Implementation of Radiation Management Plan

Annual Report for Rössing Uranium Limited 2020

CNNC
Rössing Uranium
Working for Namibia

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[Abbreviations]

Bq	—	becquerels, decays per second (unit for measuring radioactivity)
FPR	—	Final Product Recory
g	—	grams
HSE & PS	—	Health, Safety, Environment and Protection Services
kBq	—	kilo-becquerels (1,000 Bq)
LLRD	—	Long-lived radioactive dust
mBq/L	—	milli-Becquerels per litre (10^{-3} Bq per litre)
mSv	—	milli-Sieverts (sieverts/1,000)
μSv	—	mico-Sieverts (sieverts/1,000,000)
μSv/a	—	mico-Sieverts per annum
mSv/a	—	mSv per annum
mg/m^3	—	milligrams per cubic metre (1/1,000th of a gram per cubic metre)
μg/m^3	—	micrograms per cubic metre (1/1,000,000th of a gram per cubic metre)
μg/L	—	micrograms per litre (10^{-6} grams per litre)
NRPA	—	National Radiation Protection Authority
NUST	—	Namibia University of Science and Technology
ppm	—	parts per million
PM10, PM_{10}	—	Particulate matter with particle size below 10 microns
RUL	—	Rössing Uranium Limited
RMP	—	Radiation Management Plan
RSO	—	Radiation safety officer (statutory role)
SEG	—	Similar exposure group
TLD	—	Thermo luminescent dosimeter
TEA Lab	—	Trace Element Analysis Laboratory
TSF	—	Tailings Storage Facility
NUI	—	Namibian Uranium Assocition Uranium Institute
UOC	—	Uranium oxide concentrate
WHO	—	World Health Organization

1. Introduction

To comply with Radiation Protection Regulations[1], Rössing Uranium Limited (Rössing) prepares an annual narrative report to the National Radiation Protection Authority (NRPA) about the implementation of the site Radiation Management Plan (RMP) as required.

Herewith we present the eighth narrative report since the implementation of this regulation.

Reports for the years 2013 to 2019 are available to the public on the Rössing website, http://www.rossing.com/reports-research.htm.

This report is accompanied by data presented separately in the prescribed format, which includes:

- average exposure dose records for each similar exposure group (SEG) for the year 2020, for each of the three pathways monitored separately;
- personal dose records for the past year for each employee working at the mine during that year;
- cumulative dose reports for all employees who have left the organisation during the past year;
- a list of sealed sources on the mine with current source activities and the location of each source;
- a list of uranium oxide exports in 2020; and
- a summary of radioactive waste deposited or stored, both mineral and non-mineral in nature.

1 Radiation Protection and Waste Disposal Regulations: Atomic Energy And Radiation Protection Act, 2005 (Act No. 5 of 2005)

2. Organisational **arrangements**

2.1 Organisational re-arrangements and structure

Johan Coetzee is still Managing Director for Rössing. Sadly, in October 2020, we lost Dr Bertram Schleicher who was the appointed Radiation Safety Officer (RSO), as well as the Specialist for Radiation Safety. In the meantime Nelao Endjala has been acting in his roles. The RSO role continues to report to the Manager: HSE & PS, Jacklyn Mwenze. The organisational structure governing Radiation Safety in 2020 is depicted in Figure 1.

Currently, the Radiation Safety section is manned by four Radiation Advisors (one acting as RSO) who are carrying out the implementation of the RMP.

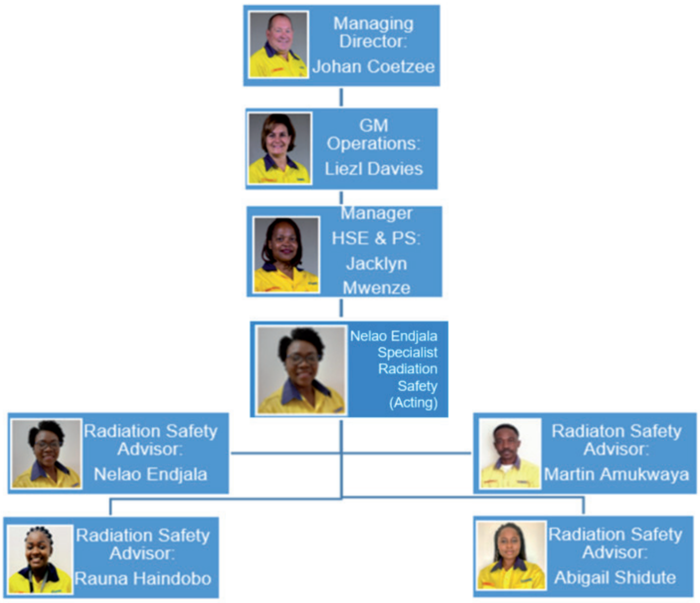

Figure 1: Organisational structure for the Radiation Safety Section, December 2020.

2.2 Capacity building

To emphasise the importance of radiation protection and the skills needed for effective radiation protection, Rössing continues to support and contribute towards the training programme for RSO offered by the Namibian Uranium Institute (NUI).

The whole Radiation Safety team are members of the NUI's Radiation Safety Working Group; Nelao Endjala is the current chairperson of the group.

3. Occupational **exposure protection**

3.1 Radiation-dose monitoring results for 2020

In 2020, exposure of workers to radiation was monitored by measuring exposure to external gamma radiation, long-lived radioactive dust (LLRD) and radon decay products. A total of 955 workers in 19 different similar exposure groups (SEGs) were monitored. Extrapolated annual doses for the individual SEGs are summarised in Figure 2.

Our monitoring applied a risk-based approach: areas subjected to historically higher levels of exposure were monitored more frequently than areas subjected to lower exposure.

In addition, some of the SEGs, which showed similar and low exposures during previous years, were assigned the same dose rates. This so-called graded approach helps focus on key areas in the assessment where the highest doses and risk are to be expected. Figure 3 shows trends of exposure of SEGs from 2014 to 2020.

Overall, the average annual dose for the entire workforce was 1.4 mSv per year, like the level monitored in 2019. The average annual dose of 1.4 mSv is significantly lower than the occupational legal limit of 20 mSv/a.

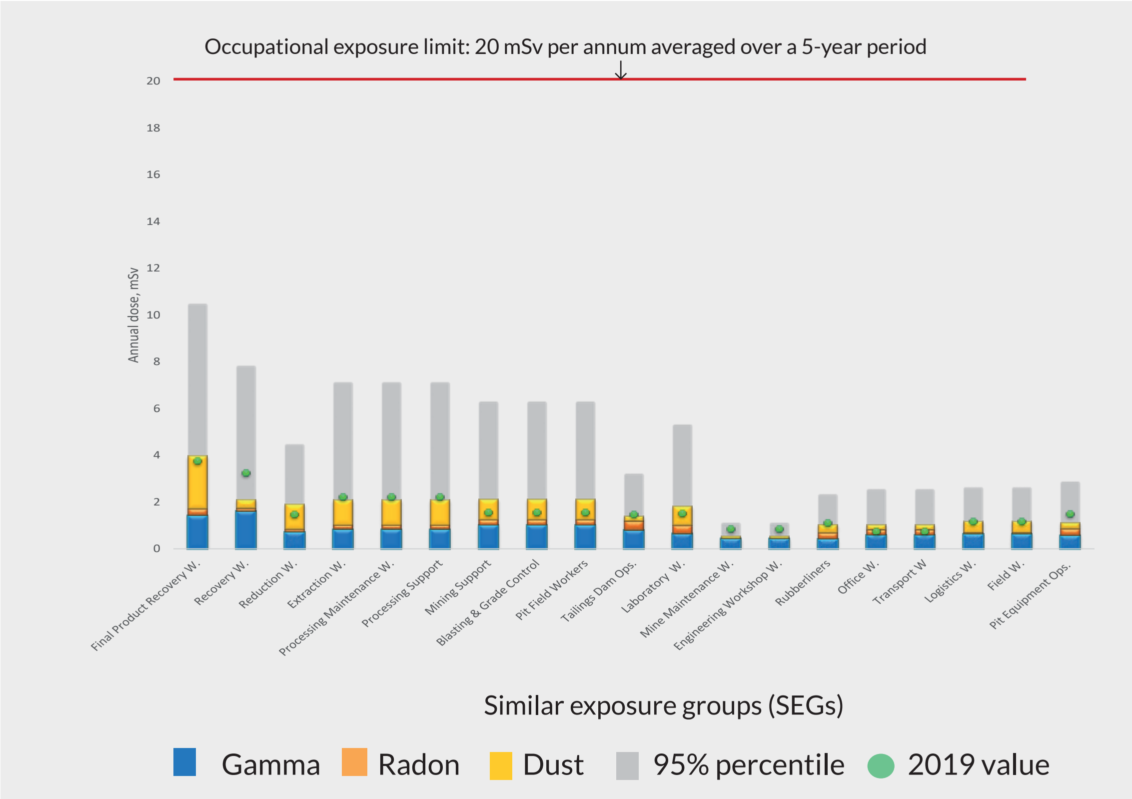

Figure 2: Average radiation dose recorded by pathway and SEG in 2020.

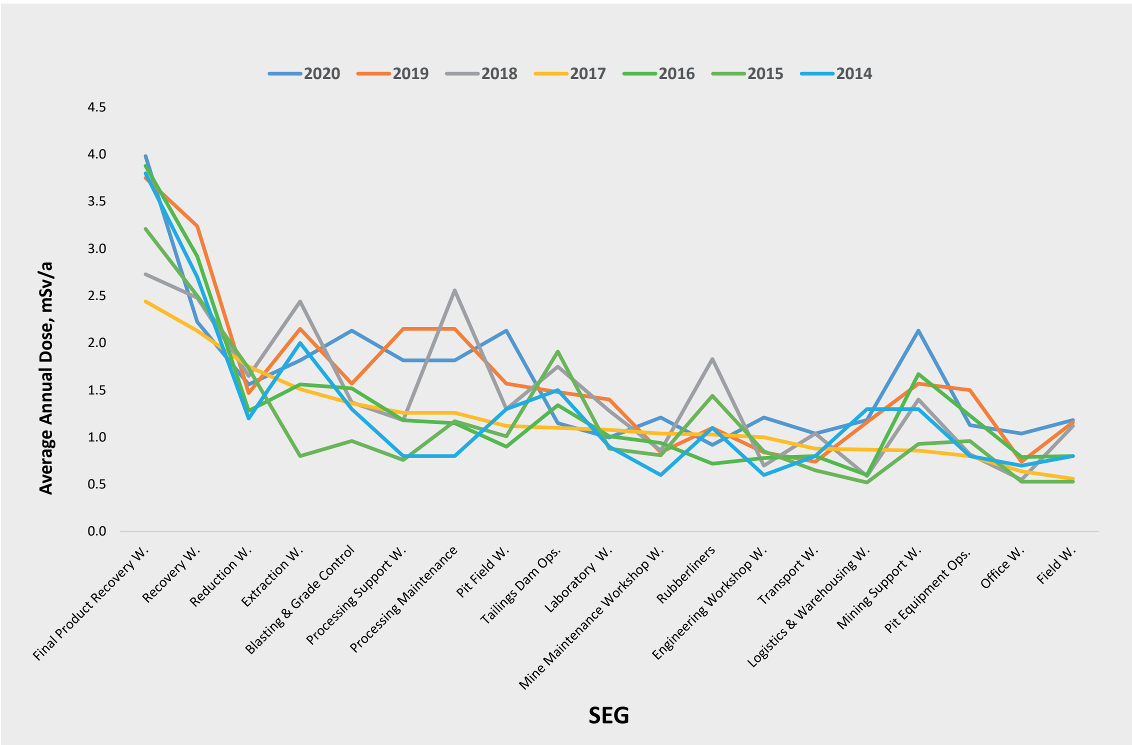

Figure 3: Shows trends in exposure for different SEGs.

3.2 Radiation workers and controlled areas

Workers who are classified as "radiation workers" are at risk of receiving a dose of 5 mSv/a or more from all exposure pathways combined. These workers, who belong to the SEGs of Final Product Recovery (FPR) workers and Recovery workers, are provided with thermoluminescent dosimeters (TLDs), which are replaced at intervals of three months. Areas are signposted to remind employees of the need to wear the dosimeters (Figure 4).

Figure 4: TLD signpost inside Final Product Recovery area.

In 2020, the annual total doses recorded were 3.98 mSv/a for FPR workers and 2.2 mSv/a for recovery workers. The dose for FPR workers increased only slightly from 3.75 mSv/a, while the recovery workers dose reduced from 3.24 mSv/a measured in 2019. The highest percentage of the total dose for FPR workers was LLRD with about 57 per cent of the total dose, while gamma and radon contributed 36 per cent and 7 per cent, respectively. The exposure distributions for Recovery workers were 13 per cent caused by LLRD, 81per cent by gamma and 6 per cent by radon decay products. Figure 5 compares the overall average, total effective doses for FPR and recovery workers from 2010 to 2020, indicating that they have been continually below 5 mSv/a.

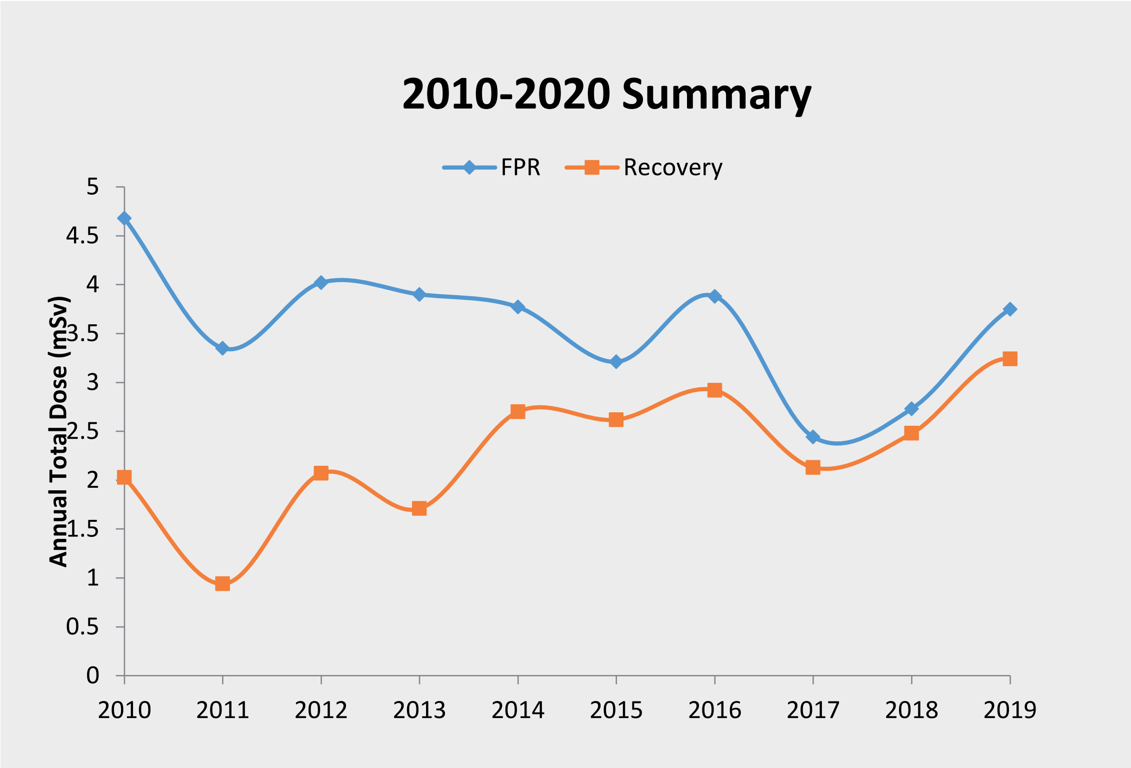

Figure 5: The average annual doses for FPR and Recovery workers from 2010 to 2019.

The FPR area is a restricted, controlled area, with access restriction, fingerprint control and contamination checks for exiting persons. Due to exposure to uranium dust, the wearing of respirators is mandatory. It is conservatively assumed the use of respirators reduces the annual LLRD dose by 90 per cent (respiratory factor). To ensure clean working conditions, we have set a target of a maximum average, non-fixed surface contamination of 1 Bq/cm^2 and a maximum average dust inhalation dose rate of 10 μSv/h.

In 2020, our target of 1 Bq/cm^2 non-fixed surface contamination in the FPR area was reached with an average of 1 Bq/cm^2. There was not much significant improvement from 2019, which had a level of 0.9 Bq/cm^2.

A summary of the average surface-contamination measurements for 2020 is provided in Figure 6.

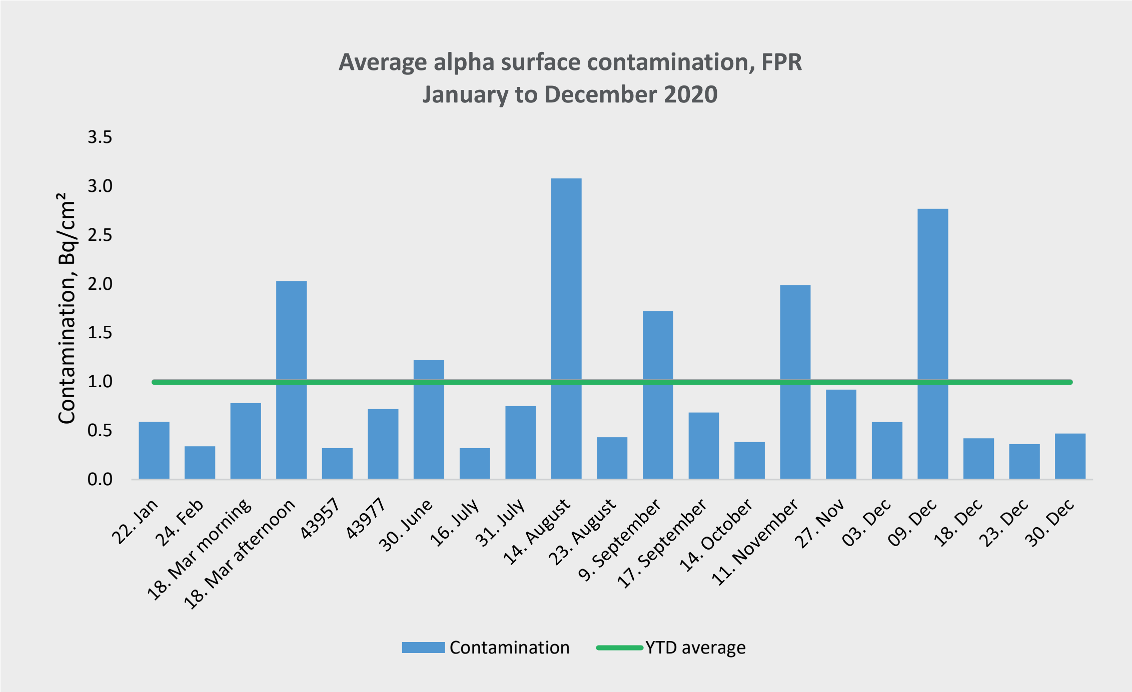

Figure 6: Summary of the average non-fixed surface contamination measurements for 2020.

Radiation workers are invited to regularly provide urine for testing of its uranium content. The urine testing is more to confirm the adequacy of controls that are put in place. Monthly pregnancy tests ensure that pregnant radiation workers are moved immediately to a less exposed area.
We analysed 27 pregnancy tests of female radiation workers, as well as 24 additional pregnancy tests of females not classified as radiation workers.

In 2020, 693 urine samples were analysed to determine their uranium concentration, about 52 per cent of the previous year.

Samples continued to be sent to PathCare laboratories in South Africa since the accreditation of the local service provider, the Trace Element Analysis Laboratory (TEA Lab) in Swakopmund, is still pending. Shipping to South Africa delays the return of the results for up to three weeks or more; the TEA Lab requires only one week to return test results. (At the time of finalising this document, accreditation for the TEA Lab had been granted.)

A detection (i.e. threshold) limit for uranium in urine is about 5 µg/L, the warning level is 20 µg/L and the action level is 40 µg/L. A summary of the results is shown in Figure 7, indicating that most individual results were below or close to the detection limit, 5 µg/L, and significantly below the warning level.

However, on three occasions, the uranium-in-urine analysis revealed a concentration higher than the warning level. Unfortunately, two of the readings belonging to two different employees were above the action level of 40 ug/L (data not shown in Figure 7)

After we received the result exceeding the action level, the workers were immediately informed by the acting RSO, were brought for a medical

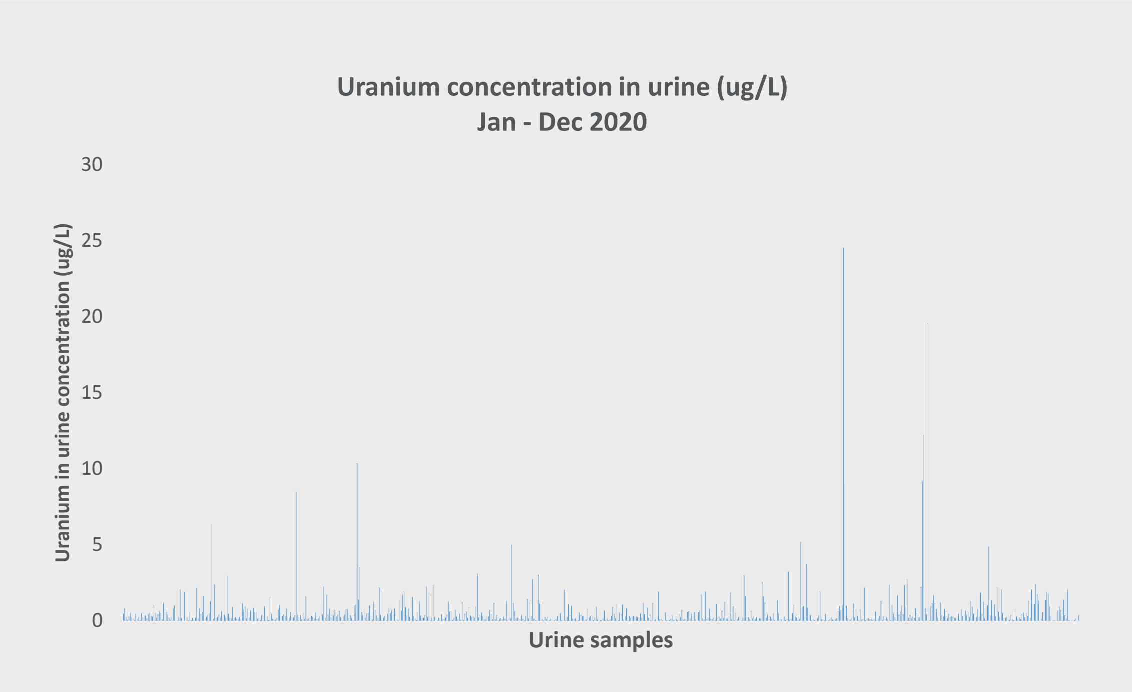

Figure 7: Uranium-in-urine sampling results, 2020

examination and transferred to a different work area. Subsequently, the workers were frequently examined, until it was established that their renal function and integrity had returned to normal. The work procedure in the area where the worker had been employed was revised to minimise the possibility that further cases of uranium-in-urine levels would exceed the limit. The regulator has been informed of this incident and a visit followed to understand the incident better. The recommendations given by the inspectors were implemented.

3.3 The rod mill tunnels

Radon (radon-222) is part of the uranium decay chain and, being a noble gas, can escape the matrix of the rock and soil in which it is formed. When radon reaches open air, it disperses quickly. However, when radon enters an enclosed space or confined atmosphere, such as a tunnel, cave, or building, it cannot disperse as easily. Therefore, it is usually found at higher levels than outdoors, resulting in exposure to workers working in those areas. The reference level (limit) for radon concentrations for the workers is 1,000 Bq/m³.

At the end of 2019,an average of above 1,000 Bq/m³ was measured between the four rod mill tunnels. Monitoring continued in 2020 to determine the changes in radon concentration levels. After investigation, it was discovered that the high concentration was caused by poor ventilation in the tunnels, resulting from ore built-up that has blocked the openings at the end of the tunnels. The location of the measuring instruments is shown in Figure 8.

Figure 8: A rod mill tunnel (left) – the arrow shows the location of the monitoring equipment close to rear of tunnel.

A project was initiated to open all ends of rod mill tunnels to increase ventilation of the indoor spaces with outdoor air to reduce radon levels, thereby drastically reducing the radon exposure to personnel working in the tunnels. The level of radon concentration dropped just to below 1,000 Bq/m³ after the cleaning exercise. To optimise worker protection for employees intending to carry out work in the tunnels and to keep exposure as low as reasonably achievable, work in the tunnels have been restricted to 6 hours per day, although historically, workers usually work in the tunnels not longer than four hours per shift. The tunnels are signposted to provide awareness to those entering the area as indicated in the image below (Figure 9).

Figure 9: Rod mill tunnels with time restriction signage.

3.4 FPR stack monitoring

In the FPR area, five stacks are employed, three of which are low-emission, and venting stacks from the FPR building and two are from the FPR roasters. As the latter two are fed with exhaust from the uranium roasting process, emissions are monitored and controlled.

Stack emissions monitoring or sampling is an annual exercise and commitment as per Rössing commitment in the Rössing internal criteria on air quality to manage and monitor impacts all sources. The commitment is as per international best practice, because there are no defined limits and regulations on stack emissions in the Namibian regulatory framework. Therefore, emissions limits from the South African Listed Activities legislation (GN 893 of 2013) have been used as emissions guidelines. Subcategory 4.1, described as “drying and calcining of mineral solids including ore”, is most applicable to the roasters at Rössing. Emissions guidelines have only been applied to the outlet of Roaster Scrubber 2 and the baghouse, and not the roaster inlet. The roaster inlet concentrations were only measured so that the efficiency of the roaster scrubbers could be evaluated.

In 2020, during the period 26 November 2020 until 03 December 2020, a contracted company, Yellow Tree, conducted emissions sampling on five stacks at Rössing. The most relevant stacks in this report are FPR stacks.

The efficiency of the scrubber for PM emissions was found to be 75 per cent, 80 per cent for uranium and 92 per cent for SO_2 emissions. It is encouraging to note that PM and uranium are removed at a very similar efficiency, as the majority of uranium is in particulate form. The emissions are checked and regularly tracked at business level and is part of annual improvement plan/strategies. As such the business has made a decision to improve various FPR roasters components in the past year and Rössing is currently busy reviewing an option to replace the entire roaster and its scrubbing system.

3.5 Radiation-awareness training

Radiation awareness training at Rössing continued in 2020. These included the Radiation Safety Induction and Refresher Courses, as well as Final Product Recovery and the Recovery areas training modules. A total of 290 Rössing employees and contractors were trained in several courses.

In order to share information about Rössing’s radiation protection programmes with the public, we make many of our reports, fact sheets and booklets available on the Rössing website under the ‘Reports-and-Research’ tab. Apart from the RMP and RMP implementation reports, we share technical information regarding environmental risk, as well as fact sheets and booklets about radiation protection in uranium mining. Information on radiation safety is also shared via the Uranium Institute and at mining and trade fairs.

3.6 Communication of monitoring outcomes to employees

One week after personal radiation exposure monitoring, a group report is prepared, summarising and explaining the monitoring outcome. This report is shared with the respective team in team discussions where practicable, but in most cases results are shared through email.

At the end of the year, all reports are shared with the respective teams via emails.

Results of urine sampling are communicated to individuals only if they exceed the warning or action levels or upon request.

All individual exposure dose results and urine sampling results are treated with confidentiality, but are available to the worker via the Rössing intranet. Each employee only has access to their own data. Workers without computer access can receive their uranium-in-urine levels via the Radiation Safety Section.

3.7 Dust levels in FPR

Monitoring programmes of the radioactive dust in selected FPR areas supplement the personal dust monitoring data. We have established an internal LLRD target of 10 μSv/h without correction for respirator use.

Since installation of the new automated drum filling assembly in early 2018, the dust level in the drum filling area has been significantly reduced. The average dose rate for 2020 was 0.8 mSv/a. Employees continue to use half-face respirators in this area.

4. Medical **exposure**

Not applicable.

5. Public exposure **protection**

5.1 Background

The dose limit for public exposure to mining activities at Rössing is 1 mSv per year on average. This dose limit does not factor exposure to background sources, neither natural nor man-made. The natural background radiation in the Erongo Region is approximately 1.8 mSv/a, while an additional dose from mining activities to critical groups in the public can be described as “very low” to “negligible”. It is therefore not possible to measure the public dose[2] directly; it must be calculated from first principles after determining the factors that potentially contribute to this public dose.

[2] The additional dose to which the public is exposed due to mining-related activities is referred to as the “public dose”. This factor explicitly excludes background-related sources of radiation exposure dose.

At Rössing, the critical population group subject to radiation exposure are the residents of Arandis. No critical group has been identified that would be affected through groundwater contamination, since the direction of water flow from the mine is to the south, towards the Khan River. Nevertheless, groundwater contamination is controlled.

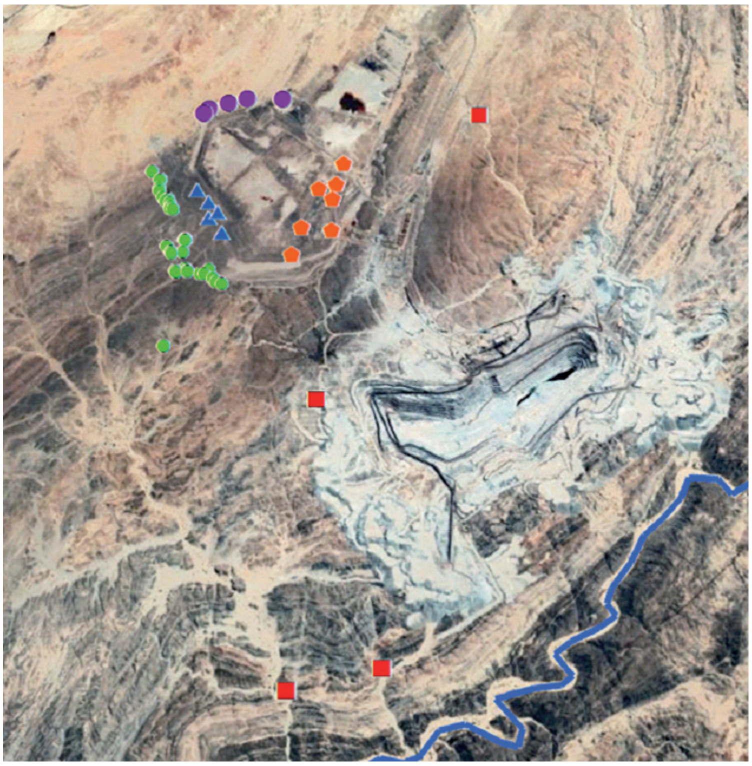

Figure 10: RUL seepage control pumping sites (NTSC in purple circles, TDDS in blue triangles, TDX in orange pentagons, DW in green circles& TRENCHES in red squares) and Khan River (blue solid line).

5.2 Water monitoring

At Rössing, wet tailings from processing uranium ore are stored in an unlined Tailings Storage Facility (TSF). There exists a hydrologic connection between the TSF and the Khan River aquifer, which is located down-gradient, through alluvium and fractured rock aquifers. The Khan River aquifer is identified as the sensitive receiving environment, which is to be protected against seepage emanating from the TSF.

Processed water recovery starts at the decant ponds, where upon deposition on the TSF, surface runoff water is directed to the engineered low point within an active paddy and pumped as return dam solution into the Processing Plant. Water which infiltrates the TSF is retrieved through pumping from several networks of abstraction boreholes, sumps, and trenches.

The abstraction network starts on the TSF and extends further down-gradient into the fractured rock and alluvium aquifers (Figure 10).

Water monitoring at Rössing entails checking variations in water levels and water quality across a network of monitoring boreholes located at various points around the TSF, and along the aquatic pathway towards and within the Khan River. Increases in water levels (outside natural recharge due precipitation) are used as early indicators of seepage movement. They are often followed by changes in chemical composition of groundwater particularly in mining environments.

Water quality monitoring is conducted based on an adaptive sampling schedule, which was agreed upon with the regulator (Ministry of Agriculture, Water and Land Reform) in 2018.

In Figure 11, boreholes used for seepage plume delineation are depicted; also shown are sample locations where radionuclide analysis were conducted - here uranium ratios (234U/238U) are given. All data presented in Figure 11 is summarised in Table 1.

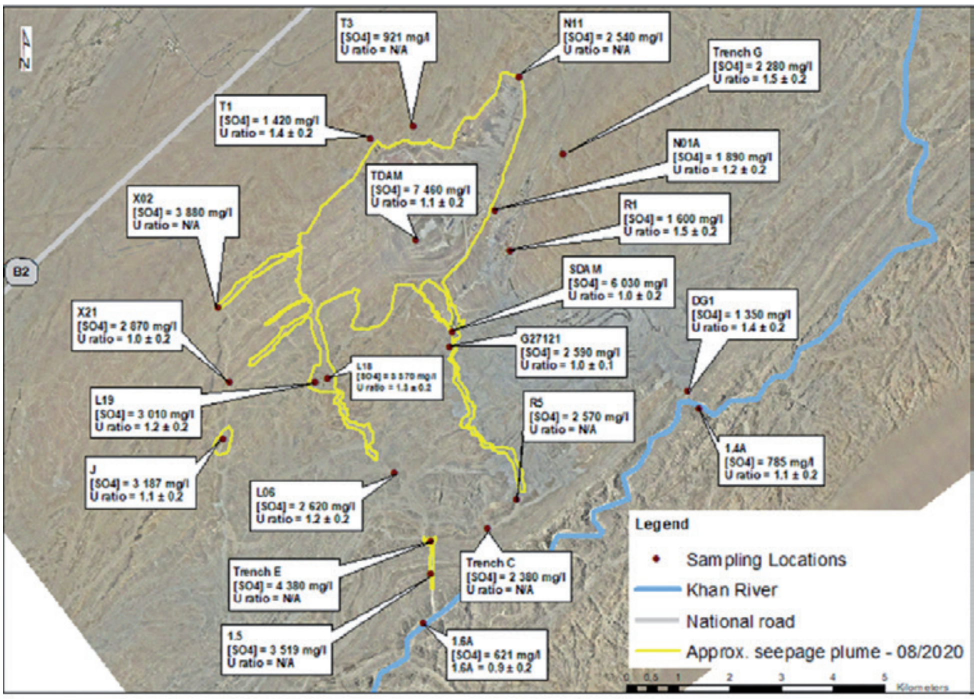

Figure 11: Sampling locations for sulphate and radionuclides.

Rössing continuously investigates scientific methods to better track the seepage plume. It is widely accepted best practice to validate any hypothesis obtained by statistical means with one or several supporting methods. .

In 2020, 15 groundwater samples were taken for radionuclide analysis and sent to an accredited laboratory[3]. Based on the analysed uranium isotopes, the boreholes are categorised into ratio

- < 1 uranium from mining related activities (red)
- ≥ 1 uranium from natural sediment (green).

The interpretation is conclusive for the 8 samples (with green diamonds), as indicative of uranium from natural sediment (Figure 12). No ratio shows a value smaller than one, which would indicate the source of uranium related to mining.

In 2020, physiochemical analysis was done on water samples collected from 64 locations (boreholes and ponds). Figure 13 depicts sulphate concentrations for some locations; only those locations where radionuclide analysis was done and those locations which are classified as primary locations (under the Rössing sampling procedure) are included in the chart. According to the sulphate concentration method, concentrations above 3,000 ppm are within the seepage plume.

The objective behind plotting Figure 13 is to show how using the uranium ratio method (shown in Figure 12) correlates to that of using the sulphate concentration (Figure 13). Although Rössing plume delineation is only based on the sulphate concentration method, observations from Figure 12 and Figure 13 are summarised in Table 1.

[3] Figure 12 depicts uranium ratio calculations at each location with consideration to the relative expanded measurement uncertainty, U [%].

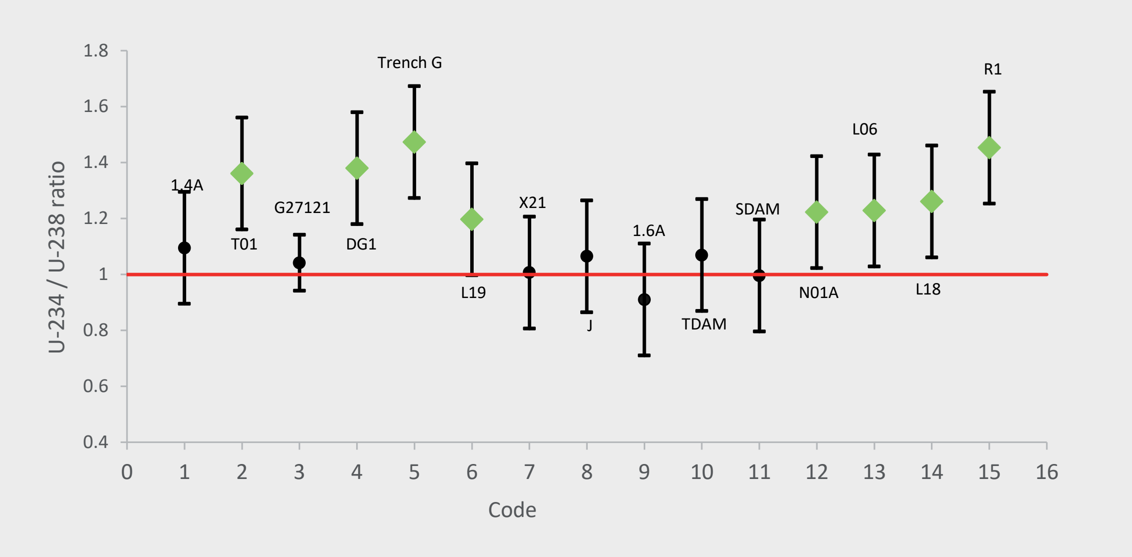

Figure 12: Uranium ratios with associated analytical errors.

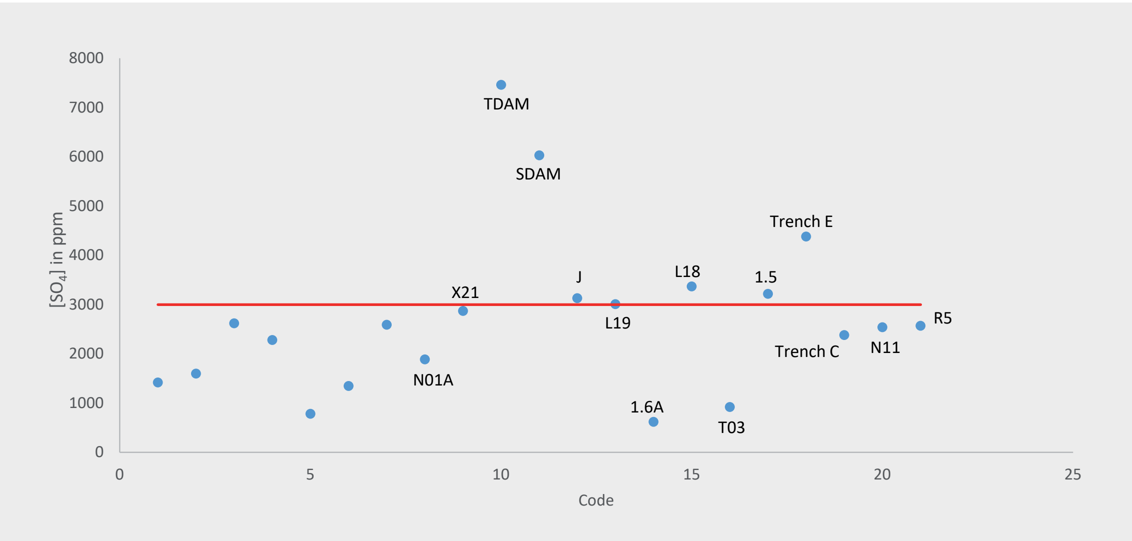

Figure 13: Sulphate sampling locations.

Although the sulphate concentration method is accepted for plume delineation, discrepancies observed in Table 1 prompted the need to investigate other analytical methods. To this regard, in 2019, Rössing sampled selected boreholes for environmental isotope analysis with focus on stable isotopes deuterium (H2) and oxygen-18. The objective was to investigate if water sourced from desalination (as done by the mine in recent years) would show a different isotope signature compared to background/natural groundwater inherent to the mine site, and further how these two waters (background and desalinated) would compare against that in the Khan River alluvium aquifer (as our sensitive receiving environment and considering its occasional recharge).

In Figure 14, deuterium and O-18 plot clusters the results into four groups. The most notable group is that which is depleted in O-18 (Transect

Table 1: Comparison on Uranium ratio against sulphate concentrations.

Location	U_{234}/U_{238}		$[SO_4]$ ppm	Remarks
	Ratio	Error ratio		
T1	1.4	0.2	1420	Methods agree that location is not impacted by seepage.
R1	1.5	0.2	1600	Methods agree that location is not impacted by seepage.
L06	1.2	0.2	2620	Methods agree that location is not impacted by seepage.
Trench G	1.5	0.2	2280	Methods agree that location is not impacted by seepage.
1.4A	1.1	0.2	785	Borehole not impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
DG1	1.4	0.2	1350	Methods agree that location is not impacted by seepage.
G27121	1.0	0.1	2590	Borehole not impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
N01A	1.2	0.2	1890	Methods agree that location is not impacted by seepage.
X21	1.0	0.2	2870	Borehole not impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
TDAM	1.1	0.2	7460	Location impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
SDAM	1.0	0.2	6030	Location impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
J	1.1	0.2	3130	Borehole impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
L19	1.2	0.2	3010	Location impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
1.6A	0.9	0.2	621	Borehole not impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
L18	1.3	0.2	3370	Borehole impacted by seepage, however, methods do not concur when analytical error on the uranium ratio is considered.
T03	N/A	N/A	921	Not impacted by seepage. Borehole not on the radionuclide analysis list.
1.5	N/A	N/A	3220	Impacted by seepage. Borehole not on the radionuclide analysis list.
Trench E	N/A	N/A	4380	Impacted by seepage. Borehole not on the radionuclide analysis list.
Trench C	N/A	N/A	2380	Not impacted by seepage. Borehole not on the radionuclide analysis list.
N11	N/A	N/A	2540	Not impacted by seepage. Borehole not on the radionuclide analysis list.
R5	N/A	N/A	2570	Not impacted by seepage. Borehole not on the radionuclide analysis list.

5A, 1.6A and DBH2), and the three samples in that group are the only samples taken from various location in the Khan River (specifically the Rössing catchment/basin). Samples from Trench G and K are also interesting, as they are taken from locations defined well outside the seepage plume.

Samples SG01 and SG02 are reference samples collected from a portable water tap on the mine. What these two samples represent, is the isotope signature in the water, which is used in the Processing Plant. Why these two samples are slightly enriched in deuterium relative to the rest is worth further investigation. However, what is evident is their enrichment in O-18 just like the rest of samples to be discussed next.

The next clusters of samples cannot conclusively be used to support the sulphate method of plume delineation, as there are a few discrepancies/exceptions to the norm, such as S09, N19 and T02, which are outside the plume.

The rest of the samples are within the seepage plume, as defined with the sulphate concentration method. Also worth mention is their relation to samples SG01 and SG02, which supports the possibility of being from a similar source (desalinated water).

With more investigations, there is potential that stable isotopes could be used to support the sulphate concentration method. One such investigation is to broaden the scope and look in greater detail at the sulphur-34 isotope (S34), which could also show variations in sulphur content between sulphuric acid used in the Processing Plant and that found within the natural environment.

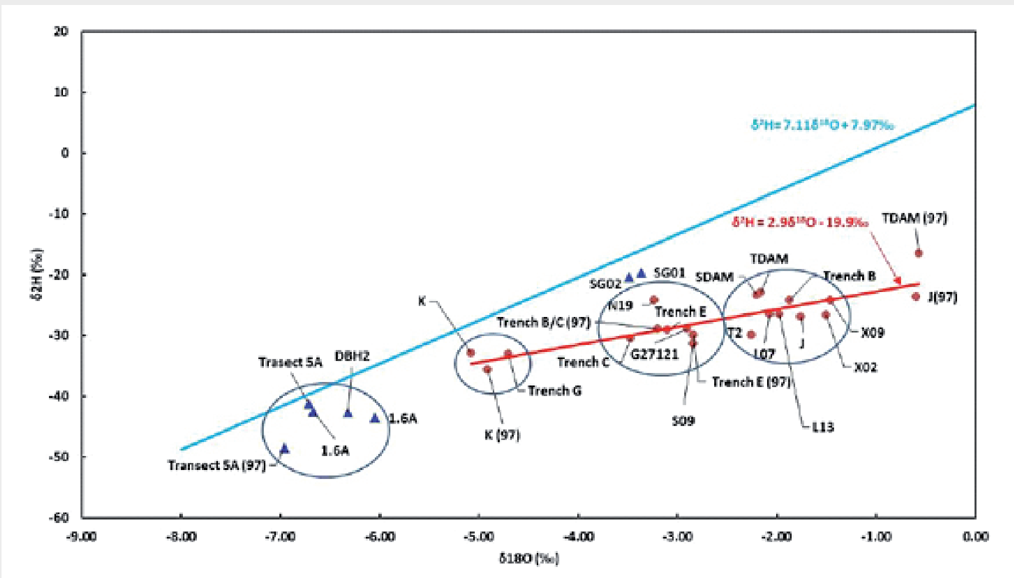

Figure 14: Stable isotopes - Deuterium (H2) vs Oxygen-18 plot. (Source: Prof. T. Abiye, 2020)

5.3 Dust monitoring

The public dose from dust inhalation can be calculated through measurements of the concentration of dust in the air. The size of particles inhaled correlates inversely to the potential health risks. Small particles, i.e. less than 10 micrometres in aerodynamic diameter, pose the greatest risk, because they can enter the lungs as inhalable dust.

Several dust monitoring stations have been placed at strategic locations around the mine site. Here the concentration of dust particles smaller than 10 microns is measured in 15-minute intervals. This dust is referred to as "particulate matter smaller than 10 microns", or PM_{10} for short. The locations of PM_{10} stations include, among others, Arandis, the Rössing TSF, and the western mine boundary.

The PM_{10} sampler at Arandis provides the PM_{10} dust concentration, wind speed and wind direction in intervals of 15 minutes. This justifies the allocation of a dust concentration as mining related (if the wind blows from the mine) or identifies it as background (when the wind is blowing in any other direction). This principle is illustrated in Figure 17.

The overall average PM_{10} dust concentration measured was on average 0.02 mg/m³, which is below the WHO guideline value for outdoor air quality of 0.075 mg/m³ when averaged over one year (Figure 16).

To establish an acceptable upper limit of the annual dose by mine dust, it is assumed that all PM_{10} dust in Arandis is ore dust coming from the mine. We further make the realistic assumption that the ore dust is in secular equilibrium, the particles have an aerodynamic diameter of 5 μm on average, and that the ore dust contains 400 ppm uranium. A PM_{10} concentration of 0.02 mg/m³ of such ore dust corresponds to an annual dose of about 18.8 μSv per year, i.e. 0.019 mSv per year.

The legally-acceptable annual dose limit for the public is 1 mSv per year, meaning all the PM_{10}

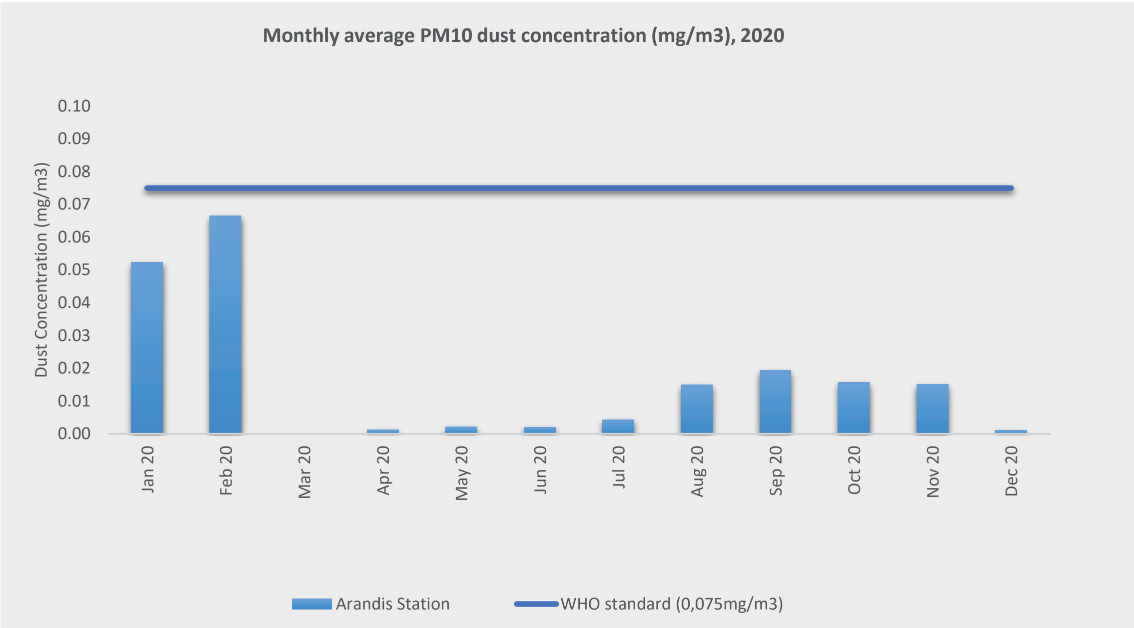

Figure 16: Arandis PM10 concentrations averaged per month, 2020.

dust in Arandis assumed to be radioactive ore dust may legally only contribute to about 2 per cent of the legal limit. Therefore, it can be asserted that the contribution of potential radioactive dust to the public dose is negligible.

In addition to the PM_{10} monitoring, long-lived radioactive dust (LLRD) was monitored using MYRAM monitors at Arandis town and Arandis airport. The highest dose to the public was recorded at Arandis airport with 0.19 mSv/a.

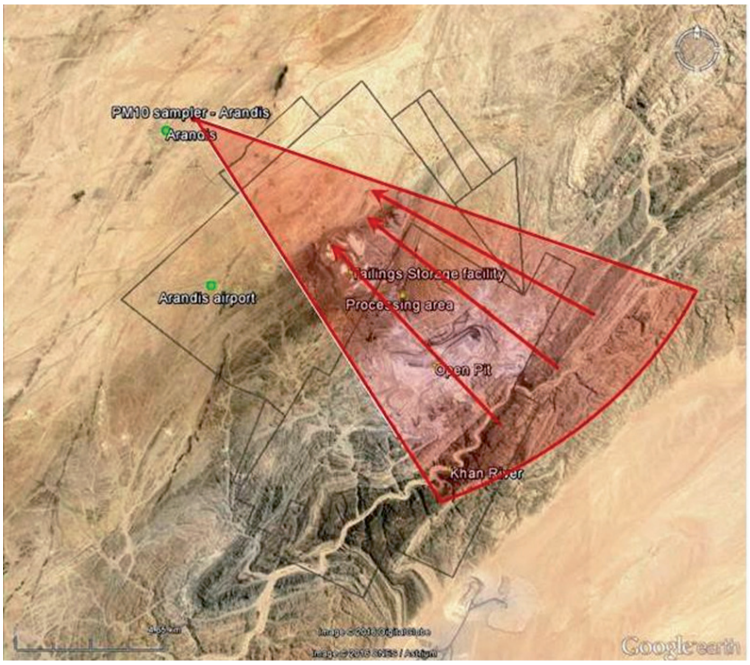

Figure 17: A satellite image showing those wind directions at the mine that could result in radioactive dust exposure at Arandis.

5.3 Radon monitoring

In 2020, Rössing undertook public monitoring for radon decay products concentrations directly for outdoor air with Doseman Pro monitors at Arandis town and Arandis airport. However, it is difficult to distinguish the radon contributions of mining operations from those of background contributions.

The radon progeny concentration for outdoor was found to vary from 5 to 23 $Bq.m^{-3}$ with an average of 12 $Bq.m^{-3}$at Arandis town, while Arandis Airport varied from 4 to 18 $Bq.m^{-3}$ with an average of 11 $Bq.m^{-3}$. Near the tailings dam, the radon progeny concentration for outdoor was found to vary from 4 to 7 $Bq.m^{-3}$ with an average of 5 $Bq.m^{-3}$. The highest dose from radon decay products exposure for the members of the public was recorded at Arandis airport with 0.64 mSv/a, including background.

6. Safety and **security of sources**

6.1 Sealed source register

The status of the sealed sources remains unchanged. All the sources on site are stored in the Radiation Storage Facility. Refer to Table 2 for a complete list of sources held at the mine. The license issued for use and operation of all our sources is SSL/113/13, which will expire in June 2021.

Three low-activity calibration sources are kept at the Radiation Safety Laboratory (Table 3).

Table 2: List of sealed sources at Rössing Uranium (radionuclide of all sources is Cs-137)

Serial Number	Activity (GBq)	Location	Use	Comment
27255 N	37,8	Radiation Store	Level	Not in use
004/12	31,6	Radiation Store	Level	Not in use
H500081140	37,0	Radiation Store	Level	Not in use
005/12	31,6	Radiation Store	Level	Not in use
70682	0,2	Radiation Store	Level	Not in use
2771	13,2	Radiation Store	Level	Not in use
PA 304	0,3	Radiation Store	Density	Not in use
PA 299	0,3	Radiation Store	Density	Not in use
PA 301	0,3	Radiation Store	Density	Not in use
PA 302	0,3	Radiation Store	Density	Not in use
PA 298	0,3	Radiation Store	Density	Not in use
PA 297	0,3	Radiation Store	Density	Not in use
2772	13,2	Radiation Store	Level	Not in use
2770	13,2	Radiation Store	Level	Not in use

Table 3: List of calibration sources at Rössing Uranium

Nuclide	Type of source	Half-life (years)	Initial activity (kBq)	Date of manufacture	Time elapsed (years)
Cs-137	Beta	30	3	2011/12/13	9
Th-230	Alpha	75,000	1	2011/12/16	9
Nat U	Alpha	4.5 billion	1.4	2017/01/09	3

6.2 Sealed source checks

Every 6 months, the sealed sources are inspected and tested for leakages. A service provider was identified and agreed to remove our sealed sources. All sealed sources are planned for disposal in 2021; the process to export them already commenced in 2020.

6.3 X-ray generating equipment

The Rössing chemical laboratory uses two analytical x-ray units, as per registration and license EPL/113/01/18, which will expire in 2021.

7. Transport of radioactive material

7.1 Transport and export of UOC

With the authorisation TRM/113/01/20/ET, Rössing transported uranium oxide to overseas converters. A total of 2, 680 tonnes of uranium oxide of chemical composition U_3O_8 (whose content was 2, 272 tonnes of uranium) were exported in 2020, and is summarised in Table 4.

Table 4: List of UOC shipments from Rössing Uranium in 2020			
Shipping date	**Country of final destination**	**Quantity of exported (kg)**	**Quantity of contained element (kg)**
17 January 2020	Canada	180,358.539	152,944.041
29 February 2020	Canada	183,629.389	155,717.722
16 March 2020	Canada	240,496.134	203,940.722
21 March 2020	China	302,180.260	256,248.860
26 April 2020	China	316,007.089	267,974.011
01 May 2020	Canada	241,229.802	204,562.872
19 August 2020	China	356,195.727	302,053.976
14 September 2020	China	346,723.376	294,021.423
22 October 2020	China	256,541.662	217,547.329
25 November 2020	China	256,379.546	217,409.855
		2,679,741.52	2,272,420.81
Total in tonnes		2,680	2,272

8. Emergency **preparedness and response**

A uranium-spill drill was conducted in 2020 by Rössing in collaboration with other operators in the region. The drill took place at the Walvis Bay harbour and the regulator took part as one of the observers. The report of this drill is attached to this document. However, Rössing also has a procedure, *JK60/PRD/009-Uranium Oxide Spillage,* in place for emergency response to uranium spills. This procedure is reviewed on a regular basis.

9. Disposal of **radioactive waste**

9.1 Disposal of contaminated non-mineral waste

In 2020, a total of 1,558 tonnes of contaminated solid waste were deposited on the TSF. The cumulative total of stored non-mineral contaminated waste is 32,206 tonnes.

9.2 Mineral waste

Both tailings material and waste rocks deposited without processing are regarded as mineral waste. In 2020, 8,718,593 tonnes of tailings were deposited onto the TSF, which now holds a cumulative amount of roughly 474.2 million tonnes of tailings material. Another 10,357,576 tonnes of waste rock were deposited onto the Waste Rock Dumps, bringing the cumulative total of waste rock material deposited to roughly 991.7 million tonnes of material. The exposed surface area of the two mineral waste storage facilities remained approximately the same since 2016 and cover an estimated area of 1,488 ha.

10. Research

In 2014, Rössing began to conceptualise a study to establish whether potential links exist between workforce exposure to occupational risks, notably radiation exposure, and adverse health conditions.

The research was explained in detail in the Implementation of Radiation Management Plan 2017. It is our pleasure to report that the study has been concluded and the outcome of the study was shared with the stakeholders and the public in January 2021.

The cancers of interest that were considered in relation to exposures at Rössing mine were lung cancer and cancers of the extra thoracic (upper) airways, leukaemia, brain cancer and kidney cancer.

This study does not provide strong evidence that radiation or other exposures at the Rössing mine caused an increased risk of cancers in the workforce.
However, there are important uncertainties in the study findings and interpretation due to the suboptimal quality of the cancer registry data, as well as considerable uncertainties in some of the dose estimates, particularly those to the lung from radioactive dust and uncertainty in some other key variables (e.g., smoking).

More information and the summary of the results on the health study are published on the Rössing website, http://www.rossing.com/reports-research2.htm. This site is also used to share detailed information with the public regarding Rössing's performance. Environmental impact assessments and closure plans, environmental and biodiversity management plans, and discussion of some frequently-asked questions about the mine's management of health and environmental issues are also published on the site. Rössing's RMP and its annual reports to the NRPA are presented there for public information.

11. Conclusions

The monitoring results show that radiation exposure at Rössing Uranium is very low. The monitoring data for the public clearly indicates an annual dose below 1mSv per year, which is the legal public limit.

We will continue making relevant radiation safety information available to the public. This will help the stakeholders such as communities to put risk into perspective and to address concerns to the relevant persons at Rössing.

Awareness of the risks related to radiation remains a focus, and awareness sessions facilitated by trained experts for all workers remain an important and deliverable programme.

In addition to the regular monitoring activities described above, we decided to especially focus on:

- The removal of sealed radioactive sources from site for disposal.
- Internal and external training for all Radiation Safety team members, as well as participation in online workshops/ conferences;
- Strengthening our induction training approaches for the workforce;
- Continuing with the implementation of the graded monitoring approach;
- Further reduce levels of uranium dust in the Final Product Recovery area;
- Intensify radon monitoring on site and public monitoring in general; and
- Continue radioactive dust survey at the mine.

[Notes]

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