Rössing Uranium Limited
Working for Namibia

Report: Baseline and Mining-related Radon Concentrations in the Rössing Mining Area

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Abstract

A radon survey across an area covering 16 km by 16 km and including the Rössing Uranium mine site and surrounding areas was performed over a 3-year period. Track etch radon gas monitors were placed 1 m above the ground at a total of about 100 locations within this area.

Baseline average radon concentrations were found to range from 54 Bq/m^3 (in the Arandis area) to 63 Bq/m^3 (Dome area) over the monitoring period. Radon concentrations in the areas affected by mining were found to range on average from 96 Bq/m^3 (Operations area) to 162 Bq/m^3 (Tailings Storage Facility area) when measured outdoors.

Abbreviations

The following abbreviations are used throughout in this report:

Bq/m^3	–	becquerels per cubic metre (unit to quantify the radon activity concentration in air)
mSv	–	milli-sievert, i.e. 10^{-3} sievert
mSv/a	–	milli-sieverts per annum

1. Introduction

Radon is a ubiquitous radioactive gas that emanates from soils and rocks containing uranium. Mining activities result in large quantities of material being excavated and the production of huge quantities of crushed and milled ores. Size reduction and exposure of previously unexposed rock material result in the additional exhalation of radon from crushed material and disturbed soils. With a radioactive half-life of 3.8 days, the ease with which radon exhales into the air depends on:

1. the proximity of uranium-bearing material to the ground surface
2. the grain size of material exposed to air, and
3. environmental factors such as air flow, temperature, humidity, and air pressure.

In order to determine the mining-related radiation exposure dose from the inhalation of radon and radon decay products, it is necessary to determine the radon concentrations in locations which are undisturbed by mining activities, as well as in locations where disturbed ground is found. This will enable a comparison between undisturbed pre-mining conditions and disturbed mining-related radon sources, and to evaluate the potential impacts of the latter.

The first survey of this kind was performed in the Rössing Uranium Limited mining area over a period of one year between 1987 and 1988 [1]. Track etch radon gas monitors were placed at positions on a 16 km x 16 km grid covering the site of mining activities and the surrounding areas. In the area directly affected by mining activities, monitors were placed 1 km apart, while in more remote locations monitors were placed 2 km apart. A total of 108 monitors were used to cover the grid. Monitors were left in the field for periods of three to four months, resulting in three separate data sets over the measuring period. The results of the survey indicated that the baseline radon activity concentration in the area not directly affected by mining activities was 50 Bq/m^3. A three-dimensional graph displaying the atmospheric radon activity concentrations determined in the survey area is shown in Figure 1.

These measurements were used to develop the first model for the dispersion of mining-related radon concentrations at Rössing Uranium [2].

The purpose of this report is to compare present-day conditions and measurements with the results of this earlier survey so that the reliability of the data obtained using this method can be ascertained.

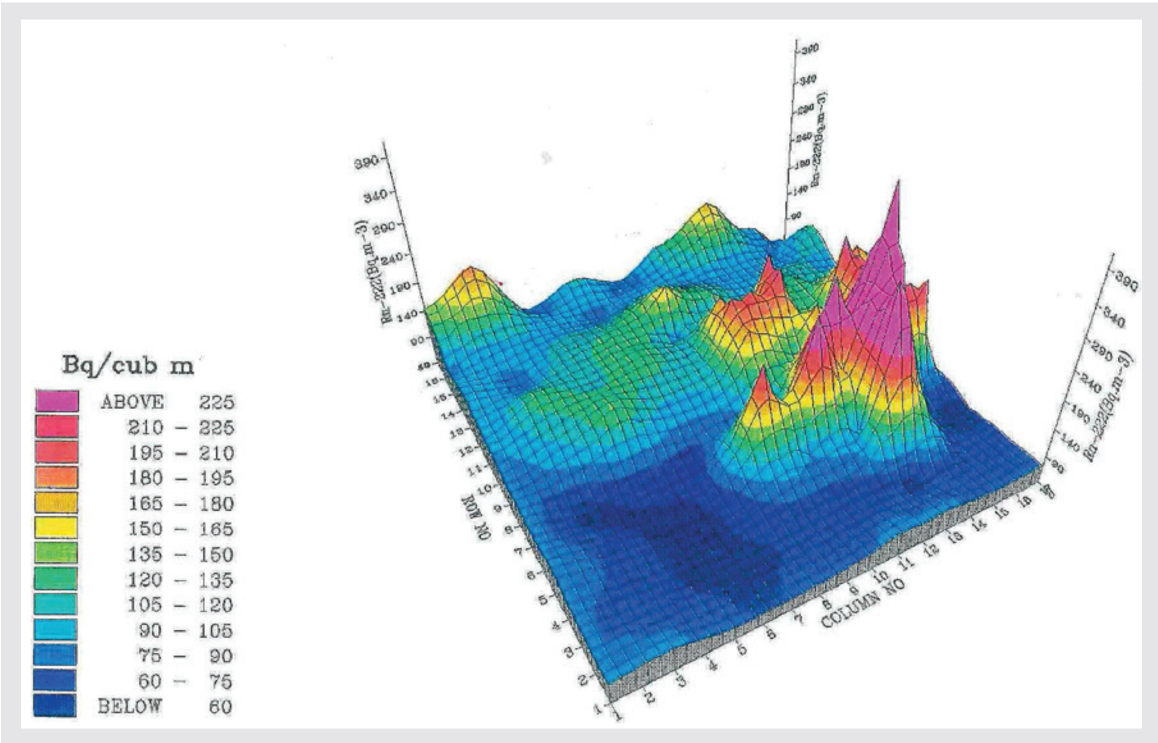


Figure 1: Radon concentrations measured during the 1987/88 Rössing Uranium radon survey

2. Method

A new site-wide radon survey was started in November 2010 and was completed in April 2013. Measurements were carried out by personnel from the Radiation Safety Section at Rössing Uranium.

The purpose of this repeat survey was to

- Confirm the reliability and validity of the data obtained during the first survey,
- Establish any changes in the mining-related radon concentration profile as a result of the increased size of the mining areas, and
- Obtain current levels of radon activity concentrations throughout the mining area and surroundings.

The original grid for the 1987/88 survey was used as a guide but many locations were changed because they offered easier access. The first grid used in 2010 consisted of 100 points. Additional survey points were later added to this grid, resulting in a grid of 120 data collection points. A total of 5 monitoring rounds were conducted, with radon monitors in the field for 3 to almost 9 months in some cases, and with an average monitoring period of 6 months. Data from one of the rounds was subsequently removed from the survey results because the monitors could not be returned to the PARC RGM laboratory in South Africa for analysis within two weeks and therefore yielded unreliable results. There was no deliberate alignment between the monitoring periods in this survey and seasons, which meant that conditions in the different monitoring periods may have been dissimilar.

Track etch radon gas monitors from PARC RGM (also referred to as radon cups) were used for the survey. Each set of cups was delivered together with a ‘control’ cup, which was kept wrapped in several plastic bags for the duration of the monitoring term. The collection period for a set of cups was several weeks, a factor that introduced considerable uncertainty into the survey as cups were stored at the Radiation Safety Section Laboratory until a batch could be returned to PARC RGM for analysis. The uncertainty associated with this complication cannot be quantified exactly but could be at least as large as the standard deviation associated with measurements, which was between 6 and 25 per cent for all data points, but was on average about 14 per cent.

The radon cups were mounted by cable tie to the inside of a plastic bucket, which was attached upside down onto a steel rod at approximately 1 metre above the ground (see Figure 2). This method prevented heat damage due to exposure to direct irradiation by the sun to most cups – there were nevertheless a few cups that could not be analysed because of heat damage.

Radon cups used for indoor monitoring were attached to door handles by cable tie or placed on a table.

Grid positions are summarised in Figure 3.

Figure 2: Photograph showing how a radon cup is affixed to the inside of the plastic bucket 1 m above ground.

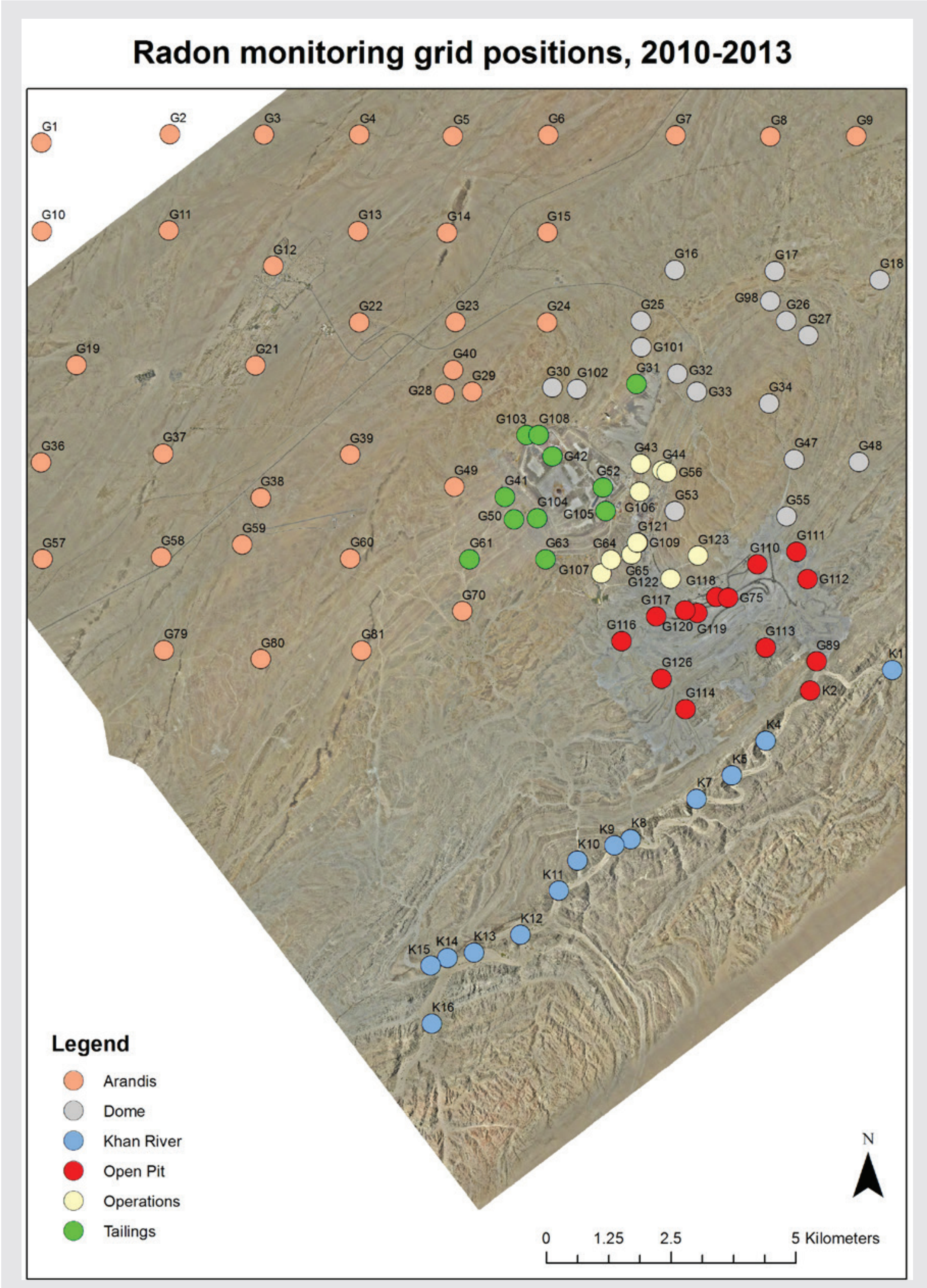


Figure 3: Grid positions superimposed on the Rössing Uranium mining area and surroundings. Grid positions are colour coded by area, i.e. Arandis and surroundings (peach), Tailings Storage Facility area (green), Open Pit area (red), Operations area (pale yellow), Kahn River (blue) and Dome area (grey). (Source of map: Google Earth)

3. Results

3.1. Outdoor monitoring grid

As the sampling occurred over a three-year period, some radon cups were lost or damaged. For example, the first set of cups placed in the SJ Pit was destroyed by subsequent mining operations. Measurements from sampling points with insufficient or inconsistent data were removed from the results analysis process.

In the recent survey, six main areas were distinguished in the original survey area, according to geographical location and area utilisation. These are summarised below and indicated in Figure 3:

1. The Dome area, i.e. the area to the east of the Tailings Storage Facility and mining areas,
2. The Khan River (all positions in the Khan River except point K2, which is adjacent to a Waste Rock Dump),
3. The Open Pit area, consisting of the SJ Pit and the Waste Rock Dumps surrounding it,
4. Arandis town and vicinities,
5. The Tailings Storage Facility area, and
6. Operations area, i.e. the area comprising the Processing Plant and the various office areas and administrative buildings.

A further area, the Z20 radiometric anomaly, was not part of the earlier survey but monitoring cups were placed there during Term 4 of the recent monitoring programme.

The area for the recent survey was chosen to coincide with the earlier survey as far as possible. In the previous survey, a 16 km x 16 km grid overlaying the Mining Licence Area was selected. Grid lines were 2 km apart on the grid, but 1 km apart in the areas directly affected by mining; the radon cups were placed on grid corners selected in this way.

Table 1: Radon concentration in Bq/m³, Dome area

Location number	Term 1	Term 2	Term 3	Term 4	Weighted average radon concentration	Standard deviation	Latitude (S)	Longitude	Area average (Bq/m³)
G16	52.4	35.6	66.2	103.6	**63.6**	**11.4**	22°25.004’	15°02.990’	**63±10**
G17	51.1	56.0	60.2	82.5	**62.2**	**7.6**	22°25.015’	15°04.161’	
G18	42.3	88.7	73.1	94.0	**75.6**	**9.7**	22°25.11’	15°05.386’	
G25	49.3	27.9	60.4	85.2	**56.1**	**5.9**	22°25.556’	15°02.596’	
G26	41.4	37.8	64.0	-	**48.3**	**11.6**	22°25.556’	15°04.295’	
G27	49.0	38.8	84.9	79.3	**61.3**	**9.3**	22°25.714’	15°04.550’	
G30	48.0	47.6	79.8	83.2	**65.7**	**7.8**	22°26.282’	15°01.562’	
G32	62.1	45.5	63.7	67.8	**59.9**	**12.4**	22°26.131’	15°03.022’	
G33	51.9	78.3	93.1	97.1	**82.4**	**12.2**	22°26.325’	15°03.251’	
G34	56.1	-	-	88.0	**67.6**	**9.8**	22°26.453’	15°04.093’	
G47	43.4	-	-	71.0	**53.3**	**8.7**	22°27.060’	15°04.387’	
G48	59.2	-	-	-	**59.2**	**6.3**	22°27.087’	15°05.140’	
G53	50.8	50.9	105.6	-	**74.7**	**10.0**	22°27.623’	15°02.993’	
G55	47.1	-	-	90.5	**60.3**	**10.8**	22°27.679’	15°04.297’	
G98	40.6	44.6	56.1	101.7	**60.0**	**8.9**	22°25.343’	15°04.107’	
G101	-	56.8	52.0	100.4	**63.4**	**9.5**	22°25.842’	15°02.603’	
G102	-	58.4	51.3	79.1	**60.8**	**12.2**	22°26.296’	15°01.852’	

In the recent survey, the location numbers used for the original grid were maintained as far as possible but some of the grid points were shifted for easier access. Some original grid points were omitted altogether if they proved to be in inaccessible locations.

For each radon cup location, a time-weighted average radon concentration was determined based on the length of time that each cup was used for measurements (refer to Tables 1 to 7). Where no measurement is given for a particular monitoring period, no result was available because a cup was lost or damaged or none was positioned in the first place. Average error is indicated as one standard deviation (time weighted in the same way as the measurement results).

Table 2: Radon concentration in Bq/m³, Khan River

Location number	Term 1	Term 2	Term 3	Term 4	Weighted average radon concentration	Standard deviation	Latitude (S)	Longitude	Area average (Bq/m³)
K1	60.5	36.6	72.1	70.3	**60.8**	**8.6**	22°29.346'	15°05.535'	
K4	57.8	40.9	90.3	74.9	**68.1**	**10.6**	22°30.117'	15°04.056'	
K5	-	40.0	70.8	-	**57.1**	**10.6**	22°30.491'	15°03.662'	
K7	39.8	18.8	86.0	74.5	**56.9**	**9.1**	22°30.747'	15°03.249'	
K8	48.2	22.6	71.0	66.0	**52.9**	**9.4**	22°31.184'	15°02.479'	
K9	44.0	30.3	-	64.3	**46.3**	**4.2**	22°31.252'	15°02.289'	
K10	-	41.0	78.3	65.8	**63.0**	**9.9**	22°31.416'	15°01.856'	**57±9**
K11	54.6	19.7	69.3	79.3	**56.2**	**10.1**	22°31.744'	15°01.637'	
K12	64.3	26.5	99.7	74.7	**67.6**	**7.4**	22°32.221'	15°01.190'	
K13	-	14.4	77.5	55.9	**50.5**	**7.7**	22°32.415'	15°00.646'	
K14	49.8	14.3	88.5	63.4	**55.5**	**8.8**	22°32.474'	15°00.335'	
K15	45.1	21.9	90.3	74.5	**60.0**	**10.4**	22°32.558'	15°00.141'	
K16	60.3	16.3	54.8	68.5	**49.3**	**9.3**	22°33.186'	15°00.156'	

Table 3: Radon concentration in Bq/m³, Open Pit area

Location number	Term 1	Term 2	Term 3	Term 4	Weighted average radon concentration	Standard deviation	Latitude (S)	Longitude	Area average (Bq/m³)
G75	62.81	-	144.9	222.8	**108.9**	**13.5**	22°28.562'	15°03.615'	
G89	115.1	171.0	216.3	245.2	**185.0**	**24.5**	22°29.253'	15°04.649'	
G110	-	75.0	159.1	145.2	**113.2**	**17.1**	22°28.200'	15°03.956'	
G111	-	114.7	175.2	194.0	**147.8**	**24.3**	22°28.062'	15°04.415'	
G112	-	183.6	-	288.2	**212.7**	**12.9**	22°28.359'	15°04.544'	
G113	-	-	176.4	164.5	**171.6**	**15.9**	22°29.103'	15°04.053'	
G114	-	159.3	297.8	231.4	**213.6**	**24.1**	22°29.773'	15°03.119'	
G116	-	105.7	196.0	186.8	**147.9**	**19.1**	22°29.032'	15°02.372'	**156±18**
G117	-	123.5	168.5	196.1	**150.9**	**16.4**	22°28.764'	15°02.774'	
G118	-	89.5	150.2	142.0	**117.5**	**15.0**	22°28.554'	15°03.476'	
G119	-	119.8	-	248.9	**155.8**	**17.4**	22°28.727'	15°03.253'	
G120	-	120.1	130.8	132.2	**127.9**	**15.5**	22°28.701'	15°03.114'	
G126	-	-	210.1	181.5	**198.5**	**22.6**	22°29.443'	15°02.837'	
K2	88.5	81.6	158.4	127.4	**118.3**	**10.7**	22°29.569'	15°04.574'	

Table 4: Radon concentration in Bq/m³, Arandis town and vicinities

Location number	Term 1	Term 2	Term 3	Term 4	Weighted average radon concentration	Standard deviation	Latitude (S)	Longitude	Area average (Bq/m³)
G1	34.3	17.0	53.4	99.2	**48.3**	**6.1**	22°23.622'	14°55.596'	**54±8**
G2	38.5	19.1	76.4	-	**46.3**	**7.0**	22°23.530'	14°57.093'	
G3	52.2	11.6	59.8	96.9	**48.7**	**7.0**	22°23.533'	14°58.193'	
G4	40.7	11.8	71.3	88.3	**52.9**	**7.7**	22°23.537'	14°59.308'	
G5	67.8	12.6	68.0	63.4	**51.4**	**9.2**	22°235.51'	15°00.400'	
G6	23.9	24.3	73.6	-	**44.2**	**4.8**	22°23.538'	15°01.511'	
G7	43.3	27.6	52.1	67.9	**46.9**	**11.9**	22°23.541'	15°03.000'	
G8	25.7	27.6	66.6	83.3	**50.7**	**12.5**	22°23.553'	15°04.107'	
G9	-	22.3	59.6	79.9	**50.8**	**6.7**	22°23.551'	15°05.110'	
G10	36.9	13.1	78.0	-	**48.9**	**5.6**	22°24.582'	14°55.596'	
G11	-	10.2	62.6	-	**36.6**	**6.6**	22°24.576'	14°57.083'	
G12	-	54.6	57.4	72.0	**59.6**	**11.4**	22°24.96'	14°58.302'	
G13	47.3	19.4	63.9	74.9	**50.6**	**5.1**	22°24.583'	14°59.293'	
G14	-	12.8	75.7	81.9	**55.7**	**5.9**	22°24.600'	15°00.332'	
G15	49.6	42.2	65.4	78.7	**54.3**	**6.3**	22°24.597'	15°01.502'	
G19	53.4	21.1	69.6	-	**51.4**	**8.3**	22°26.035'	14°56.000'	
G21	50.9	-	71.7	61.3	**61.7**	**7.4**	22°26.039'	14°58.094'	
G22	-	30.8	59.3	55.0	**48.7**	**7.8**	22°25.574'	14°59.305'	
G23	-	19.0	67.5	58.7	**49.3**	**7.0**	22°25.569'	15°00.431'	
G24	-	26.7	64.6	45.0	**42.3**	**4.8**	22°25.574'	15°01.501'	
G28	45.7	45.4	80.8	61.6	**58.9**	**7.4**	22°26.350'	15°00.299'	
G29	43.2	28.8	49.3	93.1	**51.6**	**10.4**	22°26.327'	15°00.624'	
G36	48.1	36.0	79.6	-	**58.6**	**6.9**	22°27.093'	14°55.589'	
G37	57.3	28.3	77.8	58.2	**55.7**	**7.4**	22°26.999'	14°57.012'	
G38	38.3	-	78.5	72.5	**65.6**	**8.4**	22°27.477'	14°58.153'	
G39	58.8	75.0	61.5	90.9	**71.0**	**13.5**	22°27.009'	14°59.198'	
G40	43.2	48.7	74.5	61.5	**58.5**	**9.4**	22°26.090'	15°00.402'	
G49	60.7	52.8	-	-	**57.1**	**6.0**	22°27.357'	15°00.415'	
G57	49.6	48.2	81.7	71.1	**64.4**	**7.5**	22°28.143'	14°55.604'	
G58	-	35.7	71.4	79.4	**61.0**	**9.1**	22°28.122'	14°56.989'	
G59	52.3	23.7	64.9	96.9	**57.8**	**10.2**	22°27.985'	14°57.939'	
G60	40.9	-	-	73.0	**50.5**	**6.5**	22°28.138'	14°59.200'	
G70	7.6	58.8	97.9	85.9	**61.0**	**6.3**	22°28.710'	15°00.508'	
G79	60.2	66.3	72.7	76.0	**69.3**	**10.0**	22°29.132'	14°57.023'	
G80	49.3	43.3	87.7	77.6	**64.5**	**8.2**	22°29.230'	14°58.156'	
G81	46.0	38.9	22.2	97.4	**44.7**	**5.9**	22°29.137'	14°59.331'	

Table 5: Radon concentration in Bq/m³, Tailings Storage Facility area

Location number	Term 1	Term 2	Term 3	Term 4	Weighted average radon concentration	Standard deviation	Latitude (S)	Longitude	Area average (Bq/m³)
G31	68.3	101.7	-	170.5	**113.9**	**14.5**	22°26.241'	15°02.543'	
G41	33.5	-	117.9	-	**66.5**	**6.3**	22°27.468'	15°01.007'	
G42	46.8	-	-	390.0	**204.5**	**17.3**	22°27.027'	15°01.563'	
G50	60.6	-	-	142.9	**95.5**	**10.7**	22°27.713'	15°01.112'	
G52	161.0	206.8	311.2	324.6	**256.1**	**20.4**	22°27.366'	15°02.151'	
G61	-	50.0	158.7	187.4	**106.4**	**10.1**	22°28.145'	15°00.595'	**162±17**
G63	48.4	89.7	111.8	186.8	**96.3**	**10.8**	22°28.145'	15°01.483'	
G103	-	161.0	193.5	282.4	**206.4**	**28.2**	22°26.798'	15°01.262'	
G104	-	124.8	134.8	156.4	**138.3**	**21.7**	22°27.701'	15°01.384'	
G105	-	189.1	270.6	250.0	**238.5**	**20.0**	22°27.621'	15°02.186'	
G108	-	205.1	267.7	310.7	**261.2**	**22.5**	22°26.796'	15°01.401'	

Table 6: Radon concentration in Bq/m³, Operations area

Location number	Term 1	Term 2	Term 3	Term 4	Weighted average radon concentration	Standard deviation	Latitude (S)	Longitude	average (Bq/m³)
G43	59.3	70.4	111.7	130.6	**94.3**	**16.4**	22°27.108'	15°02.591'	
G44	82.2	133.6	108.1	169.7	**123.4**	**16.7**	22°27.181'	15°02.847'	
G56	31.5	-	88.1	96.5	**73.9**	**10.1**	22°27.200'	15°02.901'	
G64	36.1	55.8	94.9	125.6	**75.8**	**8.7**	22°28.150'	15°02.246'	
G65	-	55.0	82.2	120.5	**83.3**	**9.8**	22°28.093'	15°02.487'	
G106	-	117.2	88.5	104.5	**102.4**	**12.8**	22°27.410'	15°02.586'	**96±13**
G107	-	112.8	114.2	100.6	**109.6**	**13.3**	22°28.301'	15°02.134'	
G109	-	110.3	84.9	-	**95.7**	**13.1**	22°27.964'	15°02.554'	
G121	-	57.3	82.3	135.0	**89.2**	**9.5**	22°27.964'	15°02.560'	
G122	-	-	109.1	121.2	**114.9**	**16.7**	22°28.358'	15°02.943'	
G123	-	76.5	117.0	97.6	**97.9**	**11.6**	22°28.106'	15°03.263'	

Table 7: Radon concentration in Bq/m³, Z20 Exploration Programme area

Location number	Measured radon concentration (Bq/m³)	Latitude (S)	Longitude	Area average (Bq/m³)
Z 1	**97.3**	(tent, camp area)		**82±11**
Z 2	**79.2**	22º31.837'	15º03.718'	
Z 3	**85.5**	22º32.137'	15º03.796'	
Z 4	**88.6**	22º32.120'	15º03.659'	
Z 5	**77.3**	22º32.288'	15º03.263'	
Z 6	**66.1**	22º32.379'	15º03.603'	

A summary map of the monitoring results is provided in Figure 4.

Mining disturbance-related radon concentrations are clearly seen on this map, with the Open Pit and Tailings Storage Facility areas having average radon concentrations exceeding 130 Bq/m³. The baseline in the broader site area is seen to be between slightly more than 50 Bq/m³: for the Arandis area it is found to be 54 Bq/m³; it is 57 Bq/m³ in the Khan River; and it is 63 Bq/m³ in the Dome area to the east of the mine.

Table 3 shows that sample point K2, which is actually adjacent to waste rock dumps near the Khan River, is strongly influenced by mining activities and it has therefore been grouped with the Open Pit area instead of the Khan River for the purposes of results analysis.

The same information depicted in Figure 4 is reproduced in a three-dimensional graph in Figure 5. The figure demonstrates a slightly different outcome in the recent survey than from the initial one: while in the initial survey (Figure 1), the highest radon concentrations occurred in the Open Pit area, in the recent survey the maximum values were recorded in the Tailings Storage Facility area.

Note that this survey was not able to determine if baseline and background concentrations were identical. The background concentration is the concentration that would have existed in the area prior to the commencement of mining activities. The baseline would be affected by nearby mining activities but refers to locations that are not directly affected by mining operations.

If an average baseline/background radon concentration of 54 Bq/m³ is assumed (as was obtained for the Arandis and surroundings area), then the mining-related additional radon contributions amount to:

- 42 Bq/m³ in the Operations area,
- 108 Bq/m³ in the Tailings Storage Facility area, and
- 102 Bq/m³ in the Open Pit area.

However the baseline radon concentration in the area of the present Open Pit area is certain to have been higher than in the surrounding areas as a result of the higher uranium content in the underlying ground. The statement above would therefore represent at most an upper limit to additional contributions in each of these areas. If a background such as that found in the Khan River (57 Bq/m³) or in the Dome area (63 Bq/m³) is assumed instead, the mining-related contribution becomes correspondingly lower, i.e. as little as 33 Bq/m³ in the Operations area, and as little as 99 Bq/m³ in the Tailings Storage Facility area.

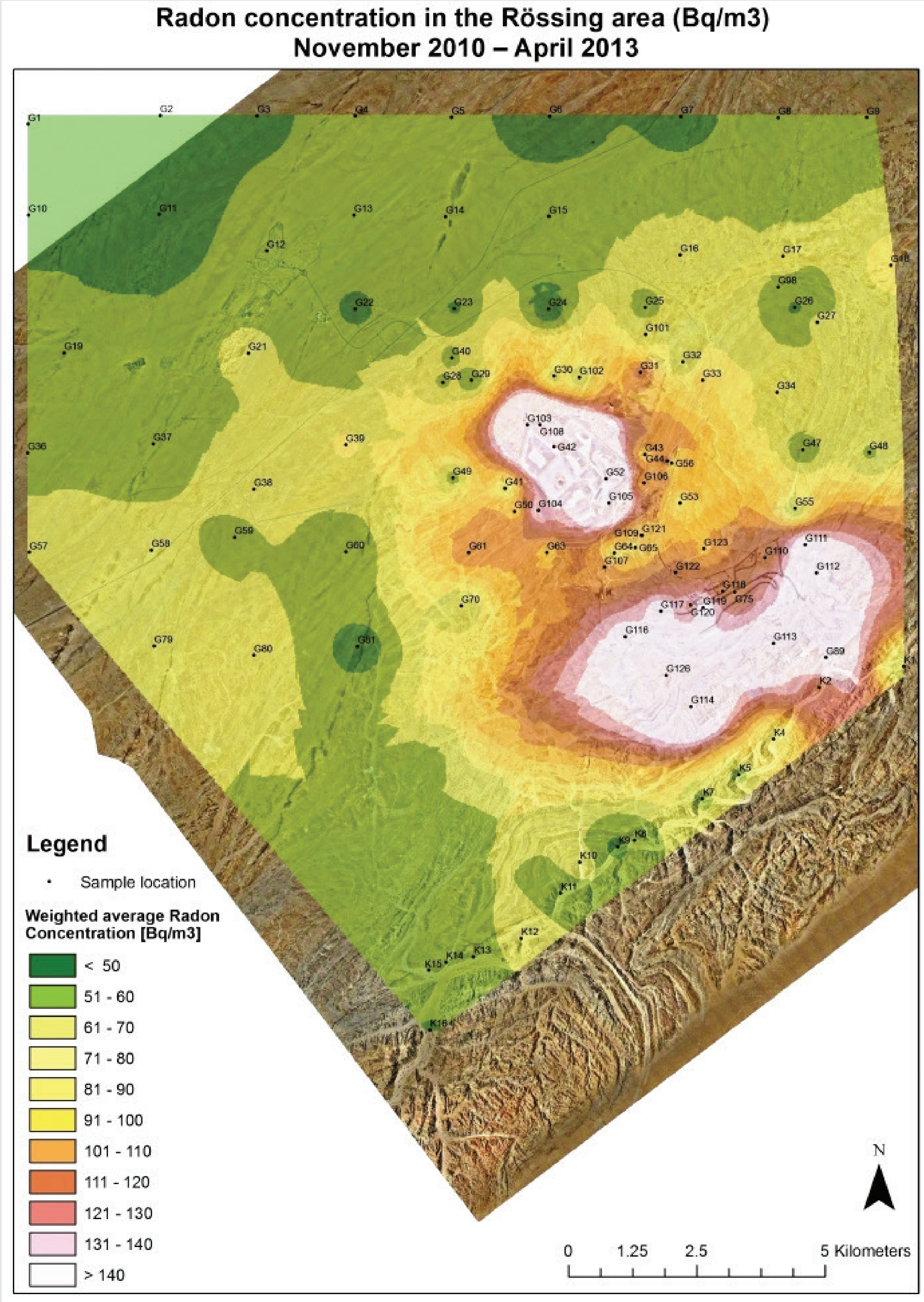
In the Dome area, the radon concentration is slightly higher than the Arandis baseline, which can be expected from the granitic nature of the Rössing Dome geology. In addition, local weather conditions in the two locations are not the same, with the flat region around Arandis more exposed to wind and air movement than the area around the Dome. The difference in environmental conditions created by factors such as wind and temperature makes it difficult to compare the two areas directly, despite the geographical proximity of the two.

The Z20 Exploration Programme site – which is situated on the Rössing Mining Licence Area lease but to the south of the Khan River – was outside the scope of the earlier survey and therefore also not included in the radon contour map, Figure 4. The average radon concentration for the area, 82 Bq/m³, is typical for a granitic area that is rich in uranium but which remains undisturbed by mining activity as yet. Only one round of sampling was conducted for this area, undertaken while the Exploration Programme was under way.

All recent survey radon concentrations were measured 1 m above the ground.

Measurements of radon concentrations at the NamWater water reservoir between Arandis and the mine site are performed by the Namibian Uranium Institute in collaboration with the Geological Survey of Namibia. The instrument (a Saphymo™ AlphaGuard) used is located some 6 m above the ground and the average radon concentration measured over a one-year period

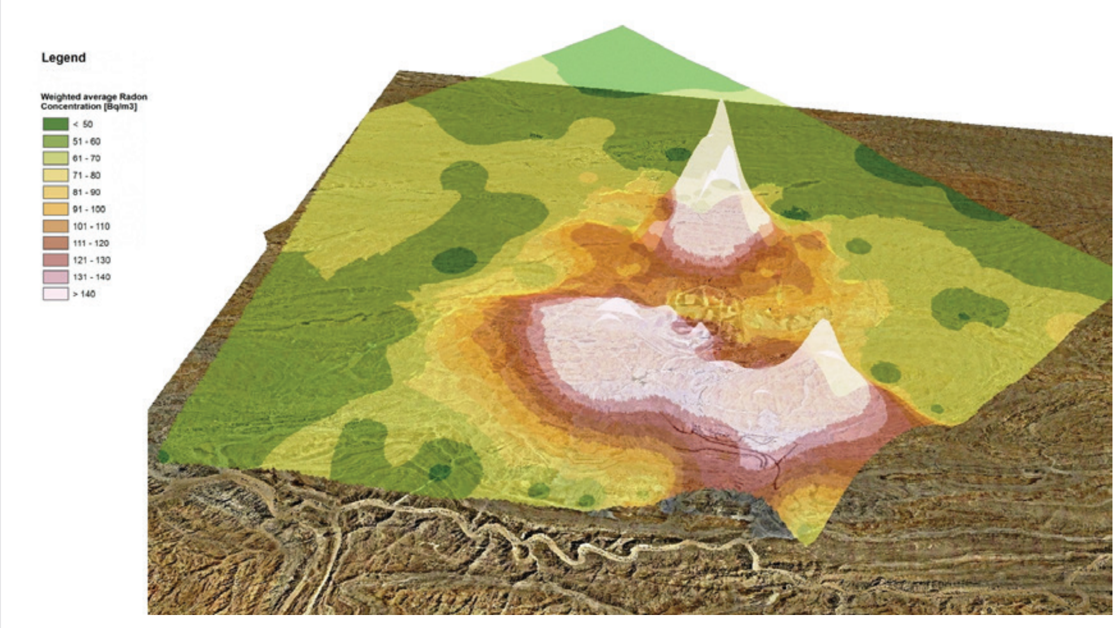
Figure 4: Radon concentrations in the Rössing mine site area and surroundings November 2010 – April 2013



was found to be 22 Bq/m^3 [3], significantly lower than the 54 Bq/m^3 average baseline recorded for the recent survey. The latter recorded value is, however, consistent with the background value of 50 Bq/m^3 quoted in the early Rössing Uranium survey.

The early radon survey was conducted by placing the radon cups directly on the ground. In that survey, a clear difference could be seen between the measured average radon baseline concentration in the vicinity of Arandis and the baseline near the Khan River, see Figure 1. The value assumed as background then was 50 Bq/m^3, based on the fact that measured values at Swakopmund ranged from 29 to 50 Bq/m^3, and because the lowest individually recorded concentration within the monitoring grid was close to 50 Bq/m^3 [1].

Figure 5: Three-dimensional representation of radon concentrations at Rössing Uranium



3.2. Indoor monitoring locations

Several radon cups were used for indoor monitoring. An area of known concern is the medical clinic building on site; five cups were therefore placed in the building for some of the monitoring periods. To compare these on-site values with other typical indoor radon concentrations, two radon cups were placed in a house in Vineta, Swakopmund – one on the ground floor and one on the first floor.

The results are shown in Table 8.

The measured concentrations at the medical clinic building were very high. After measuring period Term 3, staff members at the clinic were instructed to increase ventilation in their building and this measure would explain the lower concentration values obtained during Term 4. Additional measurements using a SARAD™ Radon Scout instrument were performed over a period of several weeks and confirmed the values obtained in Table 8. Values measured in the building using the Radon Scout monitor are given in Table 9.

These results were found to be similar enough between the two types of measurements to be considered reliable as an order of magnitude estimate. The difference of about 25 per cent in the two measurements can be attributed in part to the fact that the Radon Scout measurements were performed over a much shorter timeframe (at most two weeks at any of the specific locations) than the radon cup measurements. As a result of the radon concentrations found in the clinic building during the recent survey, work in the building has been suspended until successful ventilation measures can be put in place, or until further notice.

The radon concentration results for the Radiation Store Bunker (for temporary storage of unused sealed radiation sources) are not surprising considering the bunker is situated close to the Open Pit area and is never ventilated.

The radon concentration measured in the Radiation Safety Section Laboratory, 336 Bq/m^3, was confirmed with short-term Radon Scout measurements: a value of 343 Bq/m^3 was then obtained over a three-day sampling period. Individual radon concentrations in this area range from around 30 Bq/m^3 during the daylight hours when the building is ventilated to 1,037 Bq/m^3 during the night and weekends. This area must be regularly ventilated when occupied and should not be used as an office for continuous occupation if suitable ventilation is not consistently being applied.

The indoor radon concentrations as determined in the house at Vineta, Swakopmund – 53 Bq/m^3 on average – were higher than expected but recorded standard deviations for radon cup measurements in this location did not exceed 22 per cent of the measured value at most. These indoor values should be compared with the results of a recent outdoor survey, where the instrument (a Saphymo™ AlphaGuard) was located some 6 metres above ground level on top of a building at the NamWater reservoir at Swakopmund. Here, an average radon concentration of 11 ± 7 Bq/m^3 was found for a monitoring period of 640 days [3]. Radon Scout measurements in the same locations (S1 and S2) in Swakopmund found an average indoor value of 15 ± 1 Bq/m^3, albeit over a very short time period of only a few days.

Table 8: Radon concentrations in Bq/m³, Medical clinic building on site, Radiation Store Bunker, Radiation Safety Section Laboratory, and Vineta residence

Location number	Term 1	Term 2	Term 3	Term 4	Weighted average radon concentration	Area average (Bq/m³)	Area
MEDIXX 1	-	-	810.1	-	**810.1**	**1021** ± 201	Pharmacy
MEDIXX 2	-	-	475.2	187.7	**318.8**		Doctors room
MEDIXX 3	-	-	1994.0	691.0	**1288.8**		X-Ray room storage area
MEDIXX 4	-	-	1306.2	-	**825.3**		X-Ray room
MEDIXX 5	-	-	1488.9	1195.6	**1381.0**		Sound room
S1	17.8	44.7	54.6	-	**41.8**	**53** ± 6	Vineta house - upstairs
S2	57.4	56.9	77.1	-	**64.8**		Vineta house - downstairs
Radiation Store Bunker	335.8	308.3	733.8	766.7	**536.2**	**536** ± 103	Radiation Store Bunker
G124	-	373.6	306.8	-	**336.1**	**336** ± 37	Radiation Safety Section Laboratory

Table 9: Radon concentrations in Bq/m³, Medical clinic building, using Radon Scout instrument

Area	Radon Scout measurement, average radon concentration	Radon Scout, average (Bq/m³)	Radon cup measurement, average radon concentration	Radon cups, average (Bq/m³)
Pharmacy	381	**756** ± 11	810	**1021** ± 201
Doctors room	150		319	
X-Ray room storage area	1236		1289	
X-Ray room	1115		825	
Sound room	897		1381	

4. Summary and conclusions

The measured outdoor profile for the Rössing Uranium mine site appears realistic: It is consistent with earlier measurements, and indoor measurements at the medical clinic building could be confirmed with additional measurements.

Because of the long exposure time involved, some complications arose as a result of radon cups being in transit for an extended period. It should be noted that the measured radon concentrations obtained for each point represent a long-term average with a significant error associated, and shorter period measurements need to be made if more accurate results are required. However, for an order of magnitude indication of the mining-related radon concentrations at the mine, this survey has yielded sufficient information for a reliable overview of the situation.

Differences in the results of the recent and earlier survey can be explained by reference to the following considerations:

- Radon cups in the recent survey were collected over periods of up to three weeks, resulting in inaccuracies as a result of cups being stored in the Radiation Safety Section lab before dispatch to the PARC RGM laboratory in South Africa.
- The earlier survey was conducted over a much shorter time period (one year exactly) than the recent survey, which spanned a period of 2 ½ years.
- The peak recorded values in the earlier survey were found in the Open Pit area, while in the recent survey the peak values were found to occur in the Tailings Storage Facility area. It should be noted that at the time of the recent survey, access to the bottom of the pit was not possible due to safety reasons and thus the radon cups were placed around the perimeter of the pit instead. This may account for the lower overall values recorded for the Open Pit and Waste Rock Dumps areas in the course of the recent survey.
- Radon cups in the recent survey were placed in inverted plastic buckets 1 m above the ground. The methodology indicated for the earlier survey does not specify how the cups were positioned, although it is known that they were positioned directly on the ground.

The following representative values were found:

- Arandis area baseline: 37 to 71 Bq/m^3, with an average of 54 Bq/m^3
- Dome area baseline: 48 to 82 Bq/m^3, with an average of 63 Bq/m^3
- Khan River baseline: 46 to 68 Bq/m^3, with an average of 57 Bq/m^3
- Open Pit and area: 113 to 213 Bq/m^3, with an average of 156 Bq/m^3
- Operations area: 74 to 123 Bq/m^3, with an average of 96 Bq/m^3
- Tailings Storage Facility area: 67 to 261 Bq/m^3, with an average of 162 Bq/m^3
- Medical clinic building, indoors: 319 Bq/m^3 (in frequently ventilated offices) up to 1,381 Bq/m^3 (in unventilated treatment rooms), and
- Radiation Safety Section Laboratory: An average of 336 Bq/m^3 obtained over two measuring terms.

The following measurement parameters were found:

- The highest average outdoor concentration recorded at any location over the entire survey period was 261 Bq/m^3 in the Tailings Storage Facility area; the highest single outdoor measurement over a single term yielded 390 Bq/m^3, in the same area.
- The lowest average outdoor baseline concentration over the entire survey period at any location recorded was 37 Bq/m^3 in the plains between Arandis and the mine.
- The lowest individually recorded concentration during any term was 8 Bq/m^3 at point G70 to the west of the Tailings Storage Facility area, and
- The highest indoor concentration recorded during any term was 1,994 Bq/m^3 in the unventilated storage room of the X-ray lab in the medical clinic building.

Differences between the radon concentrations found in this recent and the earlier survey at Rössing Uranium, and those obtained by the Geological Survey using an AlphaGuard instrument, can be explained by the fact that the latter measurements used an instrument placed some 6 m above the ground, in contrast to 1 m above the ground in the recent survey. A position close to the ground inevitably experiences less air movement and will therefore display higher radon concentrations. For the purposes of estimating an exposure dose as a result of the inhalation of radon decay products, a measurement at 1 m above the ground offers the best estimate of the actual concentrations encountered by people in the relevant location.

5. References

1. Grundling, A., Leuschner, A.H. and Steyn, A. (1988): *An investigation of 222Rn concentrations at Rössing Uranium Limited.* A report for the period October 1987 to September 1988, Atomic Energy Corporation of South Africa.

2. Grundling, A. and Leuschner, A.H. (1990): *Modelling Environmental Radon Concentrations Associated with Mining Activities at Rössing Uranium Ltd.*, Atomic Energy Corporation of South Africa.

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