only be obtained through two doors and security cubicles. In addition, access to the area is by electronic access control using fingerprint identification. Only approved staff members who have completed the annual HSE Induction programme and the FPR Area Induction are granted electronic access.

The Change House facility at FPR is divided into uncontaminated (or 'clean') and contaminated (or 'dirty') sections. This principle is followed to prevent contamination of the 'clean' change house and to prevent persons leaving the controlled area if they are contaminated above the set limits. Staff members entering the change house through the 'dirty' entrance are required to discard contaminated clothing into the wash bins provided for the purpose, to shower, and to leave the area with clean clothing through the 'clean' side. All protective clothing used in this area is washed at the FPR Washing facility.

Workers are able to perform a self-check for residual contamination when they leave the changing rooms: an Electra instrument with dual alpha/beta probe is provided for a quick contamination check. However, this measure is intended as confirmation for ease of mind only, as the cleaning facilities are designed to provide adequately for personal cleanliness in respect to possible contamination.

4.4.7 Controlling the spread of contamination

4.4.7.1 Surface contamination: definition

Surface contamination results when uranium-containing material settles on surfaces, or spilled uranium solution dries on surfaces. This contamination, unless controlled, can become suspended in the air and become an inhalation risk, or it can be a source of external radiation to the skin. Surface contamination is mainly controlled through access/egress control programmes for personnel and vehicles as well as for equipment, scrap, and process materials.

Surface contamination can be regarded as being either fixed or non-fixed (removable). 'Non-fixed contamination' refers to contamination that can be removed from a surface during routine handling or transport. 'Fixed contamination' refers to contamination bonded to the surface quite firmly by chemical or physical means — such as chemical bonding, adsorption, adhesion, etc — and that cannot be easily removed from the surface. Both fixed and non-fixed contamination contribute to local beta and gamma dose rates, but only non-fixed (removable) contamination can be re-suspended and contribute to air contamination. Thus non-fixed (removable) contamination is more hazardous and must be controlled by removal, eg wash downs with subsequent recycling or disposal of the wash down solution.

'Contamination' means the presence of a radioactive substance on a surface in quantities exceeding of 0.4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 0.04 Bq/cm^2 for all other alpha emitters [23].

Low toxicity alpha emitters are: natural uranium, depleted uranium, natural thorium, uranium-235 or uranium-238, thorium-232, thorium-228 and thorium-230 when contained in ores or physical and chemical concentrates, or alpha emitters with a half-life of less than ten days. An object at Rössing Uranium is therefore said to be contaminated if its surface contamination exceeds 0.4 Bq/cm^2 [23].

Objects, items or equipment that are not radioactive but which have radioactive material distributed on their surfaces (in levels exceeding 0.4 Bq/cm^2) are known as 'surface contaminated objects' (SCOs).

SCOs are divided into two groups [23]:

'SCO-I: A solid object on which:

- the non-fixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 4 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 0.4 Bq/cm^2 for all other alpha emitters;

- the fixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 40,000 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 4,000 Bq/cm^2 for all other alpha emitters; and
- the non-fixed contamination plus the fixed contamination on the inaccessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 40,000 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 4,000 Bq/cm^2 for all other alpha emitters.

SCO-II: A solid object on which either the fixed or non-fixed contamination on the surface exceeds the applicable limits specified for SCO-I above and on which:

- the non-fixed contamination on the accessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 m^2) does not exceed 400 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 40 Bq/cm^2 for all other alpha emitters; and
- the fixed contamination on the accessible surface, averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 800,000 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 80,000 Bq/cm^2 for all other alpha emitters; and
- the non-fixed contamination plus the fixed contamination on the inaccessible surface averaged over 300 cm^2 (or the area of the surface if less than 300 cm^2) does not exceed 800,000 Bq/cm^2 for beta and gamma emitters and low toxicity alpha emitters, or 80,000 Bq/cm^2 for all other alpha emitters.'

4.4.7.2 Contamination standards and controls

The aim of contamination control is to prevent the spread of contamination with radioactive materials — from contaminated areas on site to uncontaminated areas, as well as beyond the perimeters of the site. The definition of contamination given by the IAEA *Regulations for the Safe Transport of Radioactive Material* [23] (hereafter '*Transport Regulations*'), is followed in this regard (see Section 4.4.7.1 above).

In order to prevent the spread of contamination from one to area to another on site, a clearance is required for the transport of equipment from controlled areas (such as FPR) to supervised or unclassified areas (such as the Engineering Workshops). Because equipment being repaired does not leave the site, the contamination standard for SCO-1 objects is followed for non-fixed contamination, and is 100 times less than the SCO-1 standard for fixed contamination.

For items being removed from site, the radiation clearance required is designed to prevent any object regarded as contaminated from leaving the site.

The limits of contamination for these different categories are summarised in Table 5.

Note that surface contamination is measured over an area of 300cm^2 or over the entire surface area if this is less than 300cm^2.

All items at risk are tested for contamination and only items conforming to the above standard as uncontaminated will be released from the site. In general, items originating from the 'dry' mining areas — ie items that have not come into contact with the wet product extraction process — are not regarded to be at risk of surface contamination. On the other hand, any item that has been in contact with the 'wet' extraction process is regarded to be at risk and needs to be checked before it may be released from the site. The relevant procedures describing the details of the clearance

Table 5: Summary of contamination limits

Item	Standard to be complied with	Condition of outside surface	Type of contamination	Activity limits (Bq/cm^2)
Equipment, items, material leaving site for unrestricted release	Un-contaminated	Clean	Fixed and non-fixed	0.4
Product (UOC), packed in containers for export or as samples for external analysis (scan outside surface of package only)	Un-contaminated	Clean	Fixed and non-fixed	0.4
Equipment for repairs on site or at contractors yard at Rössing Uranium site and returning to source area afterwards	SCO-1	No visible contamination	Non-fixed	4
			Fixed	400

procedure and specifying which items need a clearance are JK65/PRD/004-*Removal of Scrap Metal*, and JK65/PRD/005-*Removal of Equipment and Material from site*.

The Rössing Protection Services personnel at the mine site are instructed to detain any items classified as at risk and requiring a radiation clearance.

Items not requiring a clearance for release include the following:

- trains;
- vehicles (busses and Ivecos, combis, Rössing Uranium-owned sedan vehicles that are used for transport only, privately-owned vehicles, tyres, engine parts and other mobile equipment parts from the light vehicle workshop and mobile equipment workshops, the truck from central stores, Wesbank Transport trucks, and other supply trucks);
- office equipment: laptops, computers, furniture, books, paper, projectors, electronic office equipment, etc;
- personal equipment: food items, clothing, personal electronic equipment, books, medicines, toiletries, stationery, etc;
- new equipment purchased by contractors from the stores;
- empty or full jerry cans, containers, buckets, etc;
- urine samples taken to Swakopmund laboratories;
- radiation detection instruments sent to laboratories for calibrations or repair;
- paper and cardboard leaving the site for recycling;
- wood and parts of packaging if originating from outside the Processing plant; and
- scrap batteries, fluorescent bulbs, oil drums, petrol drums and containers used for chemicals.

Items that **do** require a clearance for release include the following:

- tools and equipment used in the Processing plant or processing workshops;
- equipment and items taken for outside repairs by contractors, unless confirmed by the area owner to be from no-risk areas;
- plant parts such as pumps, pipes, or any other metal parts (excluding stainless steel); and
- scrap metal.

(Heavy mobile equipment leaving the site does not need a clearance but needs to be visually clean.)

Items above the contamination levels (but below SCO-1 level) may be released from the site only after the Radiation Safety Officer (or his/her designate) has granted permission and in this regard, the IAEA *Transport Regulations* [23] must be followed. The receiver and transporter must be licensed to handle radioactive material and must have the required safety and emergency procedures in place. Receivers/transporters must also be in possession of all required transport and/or possession permits for radioactive materials.

No items exceeding the SCO-1 level will be released from site.

4.4.8 Personal hygiene

4.4.8.1 Facilities

The company ensures that appropriate ablution, laundry, change houses, kitchens and lunch rooms are available for all its employees. All facilities, (eg ablutions, toilets, change rooms, lockers, kitchens, lunchrooms) must be kept in a clean and hygienic state.

No person is allowed to eat, drink, chew gum or tobacco, smoke, or take snuff in working areas where concentrated radioactive materials may be ingested or inhaled. Lunch rooms in these areas are provided with adequate washing facilities.

4.4.8.2 Eating, drinking and smoking

Before eating and before leaving the mine site, employees must ensure that an adequate level of personal cleanliness has been achieved. This will include the washing of hands and faces before eating or drinking, and showering before leaving for home if there is any possibility that they have become contaminated.

Storage of food, eating and drinking are only allowed in approved lunch rooms, and no smoking is allowed outside the designated smoking areas. No food may be kept in lockers, tool boxes, etc if these are within the working areas.

Eating, drinking and smoking are prohibited throughout the Wet plant area. Eating outside buildings is discouraged everywhere on site and smoking is allowed only in designated areas located outside the Processing plant.

4.4.9 Dust control

Dust control measures are designed to reduce environmental concentrations of dust to levels that are as low as reasonably achievable. The aim is to limit the exposure to respirable silica dust, as well as to long-lived radionuclides in respirable dust[15].

The following dust suppression and reduction measures are followed:

4.4.9.1 Open pit areas

- During blasting, all people are removed from the blasting area – apart from preventing flying rocks from injuring people, the amount of dust they might inhale is reduced. By preference, blasting takes place in the afternoon, at the end of the day shift, thereby limiting the time workers spend in the vicinity of areas that are affected by dust from blasting.
- At mineral waste and sand piles, and at earth-moving operations, water is sprayed to reduce dust being generated.
- Major roads are tarred. On all other roads that are used frequently, dust-a-side[16] is used as a dust suppressant. Non-permanent roads are wetted (using brackish water from the Khan River, or seepage water from the tailings area)[17] to suppress dust levels.
- All drilling operations are carried out using sufficient water to keep dust levels as low as possible.

4.4.9.2 Crushing plant area

- Wherever practicable, dust generated in the crushing plants is suppressed at the source.
- The material submitted to the coarse ore crushers, the conveyors leading from the coarse ore crushers to fine crushing, and the conveyors from fine crushing to the Fine Ore Stockpile, is continuously sprayed with water to minimise dust blowing from these materials.
- The fine ore stockpile is positioned within a shed providing protection from wind-blown dust (see Figure 18).
- The fine crushing circuit is fitted with closed dust extractor systems collecting fine dust into covered lugger bins (see Figure 19).
- Any area where dust (containing radionuclides) has settled is not cleaned dry by either sweeping or compressed air blasts. Cleaning is done after wetting down or by vacuum suction into a dust collecting device.

Figure 18: Fine ore stockpile

Figure 19: Fine crushing dust collection system

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[15] 'Respirable dust' refers to those dust particles that are small enough to penetrate the nose and upper respiratory system and deep into the lungs. Particles that penetrate deep into the respiratory system are generally beyond the body's natural clearance mechanisms of cilia and mucous and are more likely to be retained. Inhalable dust is defined as that size fraction of dust that enters the body but is trapped in the nose, throat, and upper respiratory tract. The median aerodynamic diameter of this latter dust is about 10 µm, while the former is less than about 5 µm in size.

[16] Bitumen based material used on dirt roads for dust suppression and stabilisation.

[17] The radiological risk of this practice has been quantified in a study [9] and was found to be negligible.

4.4.9.3 Tailings

Where large areas of dry tailings have been disturbed through excavation or equipment movement, re-stabilisation practices are followed to ensure reasonable dust control. Regularly-used road surfaces on the Tailings Storage facility are stabilised by use of chemical binders or other means in order to minimise dust generation. Wind rows are prepared on dry areas that are not to be used for deposition in the near future. These wind rows assist in the minimising of dust suspension by wind.

4.4.9.4 General areas

- Paved surfaces and slopes with stone pitching are cleaned with water at a frequency determined by the supervisor responsible for the area. The cleaning frequency is consistent with good housekeeping objectives. Tarred and road surfaces are regularly cleaned by the vacuum truck.
- Laboratories are fitted with dust extraction systems in the sample preparation areas.

4.4.10 Personal protective equipment (PPE)

When engineered and operational controls are not sufficient to provide an optimised level of protection for the tasks to be performed, PPE is used.

4.4.10.1 Clothing and shoes

Depending on the risk of contamination, respirators, dust masks, overalls, head coverings, gloves, impermeable footwear, underclothes[18], towels and/or socks are provided by the company. Changing from work clothes to personal clothing and vice versa must be done in the change houses provided.

For area-specific PPE, reference must be made to the standard instructions and operating procedures of the relevant departments and sections.

All clothing worn on site must cover the full body, ie only long sleeved shirts and long trousers are allowed. Closed shoes must be worn at all times and safety shoes are mandatory for all workers not working exclusively in offices.

Protective clothing (shirts and trousers) are issued to employees individually and each item is marked with the name of the employee. For mine site areas, acid-resistant clothing is provided; for other areas cotton is used for clothing items.

Where clothing may potentially be contaminated, it must remain on site — such clothing must be laundered on site and safety shoes must remain in contaminated areas.

Protective clothing used in FPR (white overalls, only used inside the FPR area) may only be cleaned in the FPR laundry. No other clothing, including personal clothing from other areas, is washed in the FPR laundry. FPR workers are issued with gum boots, which are cleaned after each use.

4.4.10.2 Respiratory protection

For all areas with ore or tailings dust risk, dust masks are issued. Workers are given instruction on how to wear these, and are instructed to replace them regularly. Rössing Uranium has implemented a clean shaven policy, which dictates that all workers requiring respiratory protection must be clean shaven at all times at work. Respirator fit testing, ensuring respiratory protection is fitted appropriately, is performed for all workers during the periodic medicals.

The FPR area, the SX plant and the Manganese plant are respirator areas. In all areas demarcated and signposted as such, respirators must be worn at all times. In FPR, the specific respirator cartridge used is designed for protection from particulate matter as well as from ammonia. Respirators must be worn in all areas inside the FPR building, which are signposted as such. Respirators are cleaned in the FPR laundry after each use.

The Respirator Workshop maintains respirators where required. Supervisors must ensure that their subordinates are presented to this workshop for respirator servicing at least every two years. Respirators are inspected before being worn by the employee as per instruction. Damaged and defective respirators are to be sent to the Respirator Workshop for maintenance; supervisors also ensure that respirators reach the Respiratory Workshop for routine maintenance, as per the schedule.

As a general rule, respirators must be worn where there is a possibility that the exposure to LLRD exceeds ten per cent of the annual dose limit, or 2 mSv/a. This is the case for the FPR area only, where LLRD concentrations can occasionally reach up to 1 Bq/m^3.

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[18] Only FPR workers are issued with underwear, except for visitors, who are issued with T-shirts but not with underwear.

The use of respirators is carefully supervised to ensure that the expected protection will be provided. Operations and maintenance supervisors must ensure that the respirators are fitted and used properly. Only the type of respiratory protective equipment approved by the Health Management Section may be used.

4.4.11 Ventilation

Ventilation is used to ensure that the worker has an adequate supply of fresh air and is the most effective method of minimising the exposure to airborne radioactive substances. This can be achieved by general or dilution ventilation or by local exhaust ventilation.

Ventilation systems and air quality control equipment, (scrubbers, dust collectors) at the Rössing mine site are designed, operated, and maintained in order to achieve maximum efficiency. Natural ventilation is not be relied on as an effective air quality control method in areas where air contaminants are generated.

In the absence of engineering means of control, operational and administrative means are used to ensure effective protection. In particular, office workers are encouraged to open their windows once a day (except in areas sufficiently close to the crushers that opening windows would increase the risk from inhalation of radioactive dust). This measure is sufficient in most instances to reduce the indoor radon concentrations to outdoor levels. Regular area monitoring of radon levels in buildings helps to identify those areas that require control.

Where ventilation — either by natural means or by ducted air conditioning — is not sufficient to reduce average radon concentrations to below 600 Bq/m^3, the area under consideration is not suitable for permanent occupation during working hours.

4.4.12 Warning signs and their implications

Radioactive materials and radiation sources are signposted and demarcated to clearly communicate the presence of a source of ionising radiation. Signposting must include as a minimum the radiation symbol and any additional information as applicable, such as the type of radioactive material or source.

The sign 'RADIATION CONTROLLED AREA–ACCESS RESTRICTED' indicates that the worker should wear a TLD (thermo luminescent dosimeter) or a direct reading dosimeter if required to work in the area on a regular basis or remain in the area for more than one working day.

4.4.13 Procedure in case of accidents/incidents

Following all accidents/incidents involving radioactive spillage or contamination, or when a radiation dose in excess of 4.6 mSv for a twelve-week period has been recorded for an employee, an investigation into the cause is carried out by the RSO. The RSO will then submit a detailed account of the occurrence(s) to the Managing Director. The detailed report will contain the following:

- the cause for the occurrence
- the radiation dose received by each individual affected
- the measures taken to comply with the requirements of the Director of the NRPA, and
- measures applied to prevent a recurrence.

The RSO will also notify the Director of the NRPA of the occurrence. This provision is in terms of Section 32 of the Atomic Energy Act (2005).

The procedure in case of uranium oxide spillage is detailed in JA60/PRD/009-*Uranium Oxide Emergency Spillage Procedure*.

The procedure in case of an accident/incident involving sources other than uranium (sealed sources) is detailed in JA60/PRC/010-*Sealed source incidents*.

4.5 OCCUPATIONAL MONITORING PROGRAMME

Radiation protection controls are designed to reduce or eliminate exposure risks to the workforce. Regular exposure monitoring serves as a verification of the effectiveness of controls implemented, and quantifies the risks to the various working areas and groups.

4.5.1 Occupational Dosimetry Monitoring programme

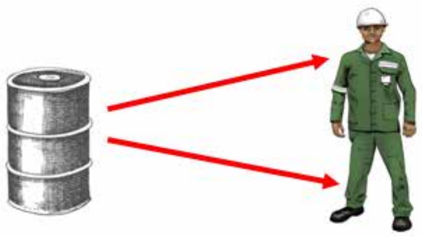
The dose limits specified in Section 4.2 refer to the sum of the relevant doses from external exposure in the specified period and the relevant committed doses from intakes in the same period.

An individual can be exposed to radiation via several possible exposure pathways. The relevant pathways for occupational exposure at Rössing Uranium include:

- direct external exposure to penetrating radiation (mostly gamma radiation)
- internal exposure from the inhalation of LLRD (which can be uranium ore dust, tailings dust or pure uranium oxide dust)
- internal exposure from the inhalation of radon and radon progeny, and
- internal exposure from the ingestion of radionuclides.

The four relevant pathways are summarised in Table 6.

Table 6: Occupational exposure pathways[19]

External	Internal	
Direct (gamma radiation) 	Inhalation: long-lived radioactive dust (LLRD)	
	Inhalation: radon decay products	
	Ingestion	

[19] Permission for using the images in this table, originally from [52], by Jenny Beresford, is hereby gratefully acknowledged.

The total assessed dose for an individual, in mSv/a, is therefore given as [22]:

(Eq 1)

$$Dose = Dose_{ext} + Dose_{radon+thoron} + Dose_{LLRD} + Dose_{ingestion}$$

where

$Dose$	=	total effective whole body dose
$Dose_{ext}$	=	personal dose equivalent from external exposure to penetrating radiation
$Dose_{radon+thoron}$	=	dose from the inhalation of radon and thoron and their progeny
$Dose_{LLRD}$	=	dose from the inhalation of LLRD
$Dose_{ingestion}$	=	dose from ingestion of radionuclides, notably those from the uranium, actinium and thorium decay chains.

The ingestion pathway is excluded by prevention and periodic spot checks (see Section 4.5.3.4) and is therefore not directly measured.

The exposure to thoron progeny is at least an order of magnitude less than that of radon progeny because of the much shorter half-life of thoron [28], and is therefore disregarded at the Rössing mine site.

The total measured dose is therefore reduced to the sum of the first three terms in (Eq 1), and excluding the contribution from thoron.

4.5.2 Dose conversion coefficients

4.5.2.1 Long-lived radioactive dust

The exposure dose as a result of the inhalation of radioactive dust depends crucially upon the chemical and radiological properties of each radionuclide present in the dust mix that is inhaled. For each specific radionuclide, an inhalation dose coefficient can be calculated according to the solubility and aerodynamic size of the inhaled radionuclide. Solubility types S (slow), M (medium), and F (fast) are distinguished. Dose coefficients for specific radionuclides are published in ICRP publications 68 [29] and 71 [30].

The breathing volume for workers is conventionally assumed to be 1.2 m^3 per hour, and the year is assumed to consist of 2,000 work hours [33].

The activity mean aerodynamic diameter (AMAD) of the dust inhaled is assumed to be 5 μm, a conservative size estimate leading to a higher dose estimate than the assumption of 10 μm. Generally speaking, the smaller the particle size, the larger the potential for inhalation of the dust deep into the lung, increasing the radiological risk and hence the potential dose.

The annual dust inhalation dose in mSv is then given by:

(Eq 2)

$$Dose_{LLRD} = DCF \cdot Conc \cdot V \cdot t$$

where

DCF	=	dose conversion coefficient specific to type of dust inhaled, in mSv/Bq
$Conc$	=	specific activity of dust inhaled, in Bq/m^3
V	=	worker breathing rate, ie 1.2 m^3/h
t	=	number of hours of occupational exposure per year, ie 2,000 h.

The dust conversion coefficient is calculated as the weighted sum of dose coefficients contributing to the mix, as explained and demonstrated by the IAEA [22]. All three decay chains need to be considered, where the ratio of activity between the uranium and actinium chains remains a universal constant given by the isotope ratio in natural uranium. The activity ratio between the uranium and thorium chains also needs to be ascertained as this varies locally. At Rössing Uranium, the ratio of uranium to thorium is assumed to be 7.5:1, a ratio that has been verified periodically by radionuclide and geochemical testing of the milled ore[20]. With specific activities of U-238 and U-235 in natural uranium of 12,356 Bq/g and 568 Bq/g respectively, the ratio between the uranium and actinium decay chain specific activities is fixed at 21.75. With a specific activity for Th-232 of 4,060 and a ratio of uranium to thorium of 7.5:1, the activity ratio between the uranium and thorium chains turns out to be 22.9. These ratios demonstrate the fact that both the actinium and thorium chains contribute about an order of magnitude less to the dust conversion coefficient than does the uranium chain. The ore dust is assumed to be in full secular equilibrium.

The resulting dust conversion coefficients are given in Table 7, for ore dust containing a ratio of uranium to thorium of 7.5:1; for pure uranium of types S and M; and for tailings from which 80 per cent of uranium has been removed, respectively.

The absorption behaviour of yellowcake (ammonium diuranate) is consistent with assignment of type M, while

Table 7: Dust conversion coefficient for ore dust containing uranium and thorium, for pure uranium oxide, and for tailings, respectively

	Uranium/thorium ore dust	Pure uranium type S	Pure uranium type M	Tailings
Dust conversion coefficient, mSv/αBq	0.0036	0.0062	0.0018	0.0030

[20] The uranium-thorium ratio in ore has been confirmed by radionuclide analysis in October 2013, performed by IAF Radioökologie GmbH, Dresden.

U_3O_8 displays variation and can be assigned to type S or type M. The final product, calcined uranium oxide, is generally assigned to type S. Both yellowcake and calcined product occur in the Final Product Recovery area. Because of the higher potential dose from calcined product dust, the dust conversion coefficient for uranium dust of type S is used throughout in the FPR area.

4.5.2.2 Radon

The inhalation dose from radon can be estimated by measuring the activity concentration of radon in air (in Bq/m^3) and then calculating the dose by using the equilibrium factor between radon and radon progeny in the inhaled mix. This method results in some inaccuracy however, as the equilibrium factor varies depending on environmental factors such as temperature and air flow and is therefore usually not known precisely. The dose from the inhalation of radon is the therefore best obtained by measuring the activity concentration of radon progeny directly. As radon progeny consists of short-lived solids, this means progeny has to be collected on a filter with an air pumping device; the activity collected on the filter has to be analysed immediately (within two hours of sampling) because of the short-lived nature of progeny.

If measuring progeny directly, the annual dose from radon, $Dose_{radon}$, is given in mSv by [28]

(Eq 3)

$$Dose_{radon} = Conc \cdot DCF \cdot CF \cdot t,$$

where

Conc	=	Equilibrium equivalent concentration of radon in air, in Bq/m^3
DCF	=	Dose conversion factor from potential alpha energy of progeny in air to a dose in mSv per mJh/m^3, ie 1.43 mSv per mJh/m^3 for occupational exposure [28]
CF	=	Conversion factor between equilibrium energy concentration and potential alpha energy concentration, ie 5.56×10^{-6} mJ/m^3 per Bq/m^3
t	=	number of hours of occupational exposure per year, ie 2,000 h.

4.5.3 Personal monitoring techniques

Personal radiation exposure is monitored according to the three major exposure pathways, ie external radiation exposure, and internal radiation exposure from the inhalation of LLRD and radon progeny respectively. The fourth pathway, ingestion, is monitored indirectly via urine sampling (see section 4.5.3.4).

Figure 20: TLD

Personal radiation monitoring is detailed in Procedure JK65/PRD/019-*The Monitoring of Personal Radiation Dose*.

4.5.3.1 External radiation exposure

A - Radiation workers

Employees working in the controlled areas are designated radiation workers (see section 4.4.2). Each radiation worker is registered with the South African Bureau of Standards (SABS) and is issued with a fresh thermo-luminescent dosimeter (TLD, Figure 20) every 12 weeks. Analysis of TLDs is performed by SABS within a week of TLDs arriving at its laboratory.

TLD dosimeters must be worn at all times during working hours. The dosimeter is pinned onto the clothing in the area of the chest (or at waist level for employees handling final product drums).

When off duty, the radiation worker must store the TLD on the TLD board in his or her area that has been provided for this purpose.

The TLD board may be used by the supervisor to check if all TLDs are worn by the crew on duty. The board also allows the quick replacement of TLDs by Radiation Safety at the end of the wearing period and ensures that TLD storage occurs at the same, low-background area for all TLDs of a particular work area.

Dosimeters are regarded as part of an employee's PPE, consequently misuse or any abuse may result in disciplinary action. An investigation is therefore conducted if a dosimeter is lost or damaged.

The Radiation Safety Section issues and collects personal dosimeters and submits them to the SABS for analysis.

TLDs not returned after the nominal wearing period of 12 weeks are automatically assigned an assumed maximum deep dose of 11.5 mSv, which corresponds to the maximum dose of 50 mSv permitted in any year scaled down to the wearing period of 12 weeks. (If the TLD is returned later, this assumed dose can be corrected and replaced with the actual value recorded.)

The TLDs are worn for about four wearing periods per year. Each wearing period is 12 weeks, and TLDs are replaced only when the batch of new TLDs has arrived. If the dose recorded on a TLD exceeds the limit summarised in Table 8, a report is submitted to the NRPA and the work area of the exposed worker is investigated jointly by the line supervisor and Radiation Safety Section.

(See Procedure JK65/PRD/031-*Personal External Radiation Dose Monitoring for Radiation Workers (using TLD)* for instructions for TLD wearers.)

Table 8: Exceedance limits for TLDs

	Deep dose (mSv)	Skin dose (mSv)
Exposure recorded for TLD	11.5	115
Exposure recorded for year	20	500

B - All other workers (non-designated workers)
All workers are grouped into similar exposure groups (SEGs) as described in Section 4.3.3. Workers not designated as radiation workers comprise all groups except FPR and Recovery staff. For each SEG, external exposure of non-radiation workers is monitored randomly using electronic personal dosimeters (EPDs) (see Figure 21). EPDs are issued for six-hour periods (the equivalent of one working day on site). The recorded exposure, in mSv, is then extrapolated to an annual exposure by assuming the working year to be 2,000 hours.

C – Daily dose limit

Consistent with the annual exposure limit of 20 mSv/a, a daily guideline of 80 µSv has been imposed at Rössing Uranium. Dosimeters are set to sound a first alarm at 75 µSv and a second alarm at 80 µSv, at which time the worker has to vacate the area for the shift. The daily limit of 80 µSv can only be reached in selected radiation areas in the controlled area, which therefore usually have time restrictions imposed in order to prevent any employee from reaching the daily exposure limit. Examples of areas where the daily limit may be reached are the CIX plant contactors (on cleaning) and full containers during container packing. Separate procedures for these areas have been developed (JK65/PRD/022-*Container Packing and Strapping, and JK50*/PRD/014-*Maintenance Work Carried Out on the CIX Contactors*), aimed at restricting the radiation dose in these areas to below the daily limit.

The external dose monitoring procedure is detailed in JK65/PRD/020-*Personal External Radiation Dose Monitoring with a Personal Dosimete*r.

4.5.3.2 Internal radiation exposure: LLRD
Inhalation of long-lived radioactive dust (LLRD) is monitored with the SARAD MyRIAM radioactivity in air monitor (Figure 22). The MyRIAM determines the inhalation dose obtained from the exposure to long-living alpha and beta nuclides in the breathing air. The instrument pumps air through an internal filter and analyses the air internally. The dose registered is read from the instrument via infrared link and is recorded with the aid of manufacturer-supplied software.

The calculated dose depends on the weighted dose conversion coefficient (as discussed in Section 4.5.2.1) which has to be entered into the instrument software prior to monitoring. Three different dose conversion coefficients are entered according to the type of dust inhaled (see Table 7 above). It should be noted that the beta dust conversion coefficients are about two orders of magnitude smaller than those for alpha particles, and hence these are disregarded.

Figure 21: EPD instruments

Figure 22: MyRIAM instrument

Inhalation of radioactive dust is monitored randomly in all exposure groups at the mine site.

The exposure measured with the MyRIAM is cumulative, as the dust collected is long lived. Filters on the instrument are replaced once a month and during each month, for every monitoring result, the previous result has to be subtracted, as the dust from previous monitoring events is still on the filter and analysed together with new dust collected. For example, if an exposure of 0.6 μSv is measured and the exposure measured with the same instrument on the previous day was 0.4 μSv, the actual dose recorded for the day is the difference between the two, ie 0.2 μSv. It is important to make sure that the type of dust monitored is consistent (ie the same dust conversion coefficient applies) because otherwise this subtraction will give an incorrect result.

Used filters are stored in the Radiation Safety laboratory for record-keeping purposes; they are labelled according to instrument number and date of filter replacement and kept for a period of one year only (after this, all dose records are finalised and will not be changed).

In FPR, where respirators must be worn at all times, the exposure from LLRD may be divided by the respirator factor of 10. In all other areas, the exposure is recorded as measured, regardless of the respiratory protection used.

Daily monitoring allows the immediate discovery of unsafe dust levels. A daily exposure over six hours of 20 μSv or more would be regarded as high and an investigation into the cause of the exposure would be started immediately.

The detailed procedure for LLRD monitoring is described in JK65/PIN/006-*Personal monitoring of LLRD using the MyRIAM instrument.*

It is worth noting that the dose results obtained using the MyRIAM instrument present a maximum potential dose, as the instruments do not separate out and record the respirable portion of the dust — the dose is obtained from a measurement of total suspended particles instead. The actual dose may be significantly lower as only respirable dust will contribute to the dose.

4.5.3.3 Internal radiation exposure: radon progeny

Exposure to radon progeny is monitored with the SARAD DoseManPro (Figure 23), which determines the exact exposure obtained by the short-living radon daughter products (progeny) in the air breathed. Air is pumped through a filter and analysed internally by the instrument. The dose registered is read from the instrument via infrared link and is recorded with the aid of manufacturer-supplied software.

Because of the short-lived nature of radon progeny, the instrument has a response time of only half an hour and the monitoring result is therefore almost instantaneous. Filters are replaced after one month of use. Used filters are discarded as the collected short-lived radon progeny will have decayed a very short time after sampling.

Figure 23: DoseManPro instrument

Inhalation of radon progeny is monitored randomly in all exposure groups at the mine site.

Daily monitoring allows the immediate discovery of unsafe radon progeny levels. A daily exposure over six hours of 20 μSv or more would be regarded as high and an investigation into the cause of the exposure would be started immediately.

The detailed procedure on monitoring radon progeny is described in JK65/PIN/007-*Personal monitoring of Radon Decay Products using the DoseManPro instrument.*

4.5.3.4 Uranium in urine bioassays

In order to assess and limit the employee internal exposures from uranium, regular urine analyses are carried out for workers most likely to come into contact with soluble uranium compounds. All designated radiation workers must submit a urine sample for analysis at least once each month during their work shift and urine samples must be taken before going on shift. Hands must be washed thoroughly before giving a sample to ensure that no contamination is possible and clothing should be clean. All analysis results are entered in the urine sampling register kept by the Radiation Safety Section.

The mine paramedic, with support from the designated Radiation Protection officer, collects the samples and dispatches them to the Trace Element Analysis

Inhalation of radioactive dust is monitored randomly in all exposure groups at the mine site.

The exposure measured with the MyRIAM is cumulative, as the dust collected is long lived. Filters on the instrument are replaced once a month and during each month, for every monitoring result, the previous result has to be subtracted, as the dust from previous monitoring events is still on the filter and analysed together with new dust collected. For example, if an exposure of 0.6 µSv is measured and the exposure measured with the same instrument on the previous day was 0.4 µSv, the actual dose recorded for the day is the difference between the two, ie 0.2 µSv. It is important to make sure that the type of dust monitored is consistent (ie the same dust conversion coefficient applies) because otherwise this subtraction will give an incorrect result.

Used filters are stored in the Radiation Safety laboratory for record-keeping purposes; they are labelled according to instrument number and date of filter replacement and kept for a period of one year only (after this, all dose records are finalised and will not be changed).

In FPR, where respirators must be worn at all times, the exposure from LLRD may be divided by the respirator factor of 10. In all other areas, the exposure is recorded as measured, regardless of the respiratory protection used.

Daily monitoring allows the immediate discovery of unsafe dust levels. A daily exposure over six hours of 20 µSv or more would be regarded as high and an investigation into the cause of the exposure would be started immediately.

The detailed procedure for LLRD monitoring is described in JK65/PIN/006-*Personal monitoring of LLRD using the MyRIAM instrument*.

It is worth noting that the dose results obtained using the MyRIAM instrument present a maximum potential dose, as the instruments do not separate out and record the respirable portion of the dust — the dose is obtained from a measurement of total suspended particles instead. The actual dose may be significantly lower as only respirable dust will contribute to the dose.

4.5.3.3 Internal radiation exposure: radon progeny

Exposure to radon progeny is monitored with the SARAD DoseManPro (Figure 23), which determines the exact exposure obtained by the short-living radon daughter products (progeny) in the air breathed. Air is pumped through a filter and analysed internally by the instrument. The dose registered is read from the instrument via infrared link and is recorded with the aid of manufacturer-supplied software.

Because of the short-lived nature of radon progeny, the instrument has a response time of only half an hour and the monitoring result is therefore almost instantaneous. Filters are replaced after one month of use. Used filters are discarded as the collected short-lived radon progeny will have decayed a very short time after sampling.

Figure 23: DoseManPro instrument

Inhalation of radon progeny is monitored randomly in all exposure groups at the mine site.

Daily monitoring allows the immediate discovery of unsafe radon progeny levels. A daily exposure over six hours of 20 µSv or more would be regarded as high and an investigation into the cause of the exposure would be started immediately.

The detailed procedure on monitoring radon progeny is described in JK65/PIN/007-*Personal monitoring of Radon Decay Products using the DoseManPro instrument*.

4.5.3.4 Uranium in urine bioassays

In order to assess and limit the employee internal exposures from uranium, regular urine analyses are carried out for workers most likely to come into contact with soluble uranium compounds. All designated radiation workers must submit a urine sample for analysis at least once each month during their work shift and urine samples must be taken before going on shift. Hands must be washed thoroughly before giving a sample to ensure that no contamination is possible and clothing should be clean. All analysis results are entered in the urine sampling register kept by the Radiation Safety Section.

The mine paramedic, with support from the designated Radiation Protection officer, collects the samples and dispatches them to the Trace Element Analysis

Laboratory (TEA-Lab cc) at Swakopmund for analysis. Each batch of samples is accompanied by at least two quality control samples, made up to a concentration of approximately 5 and 10 µg/L of uranium in water respectively. The controls allow an evaluation of the accuracy of the sample analysis to be made.

The reference and action levels for uranium in urine are summarised in Table 9. The circumstances under which an exposure has exceeded the reference level, and the degree to which an employee has been exposed, will dictate at what level of authority the investigation is conducted.

A reference level is not a limit, but is used to determine a course of action where the value of a quantity exceeds — or is predicted to exceed — the reference level.

The urinalysis sampling procedure is detailed in JK65/PRD/002-*Urinalysis Sampling Procedure*.

Table 9: Reference and action levels for uranium in urine

First sample

Reference level	Protective action
0 – 20 µg/L	• Routine monitoring to ensure that this level is maintained
Greater than 20 µg/L and up to 40 µg/L	• Employee's work area and hygiene habits discussed with employee and supervisor • Investigation to be conducted by line supervisor with support from Radiation Safety Section. Report on investigation • Re-sample (in same week)
Greater than 40 µg/L	• Re-sample (in same week) • Investigation by supervisor and Occupational Health Management and supported by Radiation Safety Section. Report on the investigation

Second sample

Reference level	Protective action
0 - 20 µg/L	• Employee and supervisor advised. • No further action.
Greater than 20 µg/L and up to 40 µg/L	• Employee's work area and hygiene habits discussed with employee and supervisor. Investigation to be conducted by line supervisor with support from Radiation Safety section. Report on investigation. • Re-sample (in same week).
Greater than 40 µg/L	• Re-sample (in same week). • Employee's work area and hygiene habits discussed with employee and supervisor. Investigation to be conducted by line supervisor with support from Radiation Safety section. • The Occupational Physician will provide a clinical and kidney status evaluation. • Employee will be removed from work area where exposure may be significant.

Subsequent sample

Reference level	Protective action
0 – 20 µg/L	• Continue with normal sampling (once per month). • Employee may return to normal work.
Greater than 20 µg/L and up to 40 µg/L	• Re-sample on same schedule. • Investigation to be conducted by line supervisor with support from Radiation Safety section. Report on investigation. • Employee to remain under medical surveillance until booked onto his/her normal work by the Occupational Physician.

Table 10: Monitoring Programme for workers

Worker Classification	Exposure type	Pathway	Monitoring strategy	Instrument	Frequency
Designated radiation worker	Internal	Inhalation of dust	Random sampling per SEG	MyRIAM radioactivity in dust monitor	Randomly
		Inhalation of radon and thoron		DoseMan Pro Radon monitor	Randomly
		Ingestion of uranium	All employees, urine sampling	TEA laboratory	Monthly
	External	Direct	All employees	TLD	Continuous
Non-designated radiation worker	Internal	Inhalation of dust	Random sampling per SEG	MyRIAM radioactivity in dust monitor	Randomly
		Inhalation of radon and thoron		DoseMan Pro Radon monitor	Randomly
	External	Direct		EPD	Randomly

4.5.4 Investigation and action levels

Dose equivalent limits are set that will serve to trigger investigation procedures into the cause of the higher doses measured.

The investigations are conducted by the Radiation Safety Section. The investigation levels are as follows:

4.5.4.1 Controlled areas

An investigation is conducted when the estimated annual dose equivalent (monitored by direct reading dosimeter, dust and radon progeny monitoring) exceeds 15 mSv/a. This will be done even if the dose estimation is based on a single measurement, such as the outcome of a twelve-week TLD measurement.

4.5.4.2 Supervised areas

An investigation is conducted when the estimated annual dose equivalent (monitored by direct reading dosimeter, dust and radon progeny monitoring) exceeds 5 mSv/a.

The daily limit for external radiation is 80 μSv, and EPDs are set to sound an alarm if this daily limit is reached. Employees are required to leave the area for the remainder of the shift after reaching the daily limit.

4.5.4.3 Personal external radiation exposure

An investigation is conducted when the monthly personal external dose equivalent (monitored by TLD) exceeds 1.6 mSv, or the 12-week dose equivalent exceeds 4.6 mSv.

4.5.5 Personal radiation monitoring schedule

Workers are classified as either radiation workers or non-classified workers (see Section 4.4.2).

The monitoring strategy for workers is outlined in Table 10. Random sampling is performed according to an annual schedule and the number of samples per SEG and pathway is 30 (or as many as are needed for a representative sample).

In addition to regular sampling, project-related sampling or intermittent investigations of problem areas are performed as the need arises.

A site-wide evaluation of the dependence of radiation dose in each SEG on the shift that was sampled was performed in 2012/13. The details are summarised in report JK15/RPT/001-*Personal Radiation Monitoring for Back Shifts - RUL Report*. The conclusion of this report was that for all SEGs except Recovery staff, only day shift sampling will be used annually as this shift represents the most conservative (largest) dose estimate.

4.5.6 Equipment used for routine monitoring

The equipment used for routine radiation monitoring is summarised in Table 11.

Table 11: Equipment used for radiation monitoring (people and equipment)

Instrument	Purpose	Calibration frequency	Calibration agent
Thermo Eberline HandECount	Read-out of alpha and beta activity from smear samples[21]	Biannual	OEN
Thermo RadEye HEC	Readout of alpha and beta activity from smear samples	Biannual	OEN
Automess 6150	Dose rate monitoring, transport index	Annual	CM Nuclear Systems cc
Thermo Electra	Monitoring of external radiation	Annual	OEN
Thermo Electra with dual DP2R/4A alpha/beta probe	Surface contamination of SCOs (surface contaminated objects)	Annual	OEN
Thermo RadEye SX with dual FLP3D probe	Surface contamination of SCOs, in particular container floor monitoring	Annual	OEN
Thermo RadEye SX with dual DP2R/4A probe	Surface contamination of SCOs	Annual	OEN
Thermo Radeye PRD	Dose/dose rate monitoring; finding and locating radioactive sources	Annual	OEN
Thermo FH40 G-10	Monitoring of external radiation	Annual	OEN
Thermo FH40 G-10 with dual FHZ 742 probe	Contamination monitoring	Annual	OEN
SARAD MyRIAM	Personal radiation in air monitor	Annual	SARAD
SARAD DoseManPro	Personal radon progeny monitor	Annual	SARAD
SARAD Radon Scout	Long-term area monitoring of radon concentrations	Annual	SARAD
SARAD DoseMan	Area monitoring of radon concentrations	Annual	SARAD
Thermo EPD	Personal external gamma exposure monitor	Annual	OEN
Tracerco PED	Personal external gamma exposure monitor, direct reading display	Annual	Tracero UK
Thermo Alpha-7	FPR area monitoring of radioactive dust	Annual	OEN
PARC RGM radon cups	Radon area monitoring	Discarded after use	PARC RGM

[21] Smear samples or 'wipe tests' are used to quantify non-fixed contamination. A specified area is wiped with a filter, and the radioactivity collected on the filter is then analysed in a sample counter.

4.5.7 Area Monitoring programme

Rössing Uranium's Radiation Protection programme follows a hierarchy of controls, using engineering controls where practicable and effective. Administrative controls and PPE are therefore used only when engineering controls are not effective or not sufficient.

The effectiveness of controls is confirmed by monitoring. In this regard, personal dose monitoring is regarded to be the most accurate form of feedback on the effectiveness of controls and is therefore the preferred option.

Where personal monitoring is not possible, or when an area risk assessment needs to be made, area monitoring is used.

For public dose assessments, personal monitoring is not effective as the signal (the public dose) is much smaller than the noise (natural background radiation dose). In this regard, area monitoring can be an effective tool for confirming compliance with the public dose limits.

Activities covered by the Area Monitoring programme include:

- area risk assessment of radon concentrations, particularly in offices;
- area measurements of radon concentrations, both for baselines and for mining-related sites; these measurements are performed in the form of area surveys when conditions have changed sufficiently from those present at earlier surveys;
- area risk assessment of uranium dust concentrations, particularly in the Final Product Recovery area;
- area risk assessment of gamma dose rates to assign time restrictions for dedicated jobs, such as tank cleaning or drum packing, where the daily dose rate of 80 μSv/h may be exceeded;
- area risk assessment of surface contamination, such as contamination levels at FPR, where annual targets are set for the control of contamination levels; and
- area risk assessment of gamma dose rates in the FPR area, where the quantity of full drums in the area affects the dose to people working in the area.

The Area Monitoring programme and the relevant instrumentation is summarised in Table 12.

Table 12: Area Monitoring programme

Area	Activity	Instrument	Frequency
Final Product Recovery	Radioactivity in dust	Alpha-7	Continuous
	Surface contamination of work areas	Smear filters, Thermo HandECount or Electra with dual probe	Weekly
	Dose rate monitoring (external radiation)	Automess	Weekly
All working areas	Radon concentrations	DoseMan, Radon Scout	On demand or as needed
Plant areas – inside tanks, thickeners, contactors, etc	Dose rate monitoring for time restrictions	EPD or PED or Radeye PRD	As per requests, and almost daily

4.6 RADIATION AWARENESS AND TRAINING PROGRAMMES

A prerequisite of starting employment at Rössing Uranium is the completion of the two-week Site Induction programme. A one-hour Radiation Awareness Induction is part of this induction schedule.

In addition to the Site Induction programme, a bi-annual one-hour refresher course is mandatory for all workers on site.

Attendance at this mine-wide training programme is compulsory for all workers. Mine-wide compliance registers are issued monthly in order to remind those who have not attended a session to comply.

Individual training is also presented where necessary. The training programmes offered are summarised in Table 13.

The radiation awareness training (ie the induction and refresher courses) covers the following topics:

- What is radiation;
- What is ionising radiation;
- The main risks associated with ionising radiation;
- Exposure pathways;
- Occupational and public dose limits;
- Background radiation;
- The importance of hygiene;
- Typical radiation exposures at the Rössing mine;
- The relevance of uranium and the uranium decay chains in radioactivity;
- Basic quantities and units used in radiation protection;
- Radiation protection principles (optimisation of protection, dose limits, etc);
- The fundamentals of practical radiation protection, eg use of protective equipment, shielding, behaviour in controlled areas;
- Specific task-related issues;
- Responsibility to advise a designated person immediately if any unforeseen occurrence involving increased radiation risk arises;
- Actions that may need to be taken in the event of an accident;
- What to do in case of pregnancy; and
- Control hierarchy and radiation controls.

The Radiation Safety Section staff should also receive internal or external radiation training on a regular basis according to the requirements set by the NRPA. If they have not already done so, each radiation safety worker is expected to attend and pass all three modules of the RSO training courses offered at the Namibian Uranium Institute (NUI), and those who have completed all three modules are required to attend the RSO refresher at the NUI annually.

Table 13: Radiation training programmes at Rössing Uranium

Training	Workers	Frequency
Sealed Source Training (correct handling techniques, isolation, health and safety procedures for sealed radiation sources)	Isolation officers working in the Processing plant and Primary Crushers	Every 2 years
Radiation Awareness Induction	All employees	Upon starting employment
Radiation Awareness Refresher	All employees	At least every 2 years
Radiation Clearance Training	Rössing Protection Services staff/ Health Management staff/Radiation Protection staff and anyone issuing confined space permits where radiation time restrictions are relevant	Annually and on demand

4.7 HEALTH SURVEILLANCE PROGRAMME

4.7.1 Dose register

Since 2012, personal dose records for workers have only been kept electronically. Personal dose records are recorded annually for all Rössing Uranium employees as follows:

- deep dose based on TLD record for all radiation workers;
- deep dose based on random sampling in all SEG areas, using EPD;
- radon progeny dose based on random sampling in all SEG areas, using DoseManPro;
- LLRD dose based on random sampling in all SEG areas, using MyRIAM;
- for radiation workers: total dose given as the sum of TLD gamma dose, and the sum of the average radon and LLRD dose results for the relevant SEG;
- for all other workers: total dose given as the sum of the average gamma, radon and LLRD dose results for the relevant SEG; and
- ninety-five per cent confidence level given for the total dose, based on the statistical range of the individual contributions measured.

Personal dose records are communicated to the NRPA annually. In addition, cumulative dose records are calculated for an employee after termination of his/her employment at Rössing Uranium; these records are communicated to the employee after termination, and are reported to the NRPA annually.

The Rössing intranet offers a tool allowing each worker to access their personal dose records, as well as their urine sampling results. Only their personal dose results are accessible to each person, but supervisors are able to also access urine sampling results of their direct reports. This ensures that supervisors can ensure compliance with the requirement of monthly urine sampling for all radiation workers.

Every register kept is preserved and kept available for inspection for 50 years. Dose records prior to 2012 are available as printed records in the Radiation Safety Section.

The Occupational Physician has access to the electronic radiation worker exposure data at all times. The TLD results are kept in the folder:

K:\HSEMS\HSE\Radiation Specific\Historical Dose results\4 Statistics\"year"\TLD\TLD"year".xls, and the annual exposure per SEG is kept in the folder K:\HSEMS\HSE\Radiation Specific\Historical Dose results\Whole Body Dose\"year"\SEG"year".xls.

4.7.2 Medical surveillance

All designated radiation workers (whether they are Rössing Uranium employees or contractors) are examined prior to appointment or employment as prescribed above, and as laid down in the *Rössing Medical Standards*. The term 'first employment' means first employment as a designated radiation worker and also re-employment followed by any cessation of such employment for a period exceeding 12 months.

The designation 'radiation worker' is linked to a specific role, not to a person. This means that each time employees move into or out of a radiation worker position, this fact is flagged for action by the Human Resources Section, thus enabling prompt action to register and de-register radiation workers, as per role requirement. The list of positions registered as radiation worker positions is summarised in Procedure JK65/PRD/032-*Radiation Worker Control Requirements at RUL*.

Designated radiation workers are examined at regular intervals as determined by the Occupational Physician, provided that the medical examinations are conducted:

- At intervals of not more than six months for designated radiation workers as long as employment as a designated radiation worker continues.
- At intervals of not more than 12 months for all workers in the SEGs: Engineering Workshop workers; Mine Maintenance Workshop workers; Field workers; Tailings Dam operators; Lab workers, Extraction staff, Reduction staff, Pit Equipment operators; and Pit Field workers.
- At intervals of not more than 24 months for all workers in the SEGs: on-site Office workers; Processing Office workers; and Mining Office workers.
- Where over-exposures to radiation are expected or have been established.
- At such other times as the appointed Occupational Physician deems it necessary, at his/her discretion.

All designated radiation workers are required to submit themselves for medical examinations in accordance with the provisions of these conditions.

Any person who has been employed previously as a designated radiation worker elsewhere is required to provide details of such employment in respect of accumulated doses of radiation (external and internal) and the name and details of his/her previous employer.

4.7.3 Medical examinations

In the interest of the health of employees, Rössing Uranium requires that employees undergo medical examinations in the following instances:

- prior to employment;
- periodically during employment;
- upon termination of employment; and
- when a designated radiation worker has received an over exposure.

4.7.3.1 Pre-employment

All prospective employees are required to undergo a medical examination by a company-appointed or approved doctor. Offers of employment are subject to medical clearance by the Occupational Physician.

Where any limitation of employee benefits is imposed arising from the pre-employment medical examination, such limitation will be specified in the formal offer of employment and accepted in writing by the prospective employee.

4.7.3.2 Periodic

All employees must undergo a compulsory periodic medical examination at intervals determined by the Occupational Physician and based on the occupation and environmental assessment of the working area of the respective employee, but not less frequently than every two years.

Examinations are conducted at company expense by company-approved medical practitioners. If a person is transferred from one area to another, medical clearance has to be obtained.

4.7.3.3 Termination of employment

Each employee terminating his/her services with the company will undergo a medical examination, on or immediately before the employee's last working shift.

4.7.3.4 Over exposure

When an over exposure to radiation has been noted and the Occupational Physician notified, an examination of the effects of the radiation on the designated radiation workers concerned will be conducted.

In the case of an exceedance of the uranium in urine action level (40 µg/L), the following procedure applies:

- collect another urine sample for uranium (see also Section 4.5.3.4);
- collect a urine sample for
    - micro albuminuria
    - B2 microglobulin in urine+;
- investigate occupational hygiene practices
- go for medical examination to check BP, U&E, fasting glucose, and urine dipstick;
- repeat urine for micro albuminuria and B2 microglobulin after one month in selected cases with abnormalities;
- return to high exposure work only if above results are normal; and
- workers are not to return to a high exposure area if the above markers of preclinical kidney involvement remain abnormal but must be permanently deployed in a low risk area.

4.7.3.5 Temporary employees

All temporary employees are required to undergo radiological examination of the chest prior to employment and chest X-rays are taken on site at a pre-arranged time. Employees who are going to work in a controlled area must undergo a full examination before employment and upon termination of employment. Temporary employees who spend more than three months of the year on site must undergo a full medical examination before employment and upon termination of employment.

4.7.4 Medical records of radiation exposure doses

From 2012 onwards, the medical records of each employee, including contractors where medical records are available, have included a dose assessment for the year elapsed. These records are recorded as follows (see also Section 4.7.1):

- Registered radiation workers: total deep (external) dose in mSv is recorded for each wearing period of 12 weeks and the total external dose is recorded in the medical records of each radiation worker. In addition, the 95 per cent confidence level for the combined internal dose (originating from the internal radon progeny dose and the internal dose from LLRD) is recorded.
- All other workers: a total combined radiation exposure dose is recorded for each worker. The dose comprises the 95 per cent confidence level for the combined external (gamma) and internal (radon and dust) exposure dose. The dose for workers not registered as radiation workers is obtained from the combined monitoring records for the SEG in which the worker is employed.

4.8 MANAGEMENT OF DOSE RECORDS

All TLD (external dose) and uranium in urine results for the years prior to 2012 are stored in a dose register (hardcopy) kept by the Radiation Safety Section and in electronic form for the years after 2012. The reports sent by external laboratories are stored in folders on the company's network system. All external doses obtained by electronic dosimeters and radon and radioactivity in dust results are also stored on the company's network system.

Records are kept for such periods as prescribed by the NRPA.

4.9 REGULATORY REPORTING REQUIREMENTS

Personal radiation monitoring data are reported to the NRPA as detailed in Table 14.

Table 14: Personal monitoring data reporting to NRPA

Data	Type of data	Method of monitoring	Frequency	Reporting frequency
External radiation exposure	Personal	TLD	12 Weekly	Yearly
External radiation exposure	Per SEG	EPD	Monthly	Yearly
Internal radiation exposure: radon progeny	Per SEG	DoseManPro	Monthly	Yearly
Internal radiation exposure: LLRD	Per SEG	MyRIAM	Monthly	Yearly
Total exposure	Per SEG		Monthly	Yearly
Total cumulative dose on terminating employment	Personal			Yearly

Furthermore, the following will be reported annually (Table 15):

Table 15: General data reporting to NRPA

Data	Type of data	Method of reporting	Reporting frequency
Sealed sources	Location, activity	Annual audit and included in narrative report	Yearly
Product exports (U_3O_8)	Quantity, destination, chemical composition, transportation route	Spreadsheet from Corporate Finance Section and included in narrative report	Yearly
Hazardous waste register	Location, quantity deposited, total accumulated	Spreadsheet	Yearly
Transport of radioactive materials	Quantity, type and activity of material transported, destination	Spreadsheet	Yearly
RMP implementation: narrative report	Summary of all reportable data	Narrative report	Yearly

5 PUBLIC AND ENVIRONMENTAL EXPOSURE PROTECTION PROGRAMME

5.1 PUBLIC DOSE LIMITS AND CONSTRAINTS

Monitoring and modelling programmes are carried out to determine the natural background radiation levels; the enhancement of these background levels due to the mining operations; and the associated radiological doses to members of the public. The public dose assessments that have been completed to date are detailed in Section 2.2.

The company ensures that the effective dose equivalent to members of the public as a result of its operations is limited according to the recommendations of the ICRP [27], and as issued in the *Radiation Protection Regulations* [37]:

Table 16: Public dose limits

Tissue	Annual dose limit (mSv)
Effective whole body dose	1 mSv in one year[22]
Equivalent dose: • skin • lens of eye	 50 mSv 15 mSv

In accordance with Namibian legislation, the optimisation of the radiation safety measures is intended to satisfy the condition that the resulting doses to individual members of the public do not exceed dose constraints that are equal to the dose limits specified in the *Radiation Protection Regulations* [37], or any lower values as may be established by the NRPA. Furthermore, Rössing Uranium's Radiation Protection programme is committed to a public dose constraint that is equal to a third of the current public dose limit — but in any case the total public dose from all operations combined should never exceed the public dose limits as specified above.

5.2 PUBLIC EXPOSURE PATHWAYS

Exposure of members of the public to ionising radiation as a result of uranium mining can potentially occur along three possible pathways: the aquatic pathway, via atmospheric dust, and via radon gas. The direct pathway — direct exposure to gamma radiation — is not significant as long as members of the public do not access the mining sites and the transport and storage of product containers does not impact areas that are accessible to the public.

5.2.1 Groundwater: the aquatic pathway

Pollution of groundwater can occur through:

- dissolution and leaching into groundwater of radionuclides in tailings, ore and waste rock dumps;
- underground migration of seepage from tailings; and
- deposit of radioactive materials on soil surfaces and subsequent dissolution in groundwater.

Radionuclides in groundwater can then lead to the uptake of radioactive material through direct water consumption, or through the consumption of crops that have been irrigated with the groundwater, or by the ingestion of animal products from animals using the groundwater as drinking water. Assuming a groundwater concentration of radionuclides, the following processes are then relevant:

- irrigation of crops and subsequent crop ingestion by humans;
- irrigation of crops, ingestion of crops by animals, and subsequent ingestion of animal products by humans;
- water ingestion by humans;
- irrigation of soil and accidental soil uptake by humans and animals; and
- irrigation of soil and direct irradiation of humans from soil.

[22] A higher value of the effective dose is allowed in a single year provided that the average over five years does not exceed 1 mSv/a.

The groundwater pathway is summarised in Figure 24. Van Blerk [48] performed a comprehensive investigation of the groundwater pathway relevant to Rössing Uranium. Since contamination of groundwater could occur by way of seepage from Rössing Uranium tailings, a system of de-watering trenches and cut-off trenches provides efficient means of controlling the spread of water contamination into the Khan River [14]. This system of trenches is intended to prevent seepage through Dome Gorge, Pinnacle Gorge and Panner Gorge into the Khan River; additional possible seepage through bedrock is monitored on a continuous basis by monitoring borehole water quality (see Section 5.7.1).

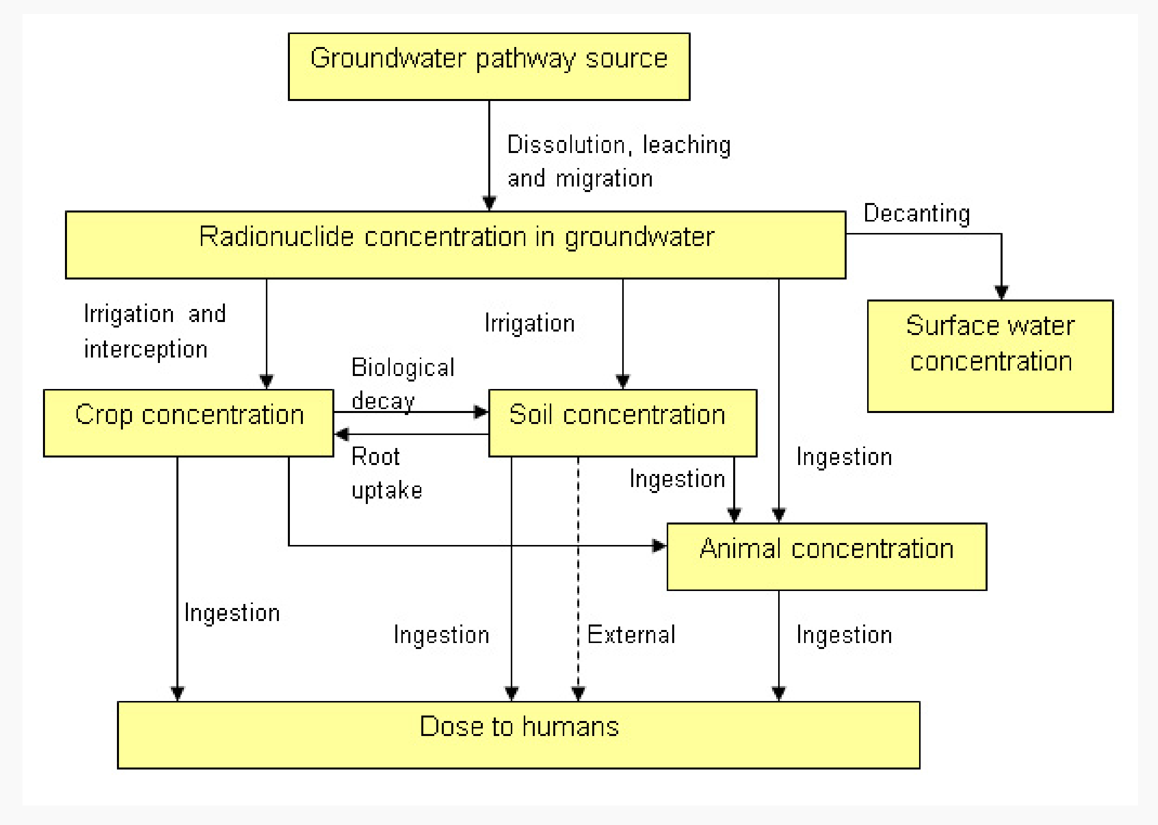


Figure 24: Schematic representation of the pathways and processes associated with the uptake of radionuclides from groundwater.

5.2.2 Long-lived radioactive dust: the atmospheric dust pathway

Fugitive dust sources at the mine site are mainly: the tailings dam surfaces; waste and ore stockpiles; the open pit (particularly during blasting); unpaved roads; and areas where fine particles from seepage are deposited. The exposure of humans to LLRD can occur internally through inhalation of dust; externally through direct irradiation from dust; or by deposition of dust on soil surfaces and subsequent uptake through the food chain. Assuming a concentration of fugitive radioactive dust, the following processes are then relevant:

- inhalation of dust (internal irradiation);
- external irradiation through dust;
- dust deposition on soil, uptake of radionuclides from soil, and subsequent crop ingestion by humans; and
- dust deposition on soil, uptake of radionuclides from soil, crop ingestion by animals and subsequent ingestion of animal products by humans.

The atmospheric dust exposure pathway is summarised in Figure 25. De Beer [10] performed a comprehensive study of public exposures along the atmospheric dust pathway. The main component of exposures along this pathway is likely to be direct inhalation, as the low ore grades preclude significant external exposure as a result of dust, and both drinking water and food are sourced mainly from areas far away from the mine.

5.2.3 The atmospheric radon pathway

Radon exhalation — in addition to the natural radon exhalation of the area — is sourced mainly at the TSF, which contains finely-ground particles with maximum surface area from which radon can escape to the environment. Further sources of increased radon

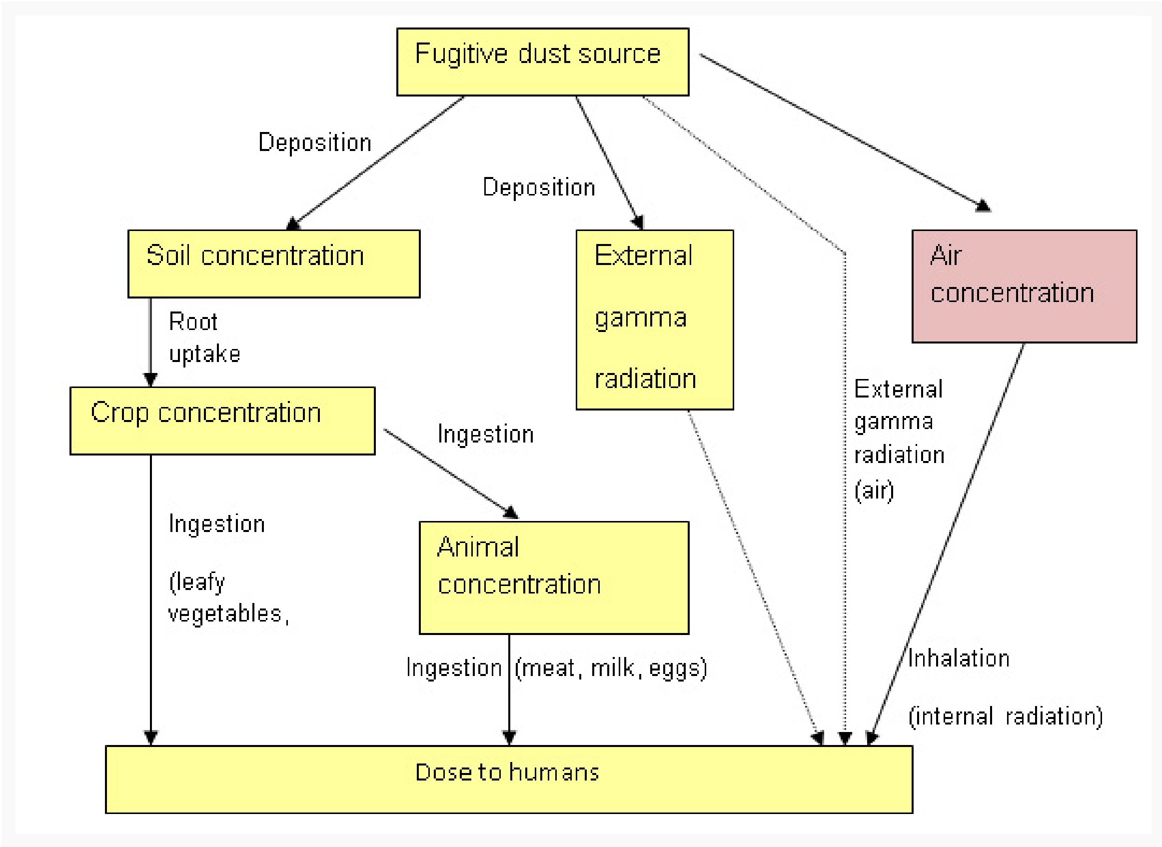


Figure 25: Schematic representation of the atmospheric pathways associated with the uptake of radionuclides from dust.

exhalation are the waste and ore stockpiles, seepage areas, crushing circuits, and open pit areas. Exposure to radon (Rn-222), thoron (Rn-220), and their daughter products can be by external irradiation or internal irradiation after inhalation. The atmospheric pathway for radon is summarised in Figure 26 [10].

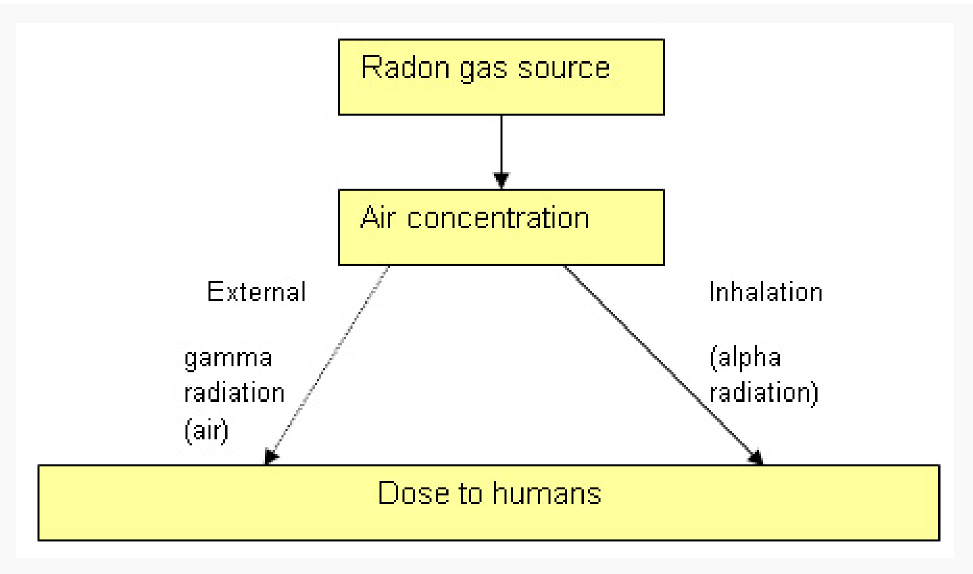


Figure 26: Schematic representation of the atmospheric pathways associated with the exposure to external and internal radiation from radon gas.

5.3 RECEPTORS AND CRITICAL GROUPS

Receptors are those people who can potentially receive a radiation dose from mining-related sources via the three pathways specified. By definition, the critical group comprises the group of people that can be reasonably expected to receive the highest dose from a source and pathway under consideration.

5.3.1 Groundwater: the aquatic pathway

The critical group is represented by communities farming in the Khan or Swakop river areas and that meet the following conditions:

- people consuming borehole water for (some of their) drinking needs;
- people consuming crops produced using borehole water for irrigation; and
- people consuming animal products from animals raised using borehole water for drinking and fed crops produced using borehole water for irrigation.

The effective dose as a result of ingestion of radionuclides via the groundwater pathway depends on the following factors:

- radionuclide concentration and chemical composition of seepage;
- subsurface and surface flow velocities of waterways;
- age distribution of critical groups;
- percentage of consumption of own grown crops versus crops imported from elsewhere;
- percentage of borehole water used for drinking, versus purchased bottled water (the water in the Swakop and Khan rivers is brackish and often not suitable for drinking purposes);
- percentage of animals and animal products consumed versus animal products sourced elsewhere; and
- state of equilibrium between water and soil relating to radiological activity (water and soil may take hundreds of years to reach a state of equilibrium).

The contributions of processes such as biological decay and animal excretion to the soil can be regarded as insignificant [48]. Similarly, activities such as food preparation and washing can also be disregarded as insignificant.

The effective dose to the public can be calculated from the concentration of radionuclides in water, taking into account the factors detailed above and using the relevant dose conversion factors for the respective radionuclides, which have been published by the ICRP [31].

5.3.2 Atmospheric pathways

The critical groups for both atmospheric pathways are represented by:

- the Arandis community;
- a hypothetical community living at Arandis Airport; and
- a hypothetical community living at the old Khan Mine.

For an assessment of the dose to humans resulting from fugitive dust, the following factors have to be considered:

- sources of dust;
- chemical composition and particle size distribution of dust;
- radionuclide content of dust;
- meteorological conditions such as wind speed and wind direction;
- age distribution of critical groups;
- rate of uptake of radionuclides by different crops from deposited dust;
- percentage of consumption of own grown crops versus crops sourced from elsewhere;
- percentage of animals and animal products consumed versus animal products sourced from elsewhere; and
- percentage of milk and milk products produced by own cattle versus products sourced elsewhere.

Dust emissions can be controlled to a considerable degree: for example, spraying roads in the open pit areas reduces dust spread by haul trucks; containing crushing plants within buildings reduces the amount of dust spread to the environment; and keeping the surface of the tailings dam moist can further reduce the hazards presented by fugitive dust. Another remediation option for tailings dams after mine closure is presented by covering the tailings dam areas with a layer of rock to prevent any dust from escaping the surface. Seepage areas, which also present a dust hazard after drying up, can also be covered with rocks after mine closure.

For an assessment of public dose as a result of radon emissions from mine sites, the following information is required:

- radon exhalation rates at various sources;
- meteorological data (wind speeds and directions); and
- local topology in the area surrounding the radon exhalation.

Detailed atmospheric dispersion modelling is required to fully evaluate the distribution of radon from its sources to areas of concern, such as towns and villages, and also for impacts of dust containing long-lived radioactive nuclides.

5.4 RADIATION TYPES ALONG EXPOSURE PATHWAYS

For external exposure, only gamma and beta radiation is relevant, as alpha radiation does not pass through human skin. For internal exposure, all three types of radiation have to be considered. However, for inhalation, alpha radiation is by far the most ionising type of radiation and beta and gamma radiation can often be disregarded by comparison. For external whole body dose, only gamma radiation is relevant as beta radiation does not penetrate further than skin deep.

The relevant critical groups and the corresponding primary exposure types are summarised in Table 17.

5.5 CONTROL OF VISITORS

Visitors are classified as members of the public and hence should not be exposed to an annual radiation dose as a result of the mining practices exceeding 1 mSv/a.

Visitors are issued with the PPE prescribed for the area of the visit; visitors to the controlled areas are issued with electronic dosimeters. Eating and drinking is not allowed, except in the approved lunch rooms; hands must be washed before eating and drinking. Smoking is not allowed except in approved areas, and hands must be washed before smoking.

Contractors are regarded as workers, for whom the annual dose limit of 20 mSv/a applies. Contractors are required to wear the PPE prescribed for the area of their work, including the respirators approved by Rössing Uranium where these are prescribed for the specific area.

All protective equipment and clothing is supplied to visitors or contractors by Rössing Uranium.

5.6 PUBLIC DOSE ASSESSMENTS

Public dose assessments are performed for each mine extension, and for each mine closure plan. The dose assessments require the consideration of detailed information about the exposure pathways, critical groups, meteorological conditions, and source terms for groundwater contaminations, dust emissions, and radon exhalations. External consulting companies are customarily employed to perform public dose assessments based on the data provided by Rössing Uranium and are required to submit detailed reports specifying the procedure followed and methods of assessment. Section 2.2 summarises the public dose assessments completed so far.

Table 17: Exposures, critical groups and exposure pathways for members of public

Critical group	Exposure pathway	Exposure type
Community at Arandis	Atmospheric	Internal (alpha)
Residents at Arandis Airport	Atmospheric	Internal (alpha)
Farming community at confluence of Khan River and Dome Gorge (hypothetical)	Atmospheric, aquatic	Internal (alpha)
Farming community at confluence of Khan River and Panner Gorge (hypothetical)	Atmospheric, aquatic	Internal (alpha)
Residents living at the old Khan Mine	Atmospheric	Internal (alpha)
Residents of Swakop River farms	Aquatic	Internal (alpha)

5.7 PUBLIC MONITORING PROGRAMME

Public dose assessments are based on knowledge of the emissions from mining operations, such as excess dust and radon, and groundwater contamination. Subsequent monitoring programmes are designed to confirm and quantify the emissions, and to correct the dose assessments if required. Monitoring includes measurements of air quality (radon and dust concentrations) and water quality, as described below.

5.7.1 Water monitoring

Monitoring of radionuclide content of borehole water quality is performed in accordance with the management of tailings seepage, specified in Section 9.4.3.

Water from monitoring boreholes is analysed for concentrations (in Bq/L) of the uranium radionuclides U-238, U-234 and U-235. The ratio of activities of U-238 to U-234 allows an analysis of the origin of the sampled water, ie if originating from freshly extracted uranium or from natural environmental sources. In freshly extracted uranium, U-238 and U-234 are in secular equilibrium whereas the equilibrium in river water sources is usually disturbed as a result of the alpha recoil effect[23].

Of the roughly 150 monitoring boreholes (see map in Figure 27), the same 26 are monitored every year (see positions marked in Figure 28, and listed in Table 18), while for the remaining boreholes the monitoring programme follows a rotating schedule.

Borehole monitoring at Rössing Uranium is used to produce a map depicting the seepage plume around the TSF. An example of the plume is shown in Figure 28.

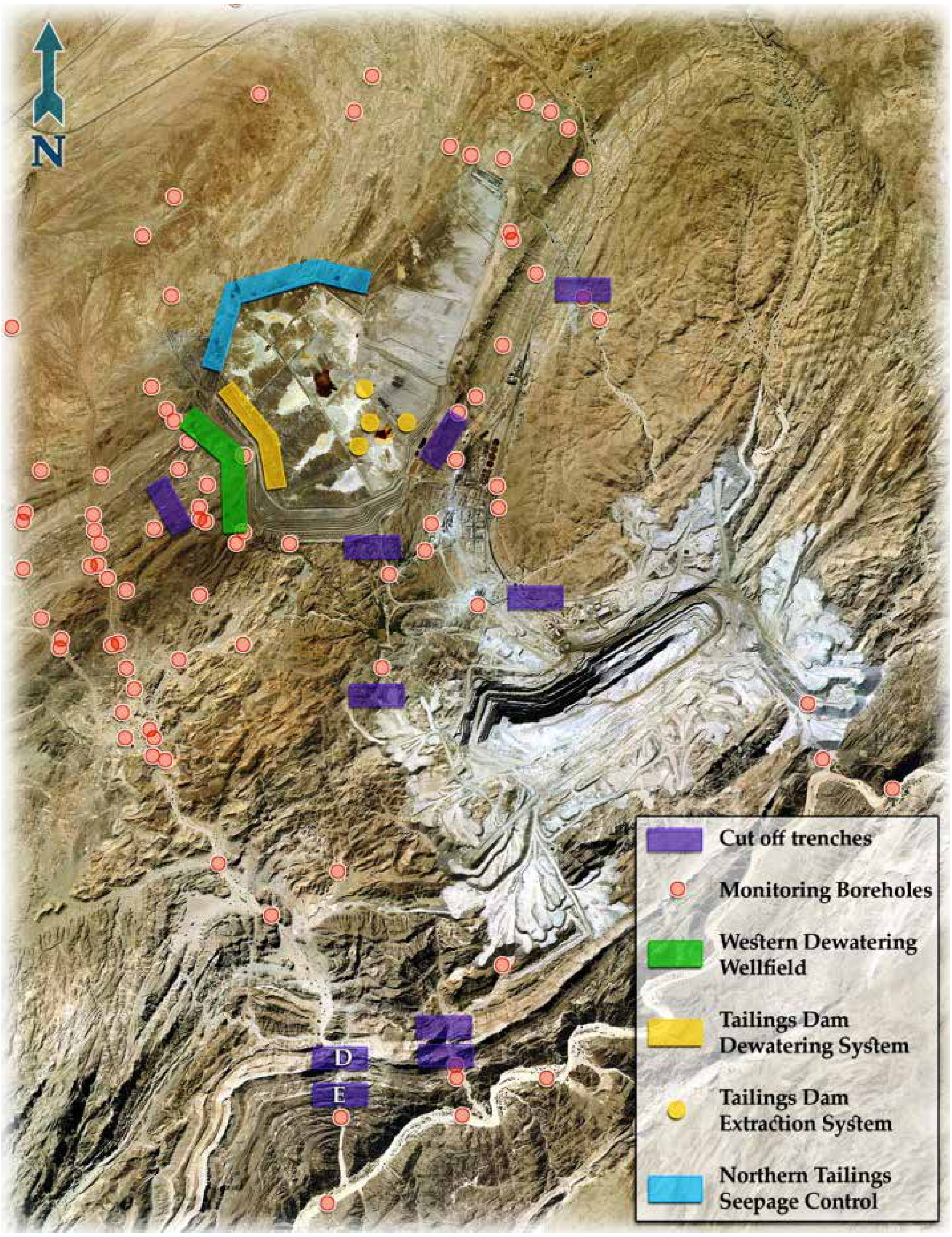
The sampling criteria, frequency, and method are detailed in Procedure JE65/OWM/004 R7-*Water Quality Monitoring.*

Table 18: Rössing boreholes used in radionuclide sampling

Site name	Longitude (deg E)	Latitude (deg S)	Type
Tailings dam (ie TSF)			Surface water
Seepage dam			Surface water
1.4A	15.5252	22.0762	Monitoring
1.6A	15.5655	22.0273	Monitoring
DG1	15.5223	22.0736	Production
G27121	15.5133	22.0327	Monitoring
J	15.5309	21.9925	Monitoring
L01	15.4767	22.0136	Monitoring
L06	15.5375	22.0224	Monitoring
L07	15.5323	22.0177	Monitoring
L08	15.5222	22.0128	Monitoring
L09	15.5132	22.0093	Monitoring
L13	15.5111	22.0032	Monitoring
L18	15.5191	22.0114	Monitoring
L19	15.5200	22.0092	Monitoring
N01A	15.4884	22.0400	Production
N08	15.4797	21.9989	Monitoring
R1	15.4956	22.0433	Monitoring
T1	15.4748	22.0183	Monitoring
Trench C	15.5477	22.0386	Production
Trench D	15.5548	22.0286	Production
Trench E	15.5502	22.0286	Production
Trench H	15.5064	22.0480	Production
X04A	15.5101	22.0029	Monitoring
X08	15.4767	22.0136	Monitoring
X19	15.4943	22.0070	Monitoring
X21	15.5204	21.9937	Monitoring
KMS	15.5651	21.9962	Surface water

[23] As an alpha particle is ejected in alpha decay, the daughter nuclide recoils in the opposite direction and moves a distance of about 550 angstroms in a typical mineral. This recoil causes a fraction of the daughter nuclides produced during a decay to be ejected from the host mineral into the surrounding medium. An additional fraction of the daughter is left residing in damaged crystallographic sites within the mineral, from where it can be more readily mobilised. Alpha recoil therefore gives daughter nuclides of alpha decay a tendency to leave their host mineral by a process that is independent of their chemistry. Alpha-recoil is most important in preferentially releasing U-234 from minerals over U-238, but also plays a role in mobilising other nuclides. Consequently, the ratio of U-238 to U-234 in natural sediments, which have been exposed to the environment over long periods of time, is generally less than 1 and typically on the order of 0.8. However, freshly extracted uranium, which originates from unexposed rock, usually contains the uranium isotopes from the uranium chain in secular equilibrium, ie at a fraction of around 1. This circumstance allows a conclusion as to the origin of borehole water: a ratio of 1 indicates freshly extracted uranium, whereas a ratio closer to 0.8 indicates the origin as natural sediments.

Figure 27: Location of monitoring boreholes at the Rössing mine site



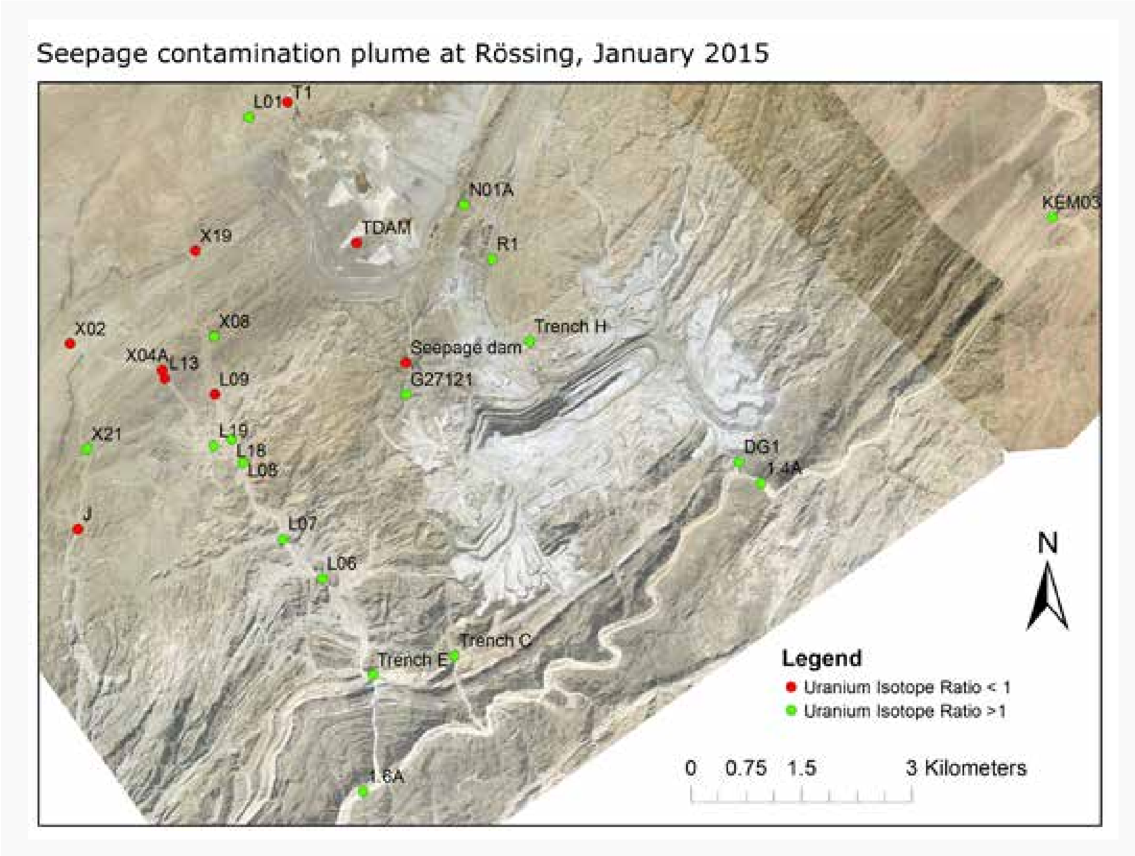


Figure 28: Extent of the uranium plume in year 2015: uncontaminated groundwater is shown in green, and contamination is indicated in red.

5.7.2 Radon monitoring

Baseline and mining-related radon concentration measurements are conducted at regular intervals and form part of the public dose assessments discussed in Section 2.2.

The most recent area monitoring programme for the assessment of radon concentrations was completed in 2013. The method followed was similar to that of earlier assessments, ie a grid of monitoring positions 1 to 2km apart covering a 16 km by 16 km area with the mining area at the centre was defined. Radon cups (RGM track etch monitors) were placed on grid positions for periods of between three to six months and the total duration of the survey was three years.

The resulting radon concentration profile is described in detail in the summary report [50]. A contour map of measured radon concentrations is shown in Figure 29.

A much simpler but very effective public dose assessment can be obtained from active radon measurements obtained from the *Strategic Environmental Management plan* (SEMP) station, operated by the Geological Survey of the Ministry of Mines and Energy. An Alphaguard instrument, located at the NamWater reservoir close to Arandis, records concentrations of radon and radon progeny at intervals of ten minutes. Radon concentrations can therefore be correlated with meteorological data obtained for the weather station at Point Bill on the TSF, at a distance of 3 km from the radon station (which is available at intervals of five minutes).

Figure 29: Three-dimensional image of radon concentration overlaying a map of the Rössing Uranium site. The broader peak is on top of the open pit and waste dumps, while the steepest peak marks the tailings area.

The basic principle is illustrated in Figure 30: radon concentration data can be correlated with the wind direction to establish which data points correspond to a wind direction from the mine site towards the radon station.

This monitoring was done for the radon data available from the years 2011 until 2014, and the public dose as a result of mining-related radon was found to be 0.02 mSv/a, less than statistically measurable.

5.7.3 Dust monitoring

Dust collected at the locations for critical groups can be analysed for radionuclide concentration, in Bq/g. The radionuclide content of dust is known from the *Radiation and Air Quality Theme Report in the Strategic Environmental Assessment (SEA) for the Central Namib Uranium Rush* [36], allowing a dose assessment to be made from concentration measurements of dust in air.

An *Air Quality Management plan* (JE20/MMP/004) guides the management of environmental dust at Rössing Uranium. Air emissions are listed in an inventory and all air quality standards applied at Rössing Uranium are documented.

In short, improvements of the air quality management practice at Rössing Uranium aim at:

- a refined understanding of Rössing Uranium's dust footprint, in correlation to wind regime;
- a review of the existing sources of emissions from mining operations;
- characterising ambient air quality;
- a better understanding of the correlation between blasting and its impacts – dust, noise, and vibration;
- a better comprehension of atmospheric impacts on the biosphere; and
- a review of control measures to recommend additional measures, if necessary, and mitigation measures to manage air quality better.

The dust monitoring methods followed are summarised below:

5.7.3.1 Dust fallout buckets

Fallout dust is measured with dust fallout buckets (Figure 31), which are located in a transect running in a south-westerly direction from the TSF, ie approximately downwind from the TSF in the prevailing wind direction during East Wind. The first fallout bucket is located at the south-western edge of the TSF. A set of 7 additional buckets is located in a line to the south-west of the first bucket, at approximately 250 m apart.

Figure 30: Satellite image displaying Rössing Uranium mine site, radon monitoring station at Arandis, and Arandis town. The wedge indicates the direction from the mine site towards the radon monitoring station, including wind directions which may result in radon concentrations above background at the station.

Figure 31: Dust fallout bucket

Dust fallout buckets are emptied monthly. The trend in the quantity of dust collected in each is used to quantify the amount particulate matter blown from the TSF, and its dependence on distance from the TSF.

5.7.3.2 Multi-vertical samplers

Seventeen multi-vertical samplers (Figure 32) are located on the south-western edge of the TSF, downwind of the TSF in the prevailing wind direction during winter, as shown on the map in Figure 33. These samplers consist of 24 sample bottles stacked on top of each other, with a sampling slit facing towards the TSF. Samplers are assembled each year in May, and disassembled for analysis during September each year. Results from this sampling method are used to quantify the amount of tailings dust blown from the TSF during East Wind conditions, and to obtain a trend of the amount of material blown from the TSF with altitude.

Figure 32: Multivertical dust sampler

Figure 34: PM10 E-sampler

5.7.3.3 PM10 samplers

A PM10 sampler (Figure 34) is located at Arandis, and another on the western site boundary. Dust collected is analysed for total suspended dust and also for the inhalable portion (PM10) of dust.

Data from the PM10 sampler at Arandis is used to confirm the validity of public dose assessments.

Throughout 2013, the average PM10 dust levels measured at Arandis were consistently lower than the WHO standard of 0.05 mg/m^3 (with an average of 0.013 mg/m^3), as can be seen in Figure 35.

Assuming secular equilibrium and a concentration of 7 ppm uranium in dust at Arandis[24], and using the dust conversion coefficient for uranium ore (see Table 7) and a public breathing rate of 0.9 m^3/h [33], this amounts to an annual public dose (including background) of 15 µSv/a, which is an insignificant dose.

In addition to the PM20 E-samplers at Arandis and at the western mine boundary, two additional PM10 samplers will be installed in 2014: one at the south-western edge of the TSF, and one at the Contractor Management Centre (CMC), about a kilometre from the north-eastern edge of the TSF. These PM10 samplers will help to quantity the difference between environmental dust (which will be the prevailing type of dust collected at the CMC) and dust originating from the mine (which will be the prevailing type of dust collected at the sampler on the south-western edge of the TSF).

5.7.3.4 Osiris monitors

Dust emission at the crushers is monitored with Osiris dust monitors. These instruments record the total particulate dust as well as the PM10 and PM2.5 portions in the dust.

Figure 33: Location of multi-vertical samplers on TSF.

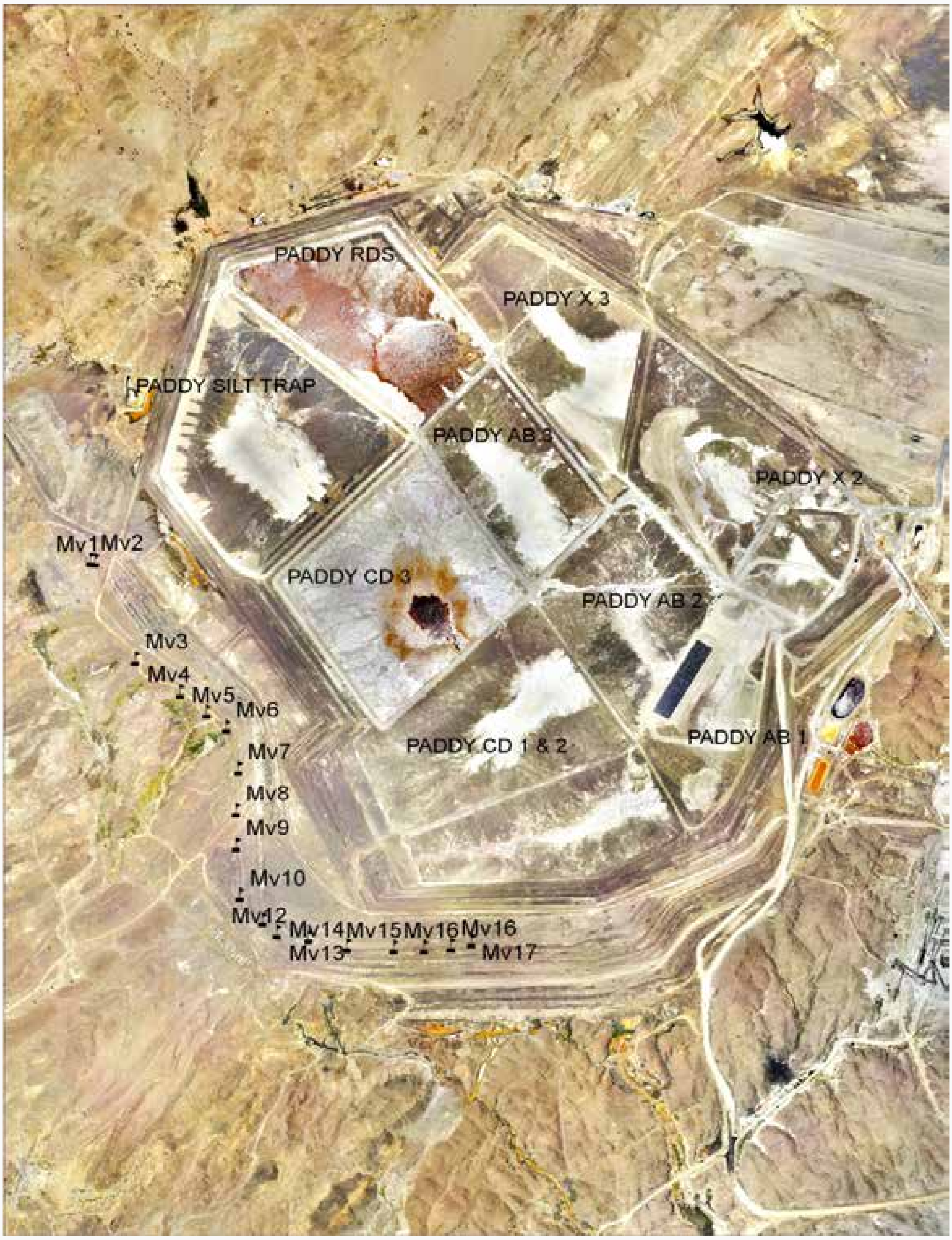
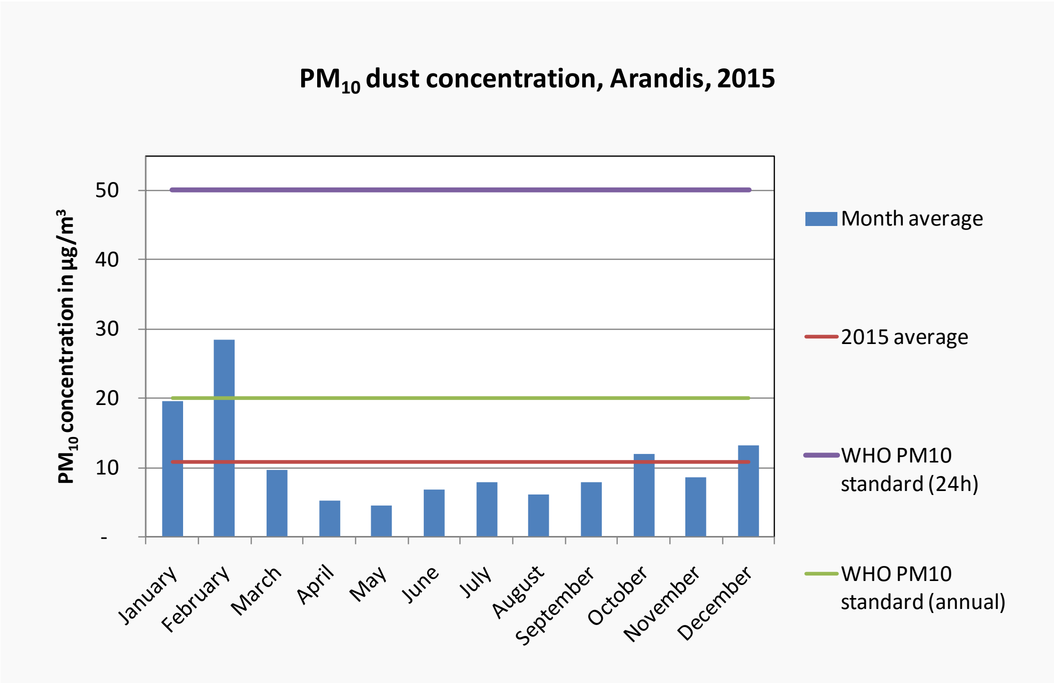


Figure 35: PM_{10} dust concentrations measured at Arandis in 2015.



Data from the Osiris monitor at fine crushing is used to determine on site air quality and to quantify if additional control is needed.

5.7.3.5 Stack monitoring

In addition, emissions from the FPR stacks are monitored by external consultants yearly. Quantities measured are:

- Gas velocity in the system;
- Gas volumetric flow rate both actual and calculated at standard temperature and pressure (STP) (0°C, 101, 33 kPa);
- Gas temperatures and system static pressure;
- Physical internal diameter of the source;
- Total particulate matter (TPM) concentrations and calculated emissions and flow rates;
- Moisture content of the gas stream;
- Elemental composition on TPM collected (including uranium); and
- Gaseous components in the gas streams.

Data from the stack emission report are used to quantify emission of sulphur and nitrogen oxides, as well as the emission of uranium to air (see for example the 2015 status report on stack emissions [51]).

5.8 MANAGEMENT OF RECORDS

The Radiation Safety Officer is responsible for collecting all records relevant to the Public Exposure Monitoring programme (records will be kept indefinitely). The records are maintained in a format that allows the presentation of yearly statistical information about the monitoring processes.

6 SAFETY AND SECURITY OF RADIATION SOURCES

6.1 RADIATION SOURCES AT RÖSSING URANIUM

The sources of ionising radiation at Rössing Uranium include:

- uranium-bearing ores and stockpiles (naturally-occurring radioactive material: NORM);
- uranium-bearing processing fluids (NORM);
- uranium concentrate (NORM);
- the tailings facility containing mineral waste and materials contaminated in the milling process (NORM);
- sealed radioactive sources used for flow and density measurements (Cs-137);
- calibration sources used for instrument calibration (various radionuclides); and
- XRF machines used for analysis at the Chemical Laboratory (X-ray).

6.2 SAFEGUARDING OF NORM

NORM at Rössing Uranium include: the ore body and waste rock dumps, processing streams and final product, and the TSF.

6.2.1 Mine site access and egress

Access to the mine site is restricted to authorised persons. Access is by electronic access card and electronic access gates using fingerprint identification. This system prevents unauthorised entry and access to the open pit, waste rock dumps, stockpiles, TSF and FPR areas.

Vehicles leaving the site at the main gate (including transfer buses for employees) are searched thoroughly. The search includes scanning with RadEye detectors for any radioactive material. The RadEye devices are used in finder mode, which enables the detection of any materials emitting more radiation than ambient background levels.

6.2.2 Safeguarding final product

The FPR area is enclosed with a double fence and entry is by fingerprint access to authorised persons only. The area is guarded continuously by closed-circuit television cameras. Camera supervision is designed to detect unauthorised or unplanned activity, as well as unauthorised behaviour (such as non-compliance with PPE requirements).

The mining area and Processing plant operate a system of electronic process accounting, which includes the following safeguards:

- Mined tonnes, haul truck destination, and estimated ore grade of each haul truck load are calculated and accounted for in the product accounting process;
- Tonnes crushed and conveyed, and ore grade and calc. content, are continuously monitored and used in the metallurgical accounting process;
- Processing materials and final product are continuously monitored and updated in the product accounting stream;
- Tonnes drummed are accurately determined and reconciled with the product accounting stream data;
- Diversion of product for laboratory sampling is accurately accounted for; an automatic sampling process during the drumming procedure diverts a fixed amount of product sample for laboratory analysis – the resulting sample container is locked with access restricted to the designated laboratory sampler; and
- The metallurgical accounting process allows for minimal losses during the metallurgical process.

6.3 SEALED SOURCE REGISTER

A register of radioactive sealed sources is kept by the Radiation Safety Section. This register contains all particulars with regard to serial number, source type, activity, relevant dates, and leakage test results of those radioactive sources that require control. The locations of sealed sources are listed and kept in the register, and the register is updated each time a sealed sourced is moved to a new location.

A complete list of sealed sources in operation is given listed in Table 19, calibration sources are listed in Table 20, and sealed sources in storage are listed in Table 21.

Licences have been obtained for all sealed sources and calibration sources that are currently on site. Copies of the valid licence are kept on the Rössing Uranium intranet on the HSE portal, under Element 2 - Legal and other requirements.

Table 19: Sealed sources in use

Serial number	Nuclide	Half life (years)	Location	Use	Initial Activity (GBq)	Date manufactured	Time elapsed (years)	Leak Test Date
27255 N	Cs-137	30	No 1 Rock Box Primary Crusher	Level	44	July 2014	1	December 2015
004/12	Cs-137	30	No 2 Rock Box Primary Crusher	Level	40	April 2012	2	December 2015
2770	Cs-137	30	Lube Room Primary Crusher 1	Level	37	April 1975	39	December 2015
005/12	Cs-137	30	Lube Room Primary Crusher 2	Level	37	November 2012	2	December 2015

Table 20: Calibration sources

Nuclide	Type of Source	Half-life (years)	Initial activity (kBq)	Purchase date	Time elapsed (years)
Cs-137	Beta	30	3	13 December 2011	3
Th-230	Alpha	75,380	1	16 December 2011	3

6.4 STORAGE OF RADIOACTIVE SOURCES

All radioactive sources not in use are stored in a locked room. This room is isolated from other buildings in a gully located to the north of the mine site and is constructed to prevent the possibility of radiation exposure beyond its confines. The store is fenced, and the gate of the fence is locked when not in use. The keys to the area and to the store are locked in the Radiation Safety Section safe. The Radiation Source Bunker is classified and signposted as a controlled radiation area. The RSO or his/her alternate controls access to the store.

Access to the four sealed sources which are in use is restricted – all sources in the Primary Crusher are locked in the Rock Box. The location of the sealed sources is signposted with a radiation warning sign.

The two calibration sources are kept in the Radiation Safety Section safe. The RSO is the key holder for this safe.

6.5 SOURCE CHECKS

All sources, whether permanently in use or not, are checked for leakage at least once a year and the results are entered into the register by the responsible person.

Sources that are currently in use must undergo integrity checks once every month. (Procedure JK65/PRD/030- *Integrity Checks for Sealed Radiation Sources* contains further details.)

Table 21: Sealed source in temporary storage in radiation bunker

Serial number	Nuclide	Half life (years)	Location	Use	Initial Activity (GBq)	Date manufactured	Time elapsed (years)
70682	Cs-137	30	Radiation Source Bunker	Level	0.40	February 1981	33
2771	Cs-137	30	Radiation Source Bunker	Level	37	April 1975	39
PA 304	Cs-137	30	Radiation Source Bunker	Density	0.4	July 2005	9
PA 299	Cs-137	30	Radiation Source Bunker	Density	0.4	July 2005	9
PA 301	Cs-137	30	Radiation Source Bunker	Density	0.4	July 2005	9
PA 302	Cs-137	30	Radiation Source Bunker	Density	0.4	July 2005	9
PA 298	Cs-137	30	Radiation Source Bunker	Density	0.4	July 2005	9
PA 297	Cs-137	30	Radiation Source Bunker	Density	0.4	July 2006	8
2772	Cs-137	30	Radiation Source Bunker	Level	37	April 1975	39
40849 N	Cs-137	30	Radiation Source Bunker	Level	44	July 2013	1

6.6 ANNUAL SOURCE INVENTORY

An annual inventory of sealed sources must be prepared by the responsible person and submitted to the NRPA for inspection.

6.7 ACCIDENTS/INCIDENTS

All accidents involving contamination through spillage of product, major spillages of radioactive material (process solutions), or over exposure are reported to the responsible person.

The responsible person immediately initiates the relevant emergency procedure, as applicable and ensures that the person(s) concerned is sent to the Medical Centre for examination.

The Holder of Authority submits a report concerning the incident to the NRPA.

(Refer to Procedure JA60/PRD/009-*Uranium Oxide Emergency Spillage Procedure* (Appendix D) for the detailed procedure in case of spillages, and to JA60/PRC/010-*Sealed source incidents* (Appendix E) for incidents involving sealed sources.)

6.8 CLEARANCE CERTIFICATES

In all cases where work is to be performed on or near radioactive sources, prior written permission on the prescribed Rössing Uranium clearance form must be obtained from an authorised person.

6.9 TRANSPORT OF SEALED SOURCES

No sealed sources are removed or transported without the permission of the responsible person.

6.10 PROCEDURE IN CASE OF FIRE WHERE SEALED SOURCES ARE USED

In the event of fire in the Primary Crushers or Final Product Recovery areas, the responsible person is notified by the fire team as soon as the fire has been brought under control. The responsible person, or his/her nominee, then monitors the surrounding area and the radiation levels, and demarcates the area to prevent personnel access.

Any source that has been exposed to direct fire or radiant heat from the fire is removed to the Radiation Source Bunker under the direct supervision of the responsible person.

The responsible person also ensures that all fire-fighting personnel who could have been in the vicinity of a damaged source are medically examined and where a source was damaged, ensures that the requirements as laid down in Section 6.8 regarding the Clearance Certificate are followed.

6.11 ISOLATION AND LOCKOUT PROCEDURES FOR SEALED RADIOACTIVE SOURCES

To ensure optimum safety when working on equipment, the equipment must be rendered safe by isolation of the radioactive sources by an authorised person in the presence of the person who is to work on the equipment. The philosophy on which this procedure is based is that every person is responsible for his/her own safety. Therefore, before venturing into any situation where there may be a risk of personal injury, every person should satisfy him/herself — as far as is humanly possible — that such a risk is eliminated.

(Safety and security of sealed sources is detailed in Procedure JK65/PRD/001-*Radiation Protection when Using Sealed Radioactive Sources.*)

6.12 X-RAY GENERATING EQUIPMENT

The Chemical Laboratory currently uses two XRF machines; these are duly licensed and X-ray warning signs identify the equipment. As no ionising radiation emanates from these machines, no further control measures are regarded as necessary.

7 TRANSPORT PLAN

7.1 URANIUM OXIDE

Uranium oxide (U_3O_8) is listed as a Class 7 hazardous material, with a United Nations Hazardous Material Number of 2912 (radioactive material, low specific activity LSA-1 non-fissile or fissile excepted). The hazardous properties of U_3O_8 are relatively low compared with other radioactive materials and most hazardous materials in general.

7.1.1 Drums

Rössing Uranium's product, uranium oxide (U_3O_8), is packaged into 210-litre steel drums and sealed. Full drums are packed into 20-ft freight containers according to Standard Instruction FPR 13-*Handling of Product Drums*. The packing procedure detailed in the standard instruction ensures secure packaging. Cleaning, marking, labelling and monitoring of product drums and containers are all done following the IAEA *Transport Regulations* [25].

Empty drums are handled according to Standard Instruction FPR 10-*Handling of Product Drums*. This ensures that the integrity of the drums is maintained. Before filling, drums are inspected according to Standard Instruction FPR 11-*Inspection of Product Drums,* to make sure only undamaged drums are used.

Before being loaded into a container, drums are inspected and handled as follows:

- Damage – drums are inspected for dents and/ or other visible damage that may lead to uranium leaks. Any damaged drums are rejected.
- Drums must be clean: each drum is washed and dried immediately before loading into the container.
- Drums are handled using the drum handler attachment on the fork lift. This prevents damage to the drums.
- After drum filling and washing, the drum information is stencilled on the drum according to Standard Instruction FPR 12-*Drum Information Stencilling.* The following information is stencilled on each drum:

On one side	On the other side	On the drum lid
RÖSSING URANIUM LTD	UN 2912	DRUM NUMBER
NAMIBIA	RADIOACTIVE MATERIAL	LOT NUMBER
LOT NO.	LOW SPECIFIC ACTIVITY (LSA – 1)	
DATE (Month and year, eg OCTOBER 02)	TYPE IP – 1	
DRUM NUMBER	PERMISSIBLE GROSS MASS: 485 KG	
GROSS MASS	DRUM NUMBER	
TARE	GROSS MASS	
NETT	TARE	
	NETT	

Furthermore, two stickers of the IAEA Category II-YELLOW label, 10cm in length, are attached to each drum, one on either side.

- Alpha and beta surface contamination on drum surfaces is prevented by cleaning drums thoroughly prior to packing containers. The radioactivity measured must not exceed 0.4 Bq/cm^2 averaged over an area of 300 cm^2; spot checks are used to ensure that this standard is complied with.
- During spot checks, a smear sample is taken at the bottom of the drum and analysed for possible contamination (the drum is contaminated if the radioactivity level exceeds 0.4 Bq/cm^2 averaged over an area of 300 cm^2).
- Workers working inside the containers during drum packing, and close to the drums during packing, cleaning and monitoring of drums, are monitored with EPDs for external radiation dose. Procedure JK65/PRD/022-*Container Packing and Strapping* specifies a daily external radiation dose limit of 80 μSv for workers engaging in the packing and handling of drums.

- A default value of 0.4 is used for the transport index (TI) of all drums. This value represents the maximum possible TI for any product drum.
- The drum label to be used for all drums is shown in Figure 36.

Figure 36: Uranium oxide drum label

7.1.2 Containers

Before containers are brought on site they are inspected and must be compliant with the following requirements:

- be ISO containers
- be made from steel
- have a wooden floor, and
- no dirty or oil contaminated containers or those with any visual defects will be accepted.

Figure 37: Uranium oxide container label

Containers are inspected according to Procedure JK65/PRD/011-*Product Shipment Inspection & Monitoring*. The inspection procedure ensures that no contaminated container leaves the site and contamination of the environment and exposure to the public is thus prevented.

Containers are prepared according to the following guidelines:

- Container floors as well as the internal and external walls of the container are to be free from contamination according the conventional standards (0.4 Bq/cm^2 averaged over an area of 300 cm^2). The wooden container surface is to be free of contamination, and must be covered with thick plastic lining before drum packing begins, to prevent contamination of the floorboards during transport.
- Once packing is complete and the Quality Controller is satisfied that the packing is done correctly, the containers are closed and sealed.
- The container storage area is to be kept clean and monitored for contamination on a monthly basis. If the contamination level is higher than 0.4 Bq/cm^2, then this area must be cleaned.
- For transport by rail, each container is cleaned and placed on the transport truck.
- Each container is labelled with the IAEA Category III-YELLOW label and marked with 'Contents: natural uranium LSA-1: max activity: 440 GBq', and the default TI 6 for the container. One Category III-YELLOW label is placed on each of the four sides of the container.
- A default label is used for all containers, shown in Figure 37. The default TI of 6 corresponds to the default given in the IAEA *Transport Regulations* [25], and the maximum activity corresponds to the maximum possible for any Rössing Uranium product container.
- Containers are stored on site in a demarcated Container Storage Area. The area is fenced off and marked 'Radiation Area – Access Restricted'. Access to the area is controlled by the Final Product Area owner.

(The use of wooden spacers for packing has been discontinued to minimise the amount of non-recyclable materials used.)

7.1.3 Shipping

Transportation of uranium oxide (U_3O_8) is governed by the IAEA *Transport Regulations* [25] as well as national and international standards and regulations. These standards and regulations stipulate the responsibilities of shippers and carriers. In many jurisdictions, carriers must be licensed to carry nuclear material.

Shipment inspection and monitoring is done according with Procedure JK65/PRD/011-*Product Shipment Inspection & Monitoring*.

Containers containing uranium oxide are transported by rail by TransNamib to the Port of Walvis Bay.

Rail trucks are monitored as follows:

- A visual inspection of the rail trucks is carried out by the Quality Controller prior to loading the containers onto the trucks. The trucks are cleaned if they are found to be dirty.
- The Quality Controller signs off on the FPS Check Sheet that the inspection has been completed.

Rail trucks are loaded as follows:

- Before a loaded container is placed onto a rail truck, the container is thoroughly inspected for any loose contamination material and re-cleaned if necessary.
- Once inspected and cleared, the loaded containers are then placed onto the rail trucks.

At the Port of Walvis Bay, containers are transferred from the rail trucks to the container storage area five days prior to shipment. The container storage area at the port is monitored as follows:

- The Logistics officer and the Radiation Safety Officer ensure that the containers are placed in the correct storage area within the Walvis Bay container storage yard.
- At the Port of Walvis Bay storage area, the container is again thoroughly inspected for any loose material.
- Containers are stored with doors facing each other to ensure that the seals cannot be tampered with during storage at the harbour.

After the shipment has been loaded on the ship, alpha contamination measurements are taken at the container storage area to provide clearance that the storage site is not contaminated. The Logistics officer and Radiation Protection officer do a final inspection of the containers (ie checking seals and assessing the cleanliness of containers etc) when the containers are loaded onto the ship. Final clearance is given and the Final Product Shipment Check Sheet is signed by the RSO or his/her designate (see Procedure JK65/PRD/011-*Product Shipment Inspection & Monitoring Procedure*).

The choice of shipping company used to transport containers to their destination will depend on the client. The companies currently used are Macslines and CSAL.

Road transport of containers, if any, is carried out by Wesbank Transport.

7.1.4 Uranium oxide spills during transport

The Emergency Procedure JA60/PRD/009-*Uranium Oxide Emergency Spillage Procedure* (Appendix D) deals with the eventuality of an accidental spillage of uranium oxide during transport from the mine site to Walvis Bay Harbour, and also at Walvis Bay generally (or at any other port). The procedure details the line of command during an accident; procedures for cleaning up spills; procedures for monitoring exposed personnel; and procedures for monitoring any exposed members of the public.

The Business Resilience and Recovery programme (BRRP) Procedure JA60/PRD/001-*Uranium Oxide Spillage* (Appendix C) deals with the eventuality of an uranium oxide spillage anywhere along the shipping route from the Rössing mine site to the client. It details the chain of command; responsible persons; emergency actions; equipment in store for emergencies; and clean-up procedures for Namibia (rail transport; storage at Walvis Bay Harbour), the High Seas, United States, Canada, China and France. It also details a radiation protection procedure for road carrier Wesbank Transport.

The transport routes followed by Rössing Uranium's uranium oxide containers to converters are shown in Figure 38.

Figure 38: Transport routes for Rössing uranium oxide

7.1.5 Prevention of theft during transport

The rail transport of containers is accompanied by an escort from Rössing Protection Services from the mine site to the storage area at the Port of Walvis Bay. The shipment is escorted by the security detail driving a 4x4 vehicle.

Containers are loaded onto the rail trucks with the two doors facing each other, so that the container seals cannot be tampered with.

An Emergency Kit accompanies each security detail escort.

7.1.6 Transport documents

Official documents accompanying a shipment are as follows:

- Shipping Instruction;
- Activity, category Labels & Transport Index lists for container lot numbers;
- Summary Packing List Consignment #;
- Drumming Report Lot nos;
- Radioactive Shipment Application and Declaration Documents Lot nos;
- Dangerous Goods Container Packing Declaration nos;
- Consignor's Certificate Documents Lot nos;
- Pro-Forma Invoice Consignment #;
- Addendum "8" Radio Active Cargo;
- Emergency Information (For Ships at Sea);
- Certificate of Packages and Containers;
- Container Inspection Certificate;
- Exchange Control Declaration (F178); and
- Material Safety Data Sheet.

7.2 URANIUM-BEARING ORE SAMPLES, SLUDGES, PULPS, ETC

Uranium ore samples are sometimes transported to laboratories off site, either within Namibia or across its borders.

Any ore sample containing natural uranium with an activity concentration exceeding 10 Bq/g (from uranium alone), and with a total activity exceeding 1,000 Bq may be transported only if a permit is obtained from the NRPA for such a transport. (For ore samples, an activity density of 10 Bq/g from uranium alone is obtained with an ore grade of 800 ppm or more.)

With the implementation of the 2012 IAEA *Transport Regulations* [25], processed ore and tailings samples are now subject to the same exemption limits as for unprocessed ore, described in the previous paragraph. For ease of calculation and consistency, for tailings the ore grade of the source material is assumed for the determination of activity concentrations and total activity as per *Transport Regulations*. In other words, a source ore grade of 300 ppm is generally assumed for Rössing Uranium tailings material.

The exemption levels for the transport of NORM materials are specified in the IAEA *Transport Regulations* [25]; Section 107(f) of the latter specifies that uranium that persists in the isotope ratio in which it naturally occurs, and that does not exceed an activity concentration of ten times that specified in Table 2 of [25], is exempted from the Transport Regulations. The activity concentration limit for exemption as per table 2 in [25] is 1 Bq/g of the leading radionuclide (U-238), which translates into an ore grade of 80 ppm U in ore. Hence NORM material is exempted from the *Transport Regulations* up to an ore grade of 800 ppm U in ore.

7.2.1 Packaging

Ore samples are placed in sealed, airtight and watertight bags for transport. If the size of the sample exceeds 1 kg, the sample is additionally packed in a lidded box or a lidded drum, which can be sealed for transport. Where necessary, the package or container is labelled with the IAEA Category-I-WHITE label, 10 cm in length and specifying 'Contents: LSA Material: uranium ore' and the activity of the sample. A Consignment Note specifying the quantity and activity of the sample accompanies each transport of ore samples, even if the exemption limits are not exceeded.

7.2.2 Transporting

Each transport is accompanied by a MSDS (material safety data sheet) listing details about the uranium-bearing ore. The MSDS specifies the hazards identification; first aid measures (none); fire-fighting measures (none); accidental release measures (spillage removal); handling and storage instructions; personal protection measures; physical and chemical properties, stability and reactivity; toxicological information; disposal considerations; and transport information.

A Clearance Certificate from the Radiation Safety Section must be obtained for each transport of uranium-bearing ore and related sample materials.

Transportation of ore samples can be done by Rössing vehicle making use of the Rössing BRRP procedures and Radiation Safety procedures, or by a transport company that is authorised by the NRPA to perform such transports.

7.2.3 Disposal

After analysis, samples can be returned to Rössing Uranium for disposal in the tailings if the receiving laboratory is not licensed to dispose of the material itself. Returned samples are transported and labelled according the IAEA *Transport Regulations* [25] in the same way as the original samples are.

7.2.4 Transport documents

Ore samples are accompanied by the following documents:

- A copy of the NRPA permit (where required)
- MSDS data sheet 'uranium-bearing ore'
- Consignment Note, and
- Radiation Safety Clearance Certificate

The MSDS accompanying the samples must be one of the following:

- MSDS for uranium-bearing ore, ore grade exceeding 800 ppm, UN number 2912;
- MSDS for uranium-bearing ore, ore grade less than 800 ppm, no UN number (not radioactive for transport);
- MSDS for uranium compound with exemption levels exceeded, UN number 2912; or
- MSDS for uranium ore, limited quantity of material, UN number 2910 (this applies only if the dose rate at any point on the external surface is less than 5 μSv/h).

The relevant MSDS sheets are available on the Rössing Uranium intranet.

8 EMERGENCY PREPAREDNESS AND RESPONSE

Potential major accidents at Rössing Uranium involve either a spillage of uranium oxide (most likely during transport) or compromising of the integrity of a sealed source. Emergency plans are therefore available for these two types of emergencies. All other accidents or incidents are handled in compliance with the site's BRRP but detailed emergency plans and drills are considered necessary.

8.1 URANIUM OXIDE SPILLS

The actions taken in an event of a uranium oxide spill during the transportation of uranium oxide drums are detailed in Rössing's Uranium's BRRP Procedure on Uranium Oxide Spillage (see JA60/PRD/001-*Uranium Oxide Spillage Procedure*, Appendix C of this RMP), and locally in the Radiation Safety Procedure JA60/PRD/009-*Uranium Oxide Emergency Spillage Procedure* (Appendix D of this RMP). Relevant emergency information sheets accompany the consignment throughout the duration of the voyage; these provide correct emergency actions to the relevant parties. Formal and legal regulations are in place in the countries through which Rössing's Uranium's product containers are transported and clearly address responsibilities and accountabilities regarding emergency response and clean-up.

A drill on the actions to be taken during an emergency should be practised regularly. Teams from the Radiation Safety, Rössing Protection Services and Safety sections would primarily be involved if such an emergency were to take place within Namibia. The Radiation Safety Section would be responsible for radiation monitoring of individuals attending to the emergency and for area monitoring to ascertain that surfaces on which spillages took place were adequately cleaned. A list of instruments and equipment required in the emergency kit is specified in Table 22.

Rössing Uranium's product is transported by rail from the mine to Walvis Bay Harbour (see Section 7 for the *Transport plan*). For the loading of containers onto ships, Radiation Safety Section staff is present at all times to perform contamination checks. The emergency kit summarised in Table 22 is carried along on each such trip.

The Rössing Protection Services team ensures that all the spilled uranium oxide is cleaned up and is responsible for bringing items such as PPE, shovels, special vacuum cleaners etc to the accident scene. The complete inventory of all items to be brought to the scene is listed in Procedure JA60/PRD/001 (Appendix C). Spilled material is to be returned to the Rössing mine site.

All contaminated clothes and equipment must be decontaminated in the FPR area and emergency crews must take showers there as well. The Radiation Safety Section will make arrangements for uranium in urine sampling of emergency crews and exposed members of the public, if deemed necessary. Medical examinations may also be done for persons most affected.

8.2 SEALED SOURCE EMERGENCIES

The actions to be taken in the event of an emergency involving the damage, loss, or malfunction of a sealed radiation source are detailed in the Emergency Procedure JA60/PRC/010-*Sealed Source Incidents*, Appendix E.

All sealed sources must be registered with the NRPA, and the sealed sources register must be kept updated and reported to the NRPA annually. A summary of the register is found in Section 6.3. A list of emergency equipment kept in a Rapid Response Kit is given in Table 23.

Table 22: Instruments used for radiation monitoring in case of emergency

Instrument	Purpose
Electra Ratemeter and dual DP2R probe	Monitor surface activity on workers and surfaces
RadEye PRD or Automess 6150	External radiation monitoring (area)
2 EPDs (electronic personal dosimeters)	External radiation (personal)
Camera	Record incident
Clearance forms, notebook, pen	Incident recording
Smear sample filters and envelopes	Measurement of non-fixed surface contamination

Table 23: Equipment used for emergency response involving sealed radiation sources

Instrument	Purpose
Electra Ratemeter and dual DP2R probe	Monitor surface activity on workers and surfaces
Camera	Record incident
Lead apron	Exposure protection
Lead gloves	Exposure protection
EPDs (electronic personal dosimeters)	Individual dose measurement
Nip tongs	Source handling
Gamma ratemeter (RadEye, Automess, FH40, Electra – any of these)	Measurement of radiation dose rate
Lead storage box for sealing and storing sources	Storage of damaged source
Barricading tape (magenta and yellow for radiation hazards) and radiation hazard sign	Barricading and signage

9 WASTE MANAGEMENT PROGRAMME

9.1 CLASSIFICATION OF RADIOACTIVE WASTE

Under the *Radiation Protection Regulations* [37], waste must be classified according to physical properties and activity concentration in terms of categories[25]. Radioactive waste at the Rössing site is present in the following forms:

- Mineral waste or tailings, Category V under the *Radiation Protection Regulations*. The disposal and monitoring of dry tailings material is discussed in Section 9.6, and the seepage from the TSF is discussed in Section 9.4.
- Contaminated waste is not explicitly categorised under the *Radiation Protection Regulations* as it is not waste that is directly produced by the extraction of a radioactive mineral. It is indirectly a product of this extraction process, however, and is therefore deposited together with tailings material in specifically monitored and prepared locations on the TSF, as discussed in Section 9.5.

9.2 DOCUMENTATION

The quantity of tailings material deposited to the TSF is recorded by the Environmental Management Section. The amount of material deposited is reported as part of the annual monitoring report to the NRPA. The quantity of all non-mineral contaminated waste deposited (as described in more detail in Section 9.5), as recorded by the Environmental Management Section, also forms part of the regular monitoring reports to the NRPA, as well as environmental management reporting to the Rio Tinto group.

9.3 SEALED RADIOACTIVE SOURCES

All sources not in use are stored in the Radiation Store, as described in Section 6.

Sources with low activity used for instrument calibration purposes are kept in a locked area and controlled by the RSO, who keeps an inventory list and controls the movement of all sources.

All sealed sources that will not be used in the future will be returned to the National Interim Storage facility once this is established. In the interim, the option of returning the sources to the supplier is under investigation but at present, all sources still on site may potentially be used and are therefore not earmarked for disposal or return to the supplier.

Each sealed source is labelled detailing radionuclide, activity in GBq and date of activity, source number, and model.

9.4 UNSEALED RADIOACTIVE SOURCES

Unsealed radioactive sources are represented by the tailings, from which material may escape to the surrounding environment.

9.4.1 Tailings Storage facility (TSF)

The tailings dam or TSF is situated in a basin formed by two sand-filled riverbeds in Pinnacle Gorge, which is a tributary of the Khan River (Figure 39). Rössing Uranium is obliged by law to ensure that no seepage from the tailings dam flows into the Khan River. Surface seepage from the toe of the tailings embankment flows down Pinnacle Gorge and is contained in the seepage dam 800m below the embankment. Two cut-off trenches further downstream catch any water that may bypass the seepage dam. The location of the cut-off trenches can be seen in Figure 40.

Small amounts of water from the tailings dam infiltrate into the underlying bedrock where fractures allow some movement of groundwater from the western side of the dam towards Panner Gorge. This water is pumped out of de-watering boreholes, which are placed on all major fractures. De-watering systems exist on the tailings itself, at the northern toe of the dam, and west of the dam (see Section 9.4.3, below). A cut-off trench is placed across the lower Panner Gorge to prevent inflow to the Khan River and trenches and boreholes are pumped continuously to lower the water table. The recovered seepage is returned to the Processing plant for re-use. The direction of seepage flow and spatial arrangement of tailings facilities is illustrated in Figure 40.

[25] Regulation 61.

Figure 39: Location of tailings and drainage into the Khan River

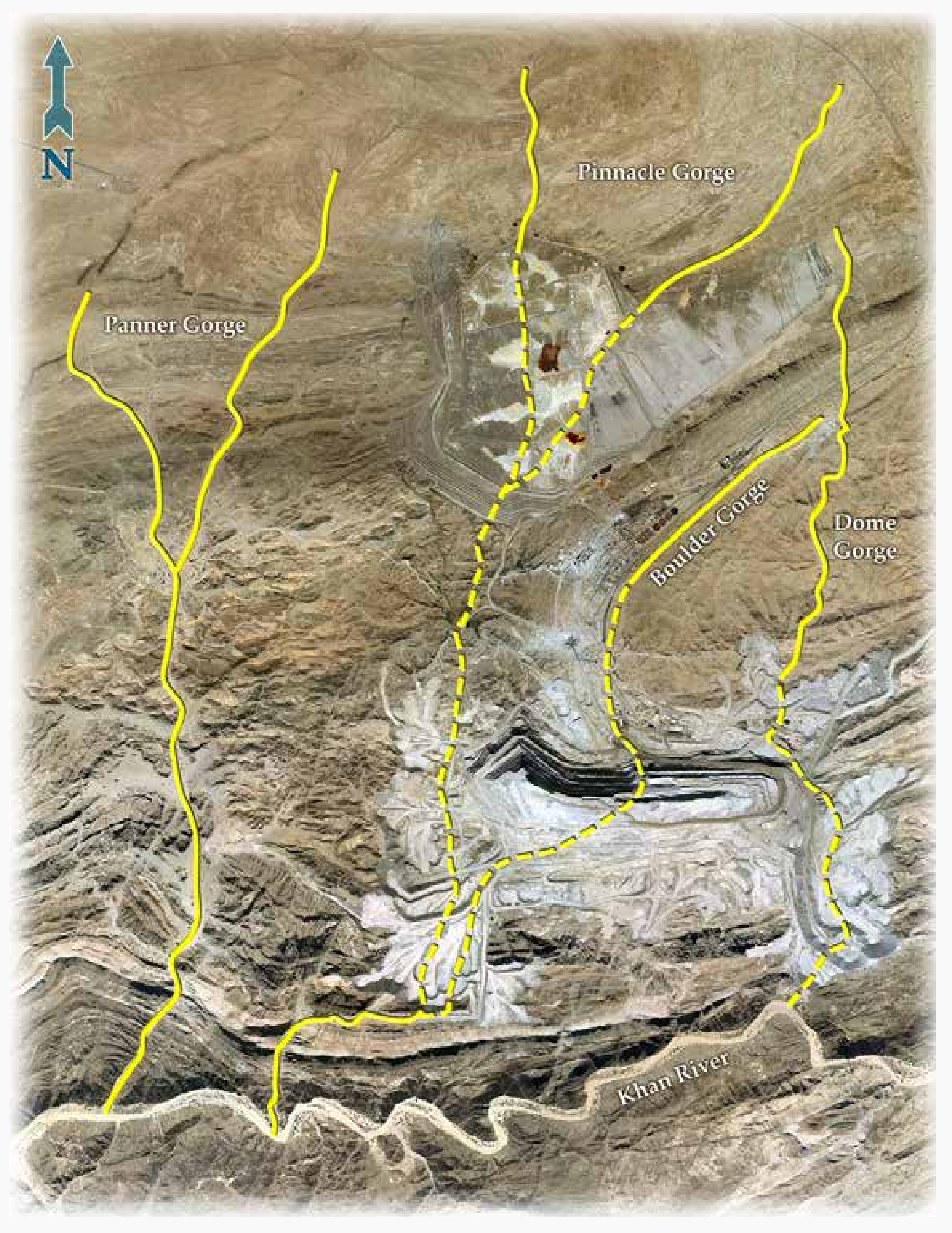
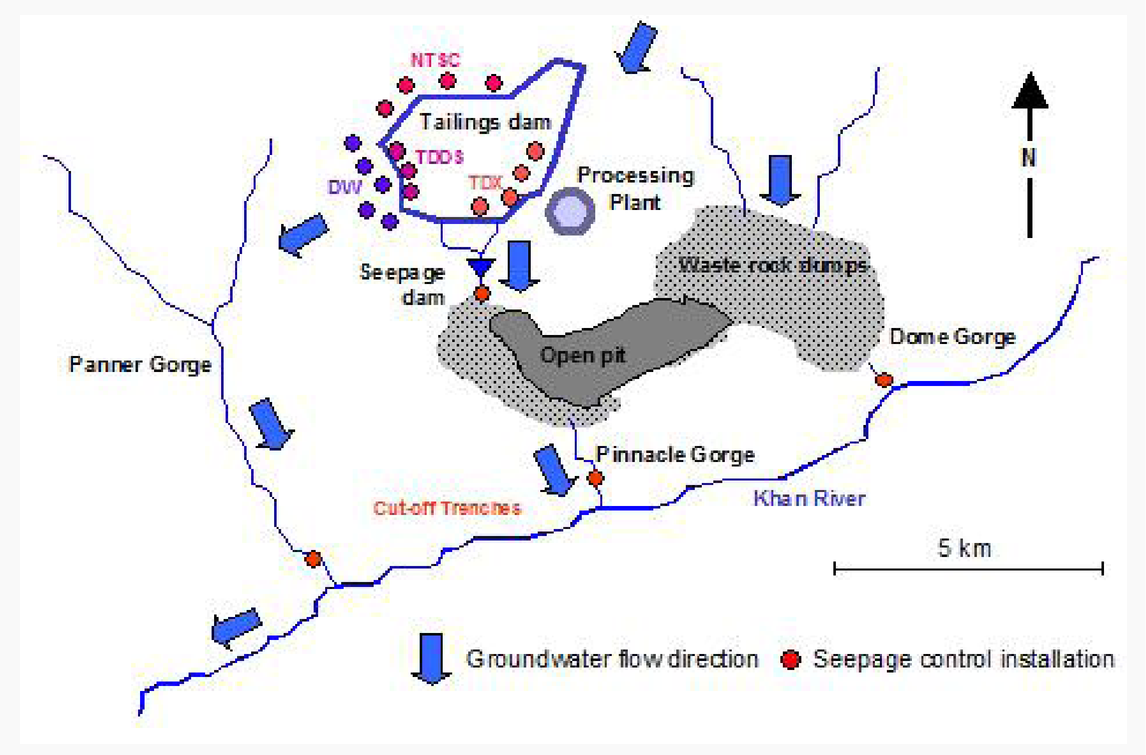


Figure 40: Seepage flow directions and control measures



9.4.2 Programmes for monitoring radionuclides in effluents

Frequent monitoring of the water quality in the mining area ensures the effectiveness of the seepage control systems. An extensive network of over 150 monitoring boreholes has been established and the water levels in most of these boreholes are measured regularly. Water quality analyses are carried out according to a sampling schedule, as required by the Department of Water Affairs. More details can be found in the water quality procedures JE65/OWM/004 R7-*Water Quality Monitoring* and JE50/SOP/002 R9-*Operation and Monitoring of the Seepage Control Systems*. (Refer also to Section 5.7.1 for the monitoring programme specific to water quality.)

9.4.3 Procedures to prevent or minimise effluent discharges into the environment

A part of the tailings solution discharged to the tailings dam infiltrates into the tailings pile and either remains entrained around the particles or percolates through and emerges at the toe of the dam. The toe seepage is mostly collected in trenches, and pumped to Lake Geoff.

Overflow from the trenches is channelled to the seepage dam from where it is recycled. Water that seeps into the bedrock under the dam is recovered by the various seepage control systems as shown in Figure 41.

Figure 41 shows the seepage collection systems on and around the tailings dam, grouped into the Northern Tailings Seepage Control (NTSC), Tailings Dam De-watering System (TDDS), Tailings Dam Extraction (TDX), De-watering Wells (DW) and Seepage Recovery systems.

Daily monitoring of seepage control installations on the tailings dam is carried out by the Tailings Dam Area Operators, while the Hydro Geologist evaluates the flow rates, water levels, and general effectiveness of the systems.

The toe seepage system pumps to the heap leach tank; P8 overflows to Trench K, from where a floating pump transfers the water to the seepage dam. Toe seepage has a high concentration of suspended solids. Seepage from the seepage dam is pumped directly to Lake Geoff.

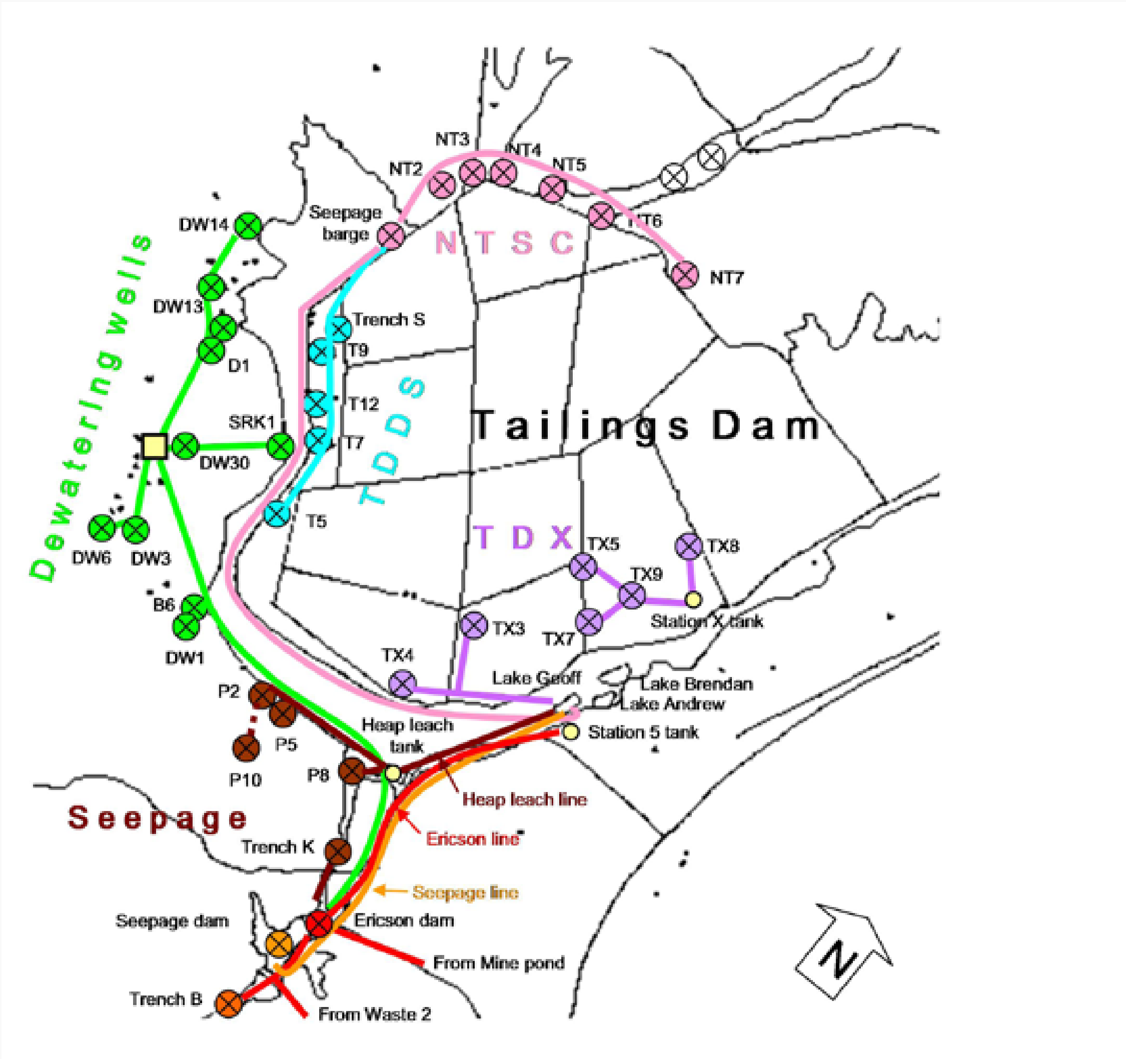


Figure 41: Seepage recovery systems, with de-watering wells (green), tailings dam seepage system (TDDS, blue), northern tailings seepage control (NTSC, pink), tailings dam extraction (TDX, purple) and seepage recovery, brown.

9.5 CONTAMINATED MATERIAL

Material that could potentially be contaminated at the mine site includes: pumps, tanks, pipes, concrete surfaces, soil, resin, and infrastructure found in the Processing plant of the mine. SCOs (surface contaminated objects) are segregated according to the following criteria (see also Procedure JK65/PRD/010-*Monitoring and Identification of Contaminated Items*):

9.5.1 Equipment requiring maintenance

All equipment or materials used at the mine site that require maintenance work at another area of the mine site (eg workshops) require a Radiation Clearance following the criteria given below. All items and equipment requiring a Radiation Clearance are dismantled in such a way so that all surfaces that are normally concealed are accessible for radiation monitoring (for example, a pump should be opened up so that contamination readings can be taken on the inside of the pump). Items with inaccessible surfaces are not granted a radiation clearance; no item is accepted — for example at a workshop — if a Radiation Clearance Certificate has not been issued. The standards for items requiring clearance are summarised in Table 24.

9.5.2 Redundant equipment

All redundant pieces of equipment and materials are identified and disposed of at the Tailings Storage facility (if contaminated) or the Landfill Site (if uncontaminated) according to the contamination criteria summarised in Table 25.

Table 24: Standards for contaminated items requiring radiation clearance

	Contaminated		Uncontaminated	
	Standard	*Radiation Clearance*	*Standard*	*Radiation Clearance*
Non-fixed radioactivity	> 0.4 but < 4 Bq/cm^2 (averaged over 300 cm^2)	Required	< 0.4 Bq/cm^2	Not required
Fixed radioactivity	< 400 Bq/cm^2 (averaged over 300 cm^2)	Required	< 0.4 Bq/cm^2	Not required
Dose rate at 1m from item	< 0.5 μSv/h	Required		

Table 25: Criteria for contamination of redundant items

	Contaminated		Uncontaminated	
	White lugger bin		*Green lugger bin*	
	Standard	*Destination*	*Standard*	*Destination*
Total of fixed and non-fixed radioactivity	> 0.4 Bq/cm^2 (averaged over 300 cm^2)	Tailings Impoundment	< 0.4 Bq/cm^2 (averaged over 300 cm^2)	Landfill Site

Disposal of contaminated waste occurs every Wednesday.

The responsible foreman ensures that the transport is conducted according to the provisions of JK65/PRD/007-*Transport of Contaminated Items*. This procedure details the provisions to ensure that waste material cannot be blown off during transport, ie that the lugger bins are covered with netting or the jarosite is contained in mega bags that are properly sealed. The weights of waste consignments deposited at the contaminated waste facility are recorded by the Environmental Management Section. Quantities of contaminated waste deposited are reported annually in the Rio Tinto Environmental Workbook and are also reported to NRPA annually.

When the waste material arrives at the TSF disposal site, the material is dumped into the specially-prepared trench at the demarcated waste disposal area in the presence of the Operations Foreman and Rössing Protection Services.

The Chief Surveyor is notified a week in advance by the Tailings Operations Foreman that a new disposal site is required. The area must be surveyed and marked off by the Survey Section. The area is mapped and recorded and its details stored for future reference.

Material collected with the road sweeper during the cleaning of the roads is disposed of at the contaminated waste disposal area on the TSF or washed out in the trench between the leach tanks.

All grit from the Gritblasting Yard is disposed of at the identified waste disposal area of the TSF.

(See JK65/PRD/003-*Disposal of Contaminated Items* for the detailed disposal procedure for contaminated items.)

The quantity and disposal location of contaminated waste is recorded by the Environmental Management Section. The location of the contaminated waste trenches on the TSF is shown in Figure 42.

9.5.3 Equipment required for future use

All equipment and materials that need to be stored are stored at the Radiation Storage Yard(s) or the Salvage Yard(s), according to the contamination criteria summarised in Table 26.

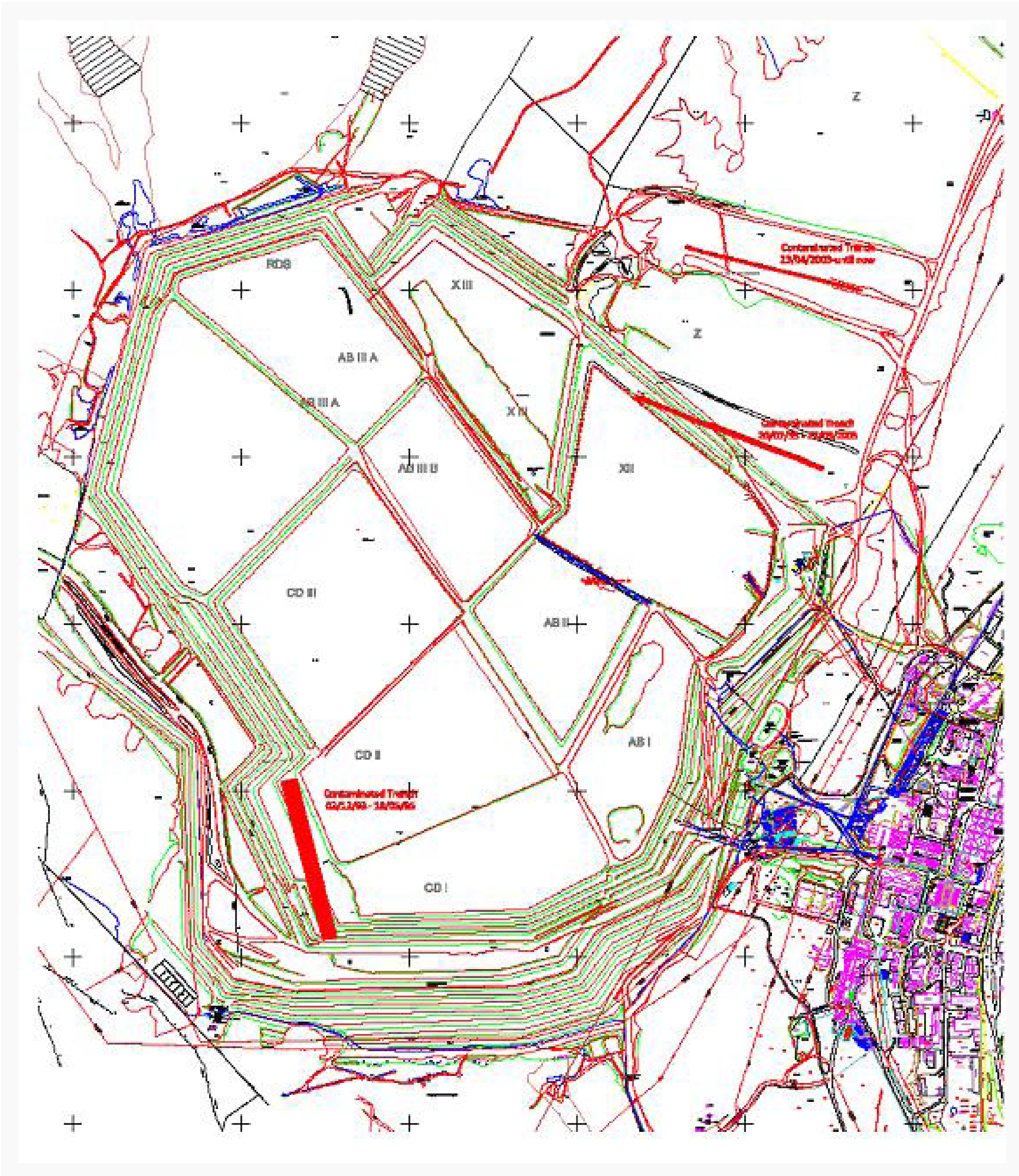


Figure 42: Location of contaminated waste trenches on the TSF.

Table 26: Contamination criteria for storing equipment

	Contaminated		Uncontaminated	
	Standard	*Destination*	*Standard*	*Destination*
Total of fixed and non-fixed radioactivity	> 0.4 Bq/cm^2 (averaged over 300 cm^2)	Radiation Storage Yard	< 0.4 Bq/cm^2 (averaged over 300 cm^2)	Salvage Yard

9.5.4 Removal from site

All items to be transported off the mine site may require clearance from the Radiation Safety Section following the contamination standard given in the IAEA *Transport Regulations* [25] and quoted in Section 4.4.7.2.

The levels of contamination of material and equipment for the release from Controlled and Supervised radiation areas to uncontrolled radiation areas in the public domain must not exceed the above. As Rössing's Uranium's product and ore material are low toxicity alpha emitters, the contamination limit is thus 0.4 Bq/cm^2 (average of measurements over a 300 cm^2 area).

(See Procedure JK65/PRD/005-*Removal of Equipment and Material from site* for the detailed removal procedure.)

9.5.5 Low specific activity (LSA I material)

Low specific activity material such as contaminated soil and scaling from pipes, pumps etc is disposed of at the TSF.

9.6 TAILINGS MATERIAL

9.6.1 Character of the tailings material discharged on the TSF

Tailings material is composed of various chemicals; the typical values that one would expect for the various chemicals and related parameters are given in Table 27 (both for the tailings dam and the seepage dam).

9.6.2 Management of tailings

Slimes from the fifth thickening stage are pumped to Station X on the TSF via a pipeline, while sands from the second stage rotoscoops are transported by conveyor. The two fractions are re-combined in one of two tailings sumps (Figure 43), either System 1 or System 2, after which it is deposited on the dam. The solids settle out while the return dam solution (RDS) is pumped back to the Processing plant for re-use at the Rodmills.

Table 27: Characteristics of tailings dam constituents

	Tailings dam (TSF)	Seepage dam
pH	2.0	5.4
Conductivity (μS/cm)	15,500	16,500
Total dissolved solids (ppm)	27,968	23,180
Calcium (ppm Ca)	524	487
Magnesium (ppm Mg)	1,280	1,460
Total alkalinity (ppm $CaCO_3$)	0	0
Chloride (ppm Cl)	1,190	2,200
Sulphate (ppm SO_4)	11,187	9,860
Nitrate (ppm NO_3)	70	51
Ammonia (ppm NH_3-N)	646	462
Potassium (ppm K)	137	102
Sodium (ppm Na)	1,380	2,220
Aluminium (ppm Al)	455	5.5
Manganese (ppm Mn)	1,280	335
Iron (ppm Fe)	885	20
Uranium (ppm U)	64	0.8
Sulphate/chloride ratio	9.4	4.5
Uranium-238 (Bq/L)	222	16
Uranium-235 (Bq/L)	10.5	0.75
Uranium-234 (Bq/L)	206	15
Radium-226 (Bq/L)	5.7	0.32
Radium-224 (Bq/L)	0.56	<0.024
Radium-223 (Bq/L)	1.6	<0.026
Thorium-230 (Bq/L)	720	<0.4

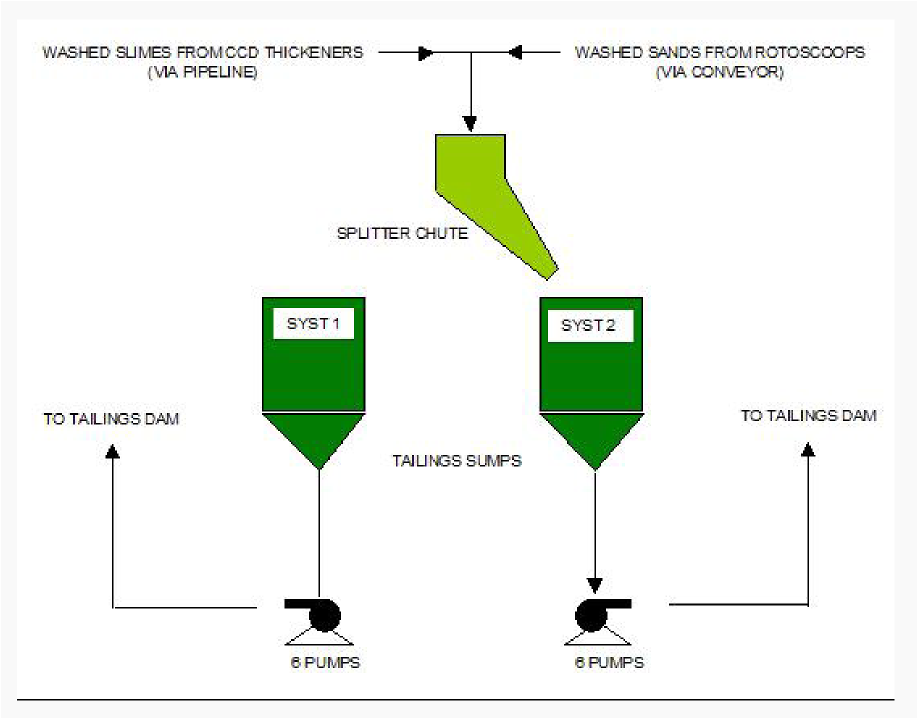


Figure 43: Tailings pumping system at Station X

9.6.3 Decommissioning of the tailings dam

Only general comments are provided here but more detail can be found in Rössing Uranium's CMPs [5], [42]. The list of actions proposed for the environmental remediation of the tailings dam area includes:

- Removal of access roads and construction and maintenance of fences around the tailings dam
- Covering the tailings dam with appropriate layer(s) of crushed rock (design in progress)
- The cover surface to be contoured to promote shedding of water along the tailings dam perimeter and to allow ponding and evaporation of rainwater on the dam surface, and
- Long-term monitoring and management of various aspects, including rainwater runoff, slope stability, erosion, seepage, and groundwater quality.

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11 LIST OF RÖSSING URANIUM'S PROCEDURES RELEVANT TO MANAGING IONISING RADIATION

Table 28: List of procedures relevant to radiation management

Reference No.	Title
JA60/PRC/010	*Sealed source incidents*
JA60/PRD/001	*BRRP - Uranium Oxide Emergency Spillage Procedure*
JA60/PRD/009	*Uranium Oxide Emergency Spillage Procedure*
JK15/RPT/001	*Personal Radiation Monitoring for Back Shifts - RUL Report*
JK50/PRD/014	*Maintenance Work Carried Out on the CIX Contactors*
JK65/COP/007	*Protection against Ultra Violet Radiation*
JK65/PIN/003	*Instrument Procedure for the Automess 6150 AD4 Dose Rate Meter*
JK65/PIN/004	*Operating Procedure for the Electra*
JK65/PIN/006	*Personal monitoring of LLRD using the MyRIAM instrument*
JK65/PIN/007	*Personal monitoring of Radon Decay Products using the DoseManPro instrument*
JK65/PRD/001	*Radiation Protection when Using Sealed Radioactive Sources*
JK65/PRD/002	*Urinalysis Sampling Procedure*
JK65/PRD/003	*Disposal of Contaminated Items*
JK65/PRD/004	*Removal of Scrap Metal*
JK65/PRD/005	*Removal of Equipment and Material from site*
JK65/PRD/006	*Decontamination of Contaminated Items*
JK65/PRD/007	*Transport of Contaminated Items*
JK65/PIN/008	*Instrument Procedure for the RadEye PRD*
JK65/PRD/010	*Monitoring and Identification of Contaminated Items*
JK65/PRD/011	*Product Shipment Inspection & Monitoring Procedure*
JK65/PRD/012	*Baseline Monitoring for Empty Containers*
JK65/PRD/013	*Analysis of smear sample for alpha radiation with Thermo Eberline HandeCount*
JK65/PRD/015	*Area Radiation Survey for Total Alpha and Beta Contamination*
JK65/PRD/016	*Area Survey for External Gamma Radiation*
JK65/PRD/018	*Procedure for contact radiation monitoring (Beta/Gamma) in Final Product Recovery*
JK65/PRD/019	*The Monitoring of Personal Radiation Dose*
JK65/PRD/020	*Personal External Radiation Dose Monitoring with a Personal Dosimeter*
JK65/PRD/021	*Monthly Pregnancy Test*
JK65/PRD/022	*Container Packing and Strapping*
JK65/PRD/025	*Determination of transport requirements for transporting radioactive materials*
JK65/PRD/026	*Microwave testing*

Reference No.	Title
JK65/PRD/028	*Analysis of Smear Samples using RadEye HEC*
JK65/PRD/029	*Low Frequency EMF Workplace Analysis*
JK65/PRD/030	*Integrity Checks for Sealed Radiation Sources*
JK65/PRD/031	*Personal External Radiation Dose Monitoring for Radiation Workers (using TLD)*
JK65/PRD/032	*Radiation Worker Control Requirements at RUL*
JK65/PRD/033	*How to give a radiation clearance (for Protection Services)*
JK65/PRC/035	*Floor contamination monitoring using the Radeye SX with floor monitor probe*
FPR 10	*Handling of Product Drums*
FPR 11	*Inspection of Drums*
FPR 12	*Drum Information Stencilling*
FPR 13	*Drum Packing and Handling of Containers*
JA 10/MMP/001	*Water management plan*
JE65/OWM/004 R7	*Water quality monitoring*

12 CHANGES AND REVISION STATUS

Issue and Revision History				
First Issue	**Issue date**	**Prepared by**	**Approved by**	
1.0	1 July 2009	F !Gaoseb et al	n/a	
Version number	**Revision date**	**Revised by**	**Approved by**	**Reason for change**
1.1	1 October 2010	G von Oertzen	P Rooi	• Update, changes requested by Regulator
1.2	14 December 2010	G von Oertzen	P Rooi	• Changes requested by Regulator (added appendices D and E, added Section 6.17)
1.3	15 November 2011	G von Oertzen	S Labuschagne	• Changed limit for controlled areas from 7 mSv/a to 5 mSv/a to comply with Rio Tinto Standard B5 • Changed limit for supervised areas from 5 mSv/a to 1 mSv/a to comply with public dose limit • Updated organisational structure • Updated sealed sources register • Added list of dust monitoring equipment with positions • Added list of monitoring boreholes with positions
1.4	20 December 2011	G von Oertzen	S Labuschagne	• Updated medical investigation procedure for uranium in urine exceedance
1.5	12 March 2012	G von Oertzen	S Labuschagne	• Added detail on exploration activities, Section 1.3.2 • Updated org. structure for Radiation Safety, Section 3.2
1.6	12 June 2012	G von Oertzen	L Nel	• Updated Section 11 • Updated Section 4.7.4 • Added Section 8.3 • Updated Section 9 • Updated Section 10
1.7	30 September 2012	G von Oertzen	B Uris	• Updated Section 1.3.2 • Updated Section 1.3.7 • Updated Section 2.3 • Updated Section 3 • Updated Table 11 • Updated Section 8.1.1 • Updated positions of *Supt Radiation Safety* to *Principal Advisor Radiation Safety* and *Manager H&S* to *Manager HSEC* throughout • Updated sealed source register • Updated list of boreholes • Updated Section 5

1.8	13 November 2012	G von Oertzen	B Uris	• Updated Section 5.7.1 with map of tailings seepage plume • Added Section 9.1 on classification of waste under *Radiation Protection and Waste Disposal Regulations* • Added Section 9.2 on waste disposal documentation
1.9	12 March 2013	G von Oertzen	B Uris	• Updated Section 8.2: numbering of Appendix E and Appendix F • Updated DM&R with BRRP throughout • Updated Definitions • Updated list of sealed sources • Updated list of procedures, Section 11 • Updated Section 6.2.1.2 with new procedure • Updated RSO designation letter, Appendix B • Updated organisational arrangements, Section 3 • Updated procedure for contaminated waste disposal, Section 9.5.2
2.0	30 November 2013	G von Oertzen	B Uris	• Complete revision of RMP, restructuring and renumbering • Update on exploration activities (now completed), Section 1.3.2 • Updated Section 1.3.6.4 with results from newly-completed radon survey • Updated number and location of sealed sources used in operation • Updated numbering and referencing system • Updated responsibilities of appointed medical practitioner to explicitly reference Regulations 26 and 31, Section 3.5 • Updated responsibility of Supt. Health Management to explicitly reference budgeting and management requirements relating to medical practitioner, Section 3.6 • Updated summary of SEGs to include mining offices and processing offices as separate SEGs, Section 4.3.3 • Update of Section 4.4.2 to include reference to radiation worker risk assessment • Update of definition of controlled and supervised areas, Section 4.4.3 • Update of Section 6.12 • Update of Sections 4.5, 4.5.3 Update of Sections 5, 9, 8, 7, 6 • Added Section 6.2 on safeguards • Updated *Transport Plan* with new procedures and with new labelling convention

2.1	30 August 2014	G von Oertzen	B Uris	• Review of layout, style and grammar • Updated all references to the number of sealed sources in operation, and the number presently on site • Updated information on water supply, which is now desalinated water • Updated information on sulphuric acid, which is now railed from Tsumeb • Removed reference to X-ray machine operated by medical service provider, as this has moved off site • Updated organisation structure, Figure 15 • Added information on public dose monitoring (radon), Section 5.7.2 • Updated with information about portal monitor, which was decommissioned in mid-2014. • Updated Transport Plan (Section 7.2) with new information as contained in the 2012 IAEA Transport Regulations. • Updated uranium-thorium ratio in ore according to 2013 radionuclide analysis, Section 4.5.2 • Updated information on personal dose recording tool on Rössing intranet, Section 4.7.1 • Updated reporting frequency for personal dose results – Section 4.9, to yearly • Updated reporting requirements with annual report on implementation of RMP: narrative summary (Table 15) • Updated information on public radon dose assessment at Arandis, Section 5.7.2 • Deleted Medixx X-Ray machine from site register as no longer operated on site • Updated Section 5.7.3, on dust monitoring.
2.2	30 January 2016	G von Oertzen	B Uris	Revision

13 APPENDIX A: DECAY CHAINS

Three decay chains are relevant to the uranium mining industry: the uranium, thorium, and actinium chains respectively. Both U-238 and U-234 are members of the uranium chain, while U-235 heads its own decay chain – the actinium chain. Thorium often occurs in association with uranium and therefore the thorium chain is also relevant.

13.1 URANIUM SERIES

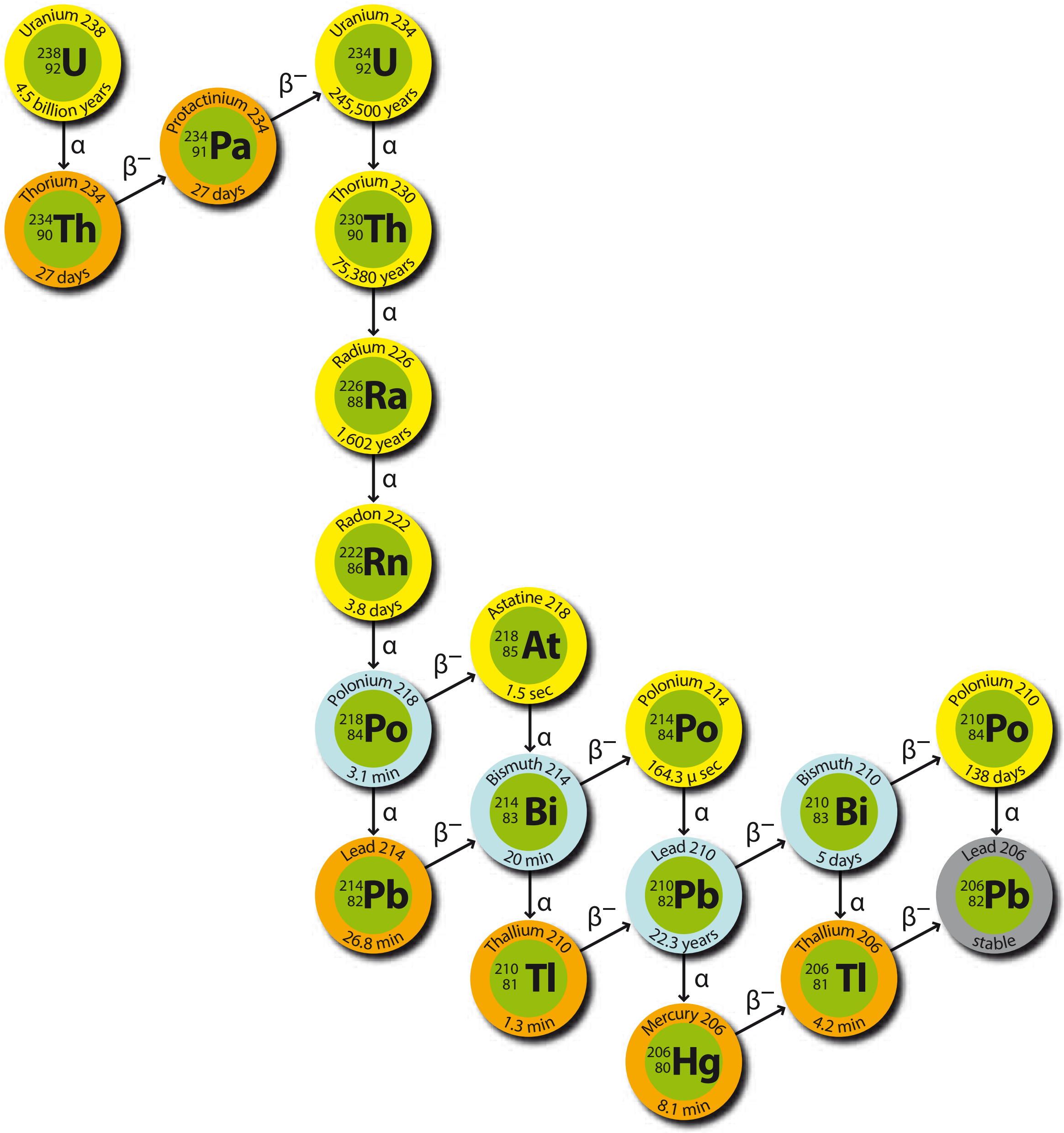

Figure 44: U-238 principal decay modes, with permission from VO Consulting, www.voconsulting.net

13.2 THORIUM SERIES

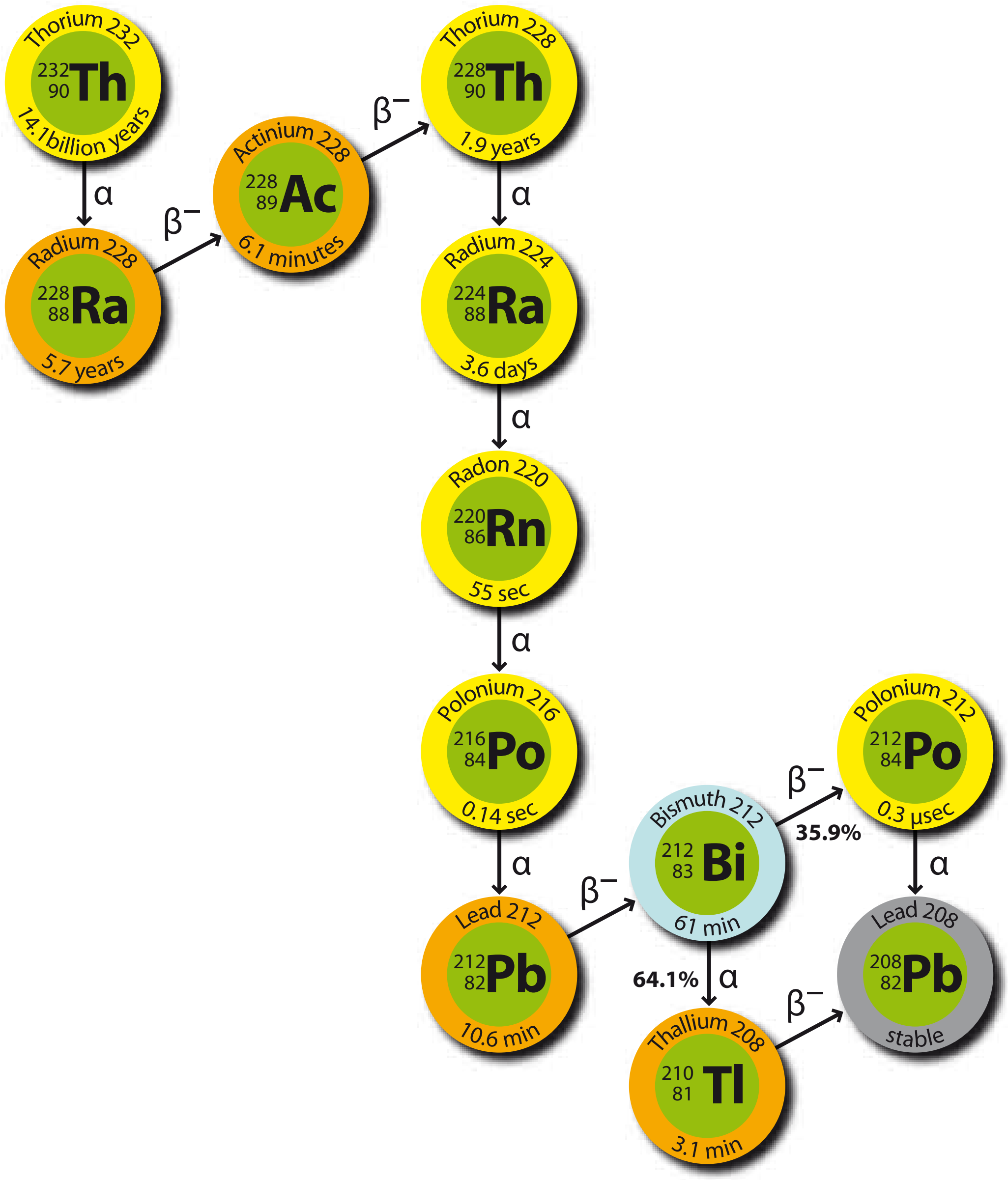

Figure 45: Th-232 principal decay modes, with permission from VO Consulting, www.voconsulting.net

13.3 ACTINIUM SERIES

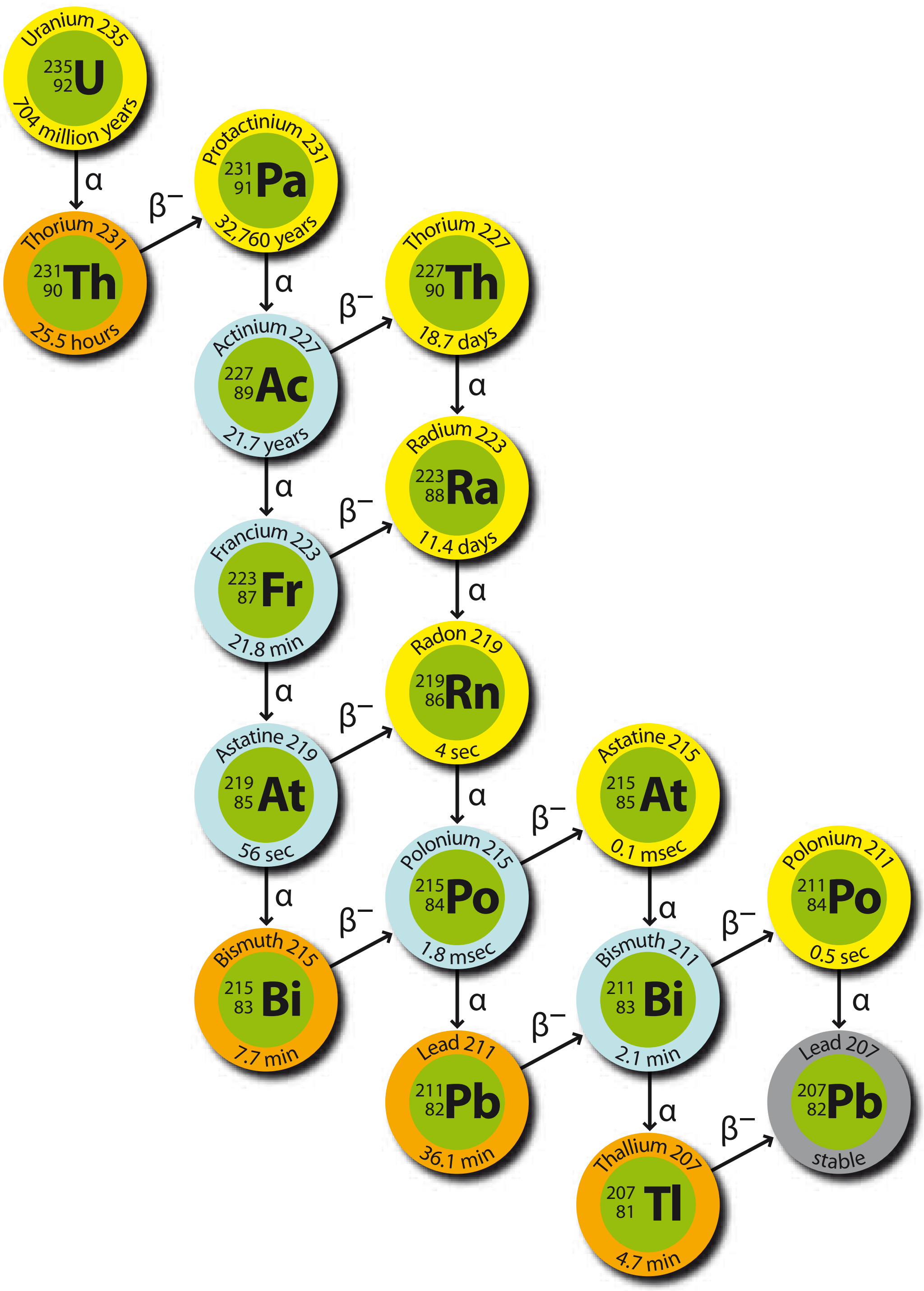

Figure 46: U-235 principal decay modes, with permission from VO Consulting, www.voconsulting.net

14 APPENDIX B: LETTER OF CONFIRMATION: RADIATION SAFETY OFFICER

Rio Tinto

Rössing Uranium Limited
Registered in Namibia No. 70/1591
28 Hidipo Hamutenya Avenue
Private Bag 5005
Swakopmund
Namibia
T +264 (0)64 520 2517
F +264 (0)64 520 2253

Private and confidential

05 February 2016

Mr Axel Tibinyane
Directorate Atomic Energy & Radiation Protection
T el: + 264- 61- 2032767
Fax : + 264- 61- 234083

Dear Mr Tibinyane

Radiation Safety Officer for Rössing Uranium Limited

This letter serves to confirm that the Radiation Safety Officer for Rössing Uranium Limited is:

Dr Gunhild von Oertzen, Principal Advisor Radiation Safety

Dr von Oertzen holds a PhD in Nuclear Physics. Her work experience includes the following:

- University lecturer in Physics, including development and delivery of physics course for radiographers (6 years, 1992–1997)
- Project management and analysis in consulting industry (8 years, 1998–2001, 2007–2008)
- Research Fellow, mining industry related surface science research (5 years, 2002–2006)
- Direction and management of Rössing Radiation Safety Programme (since 2009).
- Training and development of radiation safety expertise within the uranium mining industry, in collaboration with and in support of the Chamber of Mines Uranium Institute (since 2009).

The listed qualifications and experience fully equip Dr von Oertzen with the expertise to fulfil the duties of Radiation Safety Officer for Rössing Uranium Limited.

Dr von Oertzen's duties will include the role of Radiation Safety Officer for the Z20 exploration project on the Rössing mining lease, for the duration of the project.

Yours faithfully,

Werner Duvenhage
Managing Director

Appendix C: Uranium Oxide Spillage Procedure (International)

This procedure is an internal document and available on the Rössing intranet.

Appendix D: Uranium Oxide Spillage Procedure (Local)

This procedure is an internal document and available on the Rössing intranet.

Appendix E: Sealed Source Incident Procedure

This procedure is an internal document and available on the Rössing intranet.