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Summary

This report describes measurements of radon (^{222}Rn) activity flux, external gamma dose rate and soil radioactivity carried out on selected surfaces at Ranger Uranium Mine near Jabiru during the periods June to September 2002 and October 2003. This work was part of an ***eriss***-QUT project on radon exhalation rates in the Ranger region. The aims of the overall project include the following:

- Provide information on radon exhalation rates from the Ranger site in the present day (i.e. pre-rehabilitation).
- Give some information which will help us to predict radon exhalation rates from the site after rehabilitation.
- Help us to design more detailed experiments on the effect of various capping methods on radon exhalation rates, and hence help in rehabilitation research and planning.

The three main parts of the project are:

- Measurement of radon exhalation rates from surfaces at Ranger at one time of year (late dry season).
- Measurement of radon exhalation rate from a small number of sites over a yearly cycle (seasonal variability).
- Measurement of radon exhalation rate from a small number of sites over several daily cycles (diurnal variability).

This report describes the results of the first of these parts; results from the other two parts of the project will follow in separate reports.

A total of 298 radon exhalation rate measurements were made over the following areas: waste rock dumps, ore stockpiles, land application area (irrigated and non-irrigated areas), and mine pits 1 and 3. A summary of the radon exhalation rate data obtained may be found in Table 2. As expected, the highest Rn exhalation rates per unit area were obtained for the ore stockpiles, these being two orders of magnitude greater than average environmental rates (such environmental rates vary but average about 70 mBq m^{-2} s^{-1}). Readings from the waste rock dump/overburden sites and from mine pit walls were only about one order of magnitude greater than environmental rates. The arithmetic mean of the readings from the land application irrigated area was only slightly elevated at 112 mBq m^{-2} s^{-1}.

Radon exhalation rate flux should depend upon ^{226}Ra activity concentration of the ground, among other factors. We have used the simultaneous measurements of soil radioactivity through in situ gamma spectroscopy and the activity flux to investigate this relationship. The location-based summary (Table 7) leads to values ranging from 0.04 to 4.06 for radon exhalation rate (mBq m^{-2} s^{-1}) to ^{226}Ra concentration (Bq kg^{-1}) ratio. The wide range of values shows that the radon exhalation rate is dependent on several other parameters besides ^{226}Ra concentration; examples of such factors are soil grain size and porosity, soil moisture, and possibly height of the rock dump and location of ^{226}Ra in the soil grain. Nevertheless, the values obtained for the ratio do encompass the range of values reported in an earlier study (Mason, 1982).

Statistical analysis of the data showed that, for any one site, the exhalation rate measurements were better described by a log-normal distribution than by a normal distribution.

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1 Introduction

Radon (^{222}Rn) activity flux, external gamma dose rate and soil radioactivity measurements were carried out on selected surfaces at Ranger Uranium Mine near Jabiru during the periods June to September 2002 and October 2003. This work was part of an ***eriss***-QUT project on Determination of Radon Exhalation Rates and ^{210}Pb Deposition Fluxes for the Ranger / Jabiluka Region.

This report is primarily a compilation of the calibrated data collected during this period at Ranger. Some interpretations are also offered for the purpose of illustration of the approach taken during the measurements and for assurance that the trends and values are logical and understandable. Knowledge of fundamental concepts of radon activity flux measurements and Ranger locality is regarded as assumed knowledge. Waste Rock Dump, Ore Stock Piles, Mine Pits, Irrigated Land Application Area and the Mill are regarded as important radon emission sources.

2 Equipment

The 100 reusable activated charcoal cups used in radon activity flux measurements were manufactured at QUT - they were counted using a NaI(Tl) gamma spectroscopy set up at ***eriss*** laboratories in Jabiru East. The set up was calibrated using a ^{226}Ra activity standard source. Two ANSTO designed flow-through emanometers were also used – they were calibrated at QUT with certified ^{222}Rn standards. The difference between the two activity flux measurement systems has been in the collection surface area (charcoal cup-0.0038 m^2, emanometer-0.26 m^2) and the technique for radon measurement. The activated charcoal absorbed ^{222}Rn that was later counted through the gamma peaks of its progeny; the emanometer had chambers lined with alpha sensitive scintillant where disintegrating ^{222}Rn and its progeny were detected using a photomultiplier system. The small surface area of a charcoal cup is a particular disadvantage in areas where surface non-uniformities may exist. In this study, for a number of surfaces where both systems were used, the measurements overlap in range with averages agreeing within uncertainties – suggesting that neither of the two types of equipment measured consistently lower or higher.

External gamma radiation dose rate was measured at one metre above ground using a Mini Environmental Meter Type 6-80 with compensated GM tube environmental gamma dose rate system in a time integrated mode. The system was calibrated at the Australian Radiation Laboratories.

In situ measurements were made with a portable 3" x 3" NaI(Tl) γ spectrometer (Geofyzika GS-512), positioned 1 m above the ground. This detector has internal spectrum stabilisation using a ^{137}Cs reference source and collects 512 channel γ data over the energy range E_{γ} = 0–3000 keV. Spectral analysis of gamma ray surveys using NaI(Tl) detectors normally gives three bands of information. ^{40}K is obtained from the peak at 1.46 MeV. Bands eU ("uranium equivalent") and eTh ("thorium equivalent") represent the main peaks used for measurement of U- and Th-series activity respectively. Although often referred to as the "uranium" and "thorium" peaks, these are essentially associated with γ-rays which arise in the decay of ^{214}Bi (1.73 and 1.76 MeV) and ^{208}Tl (2.62 MeV). In practice, eU represents a measure of ^{226}Ra in the ground. Although ^{226}Ra will often be close to secular equilibrium with ^{238}U in soil, this may not always be the case. An example of where disequilibrium would be expected is the Ranger land application area. Calibration constants for the NaI(Tl) γ spectrometer determined by the manufacturer using standard test pads were used to convert count rates to nominal activity concentrations ^{40}K, eU and eTh.

Error bars in the figures represent counting statistics alone, and correspond to one standard deviation.

3 Radon activity flux measurements

Radon is produced in the rock or soil grain when its parent ^{226}Ra transmutes into ^{222}Rn though alpha disintegration. Its exhalation from the ground is a two step process. In the first step, a small quantity of the total radon produced in the ground emanates from the rock or soil grain surface into the air space between the grains and becomes a part of the soil gas. In the second step a fraction of it finds its way out of the ground surface and appears in the air above it.

Emanation from the solid grain into the soil gas depends on factors such as:

- ^{222}Rn production rate (or ^{226}Ra activity concentration) – the higher the production rate the higher the emanation
- distribution of ^{226}Ra within the grain – production near the surface leads to higher probability of escape into soil gas, and
- the grain size – the smaller the grain (or rock size) the more the surface area to volume ratio to emanate.

Exhalation of radon from the soil gas to the surface also depends on a number of complex and variable factors including porosity and permeability, soil thickness, soil moisture, precipitation, wind velocity, barometric pressure, temperature etc. (Porstendoerfer, 1994).

Porosity facilitates radon exhalation. Disturbing the soil allows any trapped radon to escape. Deeper layers of the soil make a decreasing contribution to surface exhalation; typically radon can reach the surface from depths of several meters – an estimate of diffusion length for 100micron dry grain size material is 2–2.5 metres. The values may be much larger for formations containing larger size boulders of non uniform shape, where air gaps between the surfaces may provide an easier diffusion path for the soil gas. Exhalation has a complex dependence on soil moisture – values are expected to increase somewhat as the moisture content increases from dryness, and then decrease rapidly to nearly zero as it approaches saturation. Theoretically, reduction in barometric pressure may lead to advective release of soil gas from the pores.

Radon activity flux measurements were carried out at 298 locations in eight different areas. In most cases measurement point coordinates were recorded on a GPS. All individual measurements are compiled in Table 1. The reported uncertainties are based on the statistics of counting to 1σ . Table 2 is a location based summary of arithmetic and geometric averages and deviations. In the text of this report values used are arithmetic mean as average and standard error as uncertainty.

The measurements in this report represent the dry period of the year. Seasonality of radon exhalation is being investigated and will be reported in due course of time.

Sixty readings at the non-irrigated land application area represent values for radon activity flux for undisturbed common woodland in the vicinity of Ranger project – they average at 70±2 $mBq.m^{-2}.s^{-1}$. All other sites including the irrigated land application area are higher than this value. A previous report of the ambient ^{222}Rn activity flux in Kakadu National Park in the vicinity of Ranger has been 64±25 $mBq.m^{-2}.s^{-1}$ (Todd et al., 1998).

Waste rock dump is important because post rehabilitation disturbed land at Ranger may have this material at the surface. The two waste rock dump areas selected in this study include a flat compacted area with no vegetation (pad area) and an area vegetated for the past few years (rehabilitated area). Radon activity flux for the rehabilitated area (937±98 $mBq.m^{-2}.s^{-1}$, n=21) is more than that for the pad area (526±103 $mBq.m^{-2}.s^{-1}$, n=20). The ground at the rehabilitated area was relatively porous with rills engineered to facilitate plantation. Roots may also cause soil porosity and assist in retaining moisture – thereby boosting radon exhalation somewhat.

The average of four readings in an overburden area where the surface was laid during the few weeks prior to measurements and not compacted is (971±174$mBq.m^{-2}.s^{-1}$, n=4).

The irrigated land application area exhaled more radon than the non-irrigated area – the difference being 34±9 $mBq.m^{-2}.s^{-1}$. It is a unique site due to large scale ^{226}Ra deposition absorbed within the surface few centimetres of the soil.

Ore stock piles are created firstly by paddock dumping in the area to build up a base for the stockpile. Over time as the area of the pile is filled an access ramp is created to the top of the pile and the top is compacted and flattened using graders and other heavy equipment. From here one section of the stockpile will become a tipping head where ore is dumped over or near the edge to be bulldozed. The tip head is moved on a regular basis to even the spread of material onto the stockpile. The top surface flattened and compacted for heavy machinery access is known as the 'pad' area. Several metres of the perimeter close to the slopes is made 'out of bound' for the heavy machinery for safety reasons. This is the tipping head or 'rim' it is less compacted and often contains non-pulverised larger size rocks. Also, while levelling the material dumped in a certain area, the equipment may leave surplus material near the edges in a 'push zone', where the bulldozer pushes the material over the edge of the stockpile. As the rock size and soil porosity can influence radon exhalation, measurements at the pad areas, rims and push zones have been averaged separately.

Average radon activity flux for Ore Stock Pile 7 (OSP7) rock pile and rim is $(1.69\pm0.73)\cdot10^3$ and $(0.95\pm0.35)\cdot10^3$ $mBq.m^{-2}.s^{-1}$ respectively. These two readings overlap within the standard error but are lower than that for the pad area which is $(3.14\pm0.65)\cdot10^3$ $mBq.m^{-2}.s^{-1}$. A similar trend exists for measurements at Ore Stock Pile 2 (OSP2) but the relative difference between the average value for the rim {$(1.23\pm0.54)\cdot10^4$ $mBq.m^{-2}.s^{-1}$} and pad area {$(1.57\pm0.58)\cdot10^4$ $mBq.m^{-2}.s^{-1}$} is lesser and statistically insignificant. The rim and the rock pile area contained loosely packed boulders 10-20 cm in dimensions or even more. The pad area perhaps also contained same size rocks but the space in-between was filled with smaller size rocks and pulverized course grain material that was compacted. Compaction would result in reduced pore space with constrictions and tortuous path lengths that would reduce the diffusion or advection of radon to the surface. On the other hand smaller size rocks will provide more surface area for radon to emanate. In case of OSP2 and OSP7 the net effect of these two competing factors appears as an increase in the activity flux.

At Ranger, ore stock piles are categorised in grades from 1 to 7 on the basis of bulk estimates of the uranium concentration measured with gamma discriminators – the higher the uranium concentration the higher the stock pile grade (table 3). In that respect the lower radon activity flux for OSP7 is an unexpected result that requires further investigation. A possible explanation could be the difference in the height of the two piles investigated – OSP7 3-4 metres, OSP2 about 20 metres. It is expected that for comparatively porous media like OSP's, radon could make a surface expression from depths of several metres.

The Laterite Pile contained mainly reddish (Fe bearing) fine grain uranium ore grade material. The activity flux for the Laterite Pile pad area is $(5.16\pm0.62)\cdot10^3$ $mBq.m^{-2}.s^{-1}$. The values for the rim and the push zone are substantially higher – $(3.84\pm0.51)\cdot10^4$ and $(8.06\pm1.54)\cdot10^4$ $mBq.m^{-2}.s^{-1}$ respectively. This trend at the laterite pile, of values at a less compacted (or porous) area such as the push zone being higher those at the compacted pad area, is opposite to that for OSP7 and OSP2. This is most likely because, for the laterite pile, the rock size in the rim and the push zone is generally no different from the pad area to counter the effect of porosity on radon exhalation.

Mine Pit#1 is a pit already exploited and backfilled mainly with the wet tailings. Measurements were carried out at a bench surface and a wall off the haul road above the wet season water level mark. The average of 33 activity flux measurements over the bench is $495\pm54 mBq.m^{-2}.s^{-1}$. This value is close to that for the waste rock dump pad area which is 526 ± 103 $mBq.m^{-2}.s^{-1}$. The average of three readings of the pit wall is also comparable - 304 ± 49 $mBq.m^{-2}.s^{-1}$.

The rocks, rubble and the pad area in the active mine pit, Pit # 3 gave activity flux of $(1.03\pm1.01)\cdot10^3$, $(1.68\pm0.65)\cdot10^3$ and $(2.53\pm0.62)\cdot10^3$ $mBq.m^{-2}.s^{-1}$ respectively.

When compared to the waste rock and land application area, the individual readings at the OSP's and Pit#3 show larger variations. Some of the values are unexpectedly low or high. These variations may be real. Localised factors such as presence of rocks of higher (or lower) radioactivity, and inclusions of air pockets due to surface roughness underneath the sampling point may be responsible for such point to point variations.

4 In situ gamma spectroscopy

The results in columns 1-3 of table 4 are based on the analysis of individual spectra taken at 96 different points. A location based summary is given in Table 5.

For the non-irrigated land application area (undisturbed ambient woodland) the average values are U 5.6±0.5 ppm, Th 16.7±0.7 ppm and K 0.56±0.04%. A previously reported value for this area is U 5.1±0.3 ppm, Th 20.1±1.8 ppm and K 0.62±0.04 % (Akber and Marten, 1992). For the irrigated land application area, Th and K concentrations do not vary but the uranium concentration increases to 11.9±0.5 ppm. This trend is due to the deposition of ^{226}Ra through application of mine water. As previously mentioned, the portable gamma spectroscopy analysis program assumes uniform distribution of radioactivity in the soil with primordial series equilibrium and uses selected ^{214}Bi gamma peaks for estimating U. These assumptions are not valid for the irrigated land application area and the U values for this area in table 4 and 5 should be taken as equivalent values only and rather reflect ^{226}Ra concentrations.

Uranium concentration in the waste rock dump area is 102±6 ppm or 0.009% U_3O_8. Waste rock cut off grade at Ranger is 0.02% on a truck load basis. This report shows that field measurements over an extended area are about half this cut off value.

The average uranium concentration for OSP2 area is 440±66 ppmU (0.06% U_3O_8), this value is within the operational range for the grade cut offs for OSP2 – between 0.02 and 0.08 %.

The laterite pile is higher in K, perhaps due to higher clay content of the material. Laterite pile is also higher in Th when compared to the OSP2 and the waste rock.

UNSCEAR 2000 provided the conversion coefficients that can be used to estimate the external above ground gamma dose rate if U, Th and K activity concentrations are known as shown in table 6.

UNSCEAR conversion coefficients lead to a relationship between the gamma dose rate and U, Th and K concentrations as:

$$H_{Total} = 5.65\ C_U + 2.44\ C_{Th} + 10.8\ C_K + H_{Cosmic} \qquad (1)$$

Where

H_{Total}: Gamma dose rate nSv.h^{-1} in air (Equivalent and absorbed dose rate assumed to be numerically equal)

C_U : Uranium concentration in ppm

C_{Th} : Thorium concentration in ppm

C_K : Potassium concentration in %

H_{Cosmic}: Gamma radiation dose rate due to cosmic radiation in nSv.h^{-1}.

Equation 1 has been used to estimate the gamma dose rate for the points of in situ gamma dosimetry (Table 3). The averages according to the locations are summarised in Table 7. For the cosmic radiation term, H_{Cosmic} a value of 66 nSv.h^{-1} taken from Marten (1992) has been used. It is a local value obtained using the gamma dose rate measurement equipment similar to that used in the present study.

As expected, the results show that the U series is the dominant contributor to the external radiation dose due to operations at Ranger. Excluding the cosmic component, uranium contributes to 91% of the total external gamma dose at OSP2 and 89% at the WRD. For the laterite pile of proportionately higher Th and K content it is 83%.

In the absence of direct measurements bulk uranium series concentration over surfaces such as WRD and OSP's can be estimated using a relationship:

$$C_U \approx 0.16\ (H_{Total} – 66). \qquad (2)$$

5 External gamma dose rate

External gamma dose rate was measured 1m above ground at 174 points on different surfaces. Individual values and uncertainties are given in table 4, the averages for various locations in table 8.

At 80 points on different surfaces the external gamma dose rate measurement points overlapped with those of in situ gamma spectroscopy. At these points, gamma dose rate estimates from eU, eTh and K concentrations (Equation 1) and the cosmic ray component could be compared with the direct measurements. The outcome of this comparison has been summarised in table 8.

The agreement between the measured and estimated values is excellent with an overall average ratio of 1.03±0.01. It confirms that for the surfaces at and around the Ranger operations the external gamma dose rate can be adequately estimated using Equation 1.

In Figure 1, Equation 2 has been confirmed by plotting the measured uranium concentration (using in-situ gamma spectroscopy) against the estimated value from the gamma dose rate measurements.

Some disagreement between the measured and estimated gamma dose rate at the irrigated land application area is not surprising. As mentioned earlier the assumption of uniform U, Th and K distribution and series equilibrium do not strictly hold for this area. Excluding the value for the irrigated land application area the measured to calculated gamma dose rate ratio changes to 1.01±0.01.

6 ^{222}Rn activity flux and ^{226}Ra activity concentration

Besides other geomorphologic factors, radon activity flux should depend upon ^{226}Ra activity concentration of the ground. We have used the simultaneous measurements of soil radioactivity through in situ gamma spectroscopy and the activity flux to investigate this relationship. For surfaces Laterite Pile Rim, OSP7, Mine Pit 1 and Mine Pit 3, where external gamma dose rates only were available, Equation 2 was used to estimate the uranium content and subsequently ^{226}Ra activity concentration.

If we define the ratio of the radon exhalation rate (mBq m^{-2} s^{-1}) to the ^{226}Ra concentration in the soil (Bq kg^{-1}) as $R_{E\text{-}R}$, then the location-based summary leads to values of $R_{E\text{-}R}$ ranging from 0.04 to 4.06 mBq m^{-2} s^{-1} (Bq kg^{-1})$^{-1}$ (table 9) . For a given ^{226}Ra concentration at OSP2, OSP7 and Mine Pit#3, more radon is exhaled from the flattened pad or bench areas than the loose rocks and rubble surfaces. For the fine grain laterite pile, this situation is reversed. Geomorphologic factors responsible for this behaviour were discussed earlier while explaining the differences in radon activity flux from these surfaces.

At 0.67±0.04 mBq m^{-2} s^{-1} (Bq kg^{-1})$^{-1}$, the radon exhalation rate to radium activity ratio ($R_{E\text{-}R}$) for the irrigated land application area is somewhat lower than that for the non-irrigated area. This could be due to several factors:

- The ^{226}Ra which was applied in the irrigation water was retained in the surface few centimetres of soil (Akber & Marten, 1992). The NaI(Tl) detector used to estimate the ^{226}Ra concentration gets most of its signal from the surface few tens of centimetres of soil. However, the source of ^{222}Rn exhaled would be expected to extend much deeper than this. Hence it would be expected that the measured value of $R_{E\text{-}R}$ for such a site would be depressed somewhat.
- On the other hand, the Ra from the irrigation water should be on the surface of the soil grains, and hence should give a relatively high emanation rate per ^{226}Ra concentration for the irrigated area.
- Other factors could include changes in the soil structure due to higher salinity as a result of the irrigation. This might lead to greater cohesive forces between the grains, and also to greater tendency for the soil to absorb moisture from the air.

$R_{E\text{-}R}$ for the irrigated area is 0.52±0.17 mBq m^{-2} s^{-1} (Bq kg^{-1})$^{-1}$ if only excess ^{226}Ra activity concentration and ^{222}Rn activity flux over the non-irrigated land application area is taken into account. It is lower than, but statistically overlaps with the overall value of

0.67 ± 0.04 mBq m^{-2} s^{-1} (Bq kg^{-1})$^{-1}$. The results strongly suggest that surface wetness in the irrigated land application is a dominant factor in radon exhalation behaviour.

Additional measurements in an area that was previously irrigated on an experimental basis but not included in the existing irrigation regime may provide further insight into the exhalation behaviour from the land irrigation area in a post rehabilitation phase.

Some broad trends emerge when the results are plotted in order of the ratio (Figure 2). Among the higher values, overburden and the laterite push zone are the areas where the finer grain material has been laid but not compacted. The average of radon flux to radium activity ratio for these two sites combined is 3.6 ± 0.7 mBq m^{-2} s^{-1} (Bq kg^{-1})$^{-1}$. Pit 3 pad, Laterite pad, and WRD pad are compacted surfaces with no vegetation. The ratios for these sites cluster together with an average value 0.42 ± 0.04 mBq m^{-2} s^{-1} (Bq kg^{-1})$^{-1}$. The flat vegetated surfaces of rehabilitated waste rock dump and the land application area also cluster together with a slightly higher average of 0.85 ± 0.06 mBq m^{-2} s^{-1} (Bq kg^{-1})$^{-1}$.

The observed difference in the OSP2 and OSP7 radon exhalation behaviour cannot be explained except perhaps on the basis of the thickness of the pile layer. However, the WRD pile is of comparable thickness to the OSP2. If the ore materials of different grades are differently mineralised then radon emanation could vary substantially on the basis of uranium (and hence ^{226}Ra) distribution. More stock piles should be investigated.

In an earlier study Mason et al (1982) reported $^{+96}49^{-32}$ Bq.m^{-2}.s^{-1} / % U_3O_8 as a universal average value for the Nabarlek, Ranger and Rum Jungle waste rock material and for the dry rocks of all types and ore grades. This value corresponds to $^{+0.91}0.47^{-0.31}$ mBq.m^{-2}.s^{-1} ^{222}Rn / Bq.kg^{-1} ^{226}Ra and covers a wide range of values observed during the present study.

7 Log-normal distribution of radon exhalation

The observation that radon activity flux from a given surface follows a log-normal distribution has been illustrated through examples in Figure 3. The log normal trend reflects the fact that radon exhalation from the ground depends upon a number of random variables (Ott, 1995).

To compare whether the data are statistically better described by a normal or log-normal distribution, the program *freqan* was used. The original FORTRAN version of *freqan* was written and described by Vardavas (1992); the version used here (v2.01) uses equivalent algorithms but has been rewritten in the C language. *Freqan* uses a χ^2 test to determine whether the observed distribution is consistent with the assumed theoretical distribution (i.e. normal or log-normal). Figures 4 and 5 illustrate the distribution results obtained for the pit 1 general area and LAA irrigated area datasets, respectively.

As can be seen from the figures, the log-normal distribution better predicts the data distributions than the normal distribution in both cases. This can also be seen from the fact that the χ^2 per degree of freedom is lower for the log-normal in both cases; although the value of 5.5 for the LAA irrigated dataset indicates that the data are not well described by log-normal in this case (Tables 10,11). The error probabilities ζ are less than 1.0 in both cases; this indicates that the number of data points is sufficient to allow a valid comparison in the χ^2 test (Vardavas, 1992). Applying the same test to the LAA non-irrigated soil type II and soil type III datasets gave similar results, although the smaller numbers of samples (30 in each case) gave somewhat less power to the χ^2 test ($\zeta = 1.04$).

Whether or not these findings imply that a geometric mean should be used for estimating emission from a large surface area is subject to investigation.

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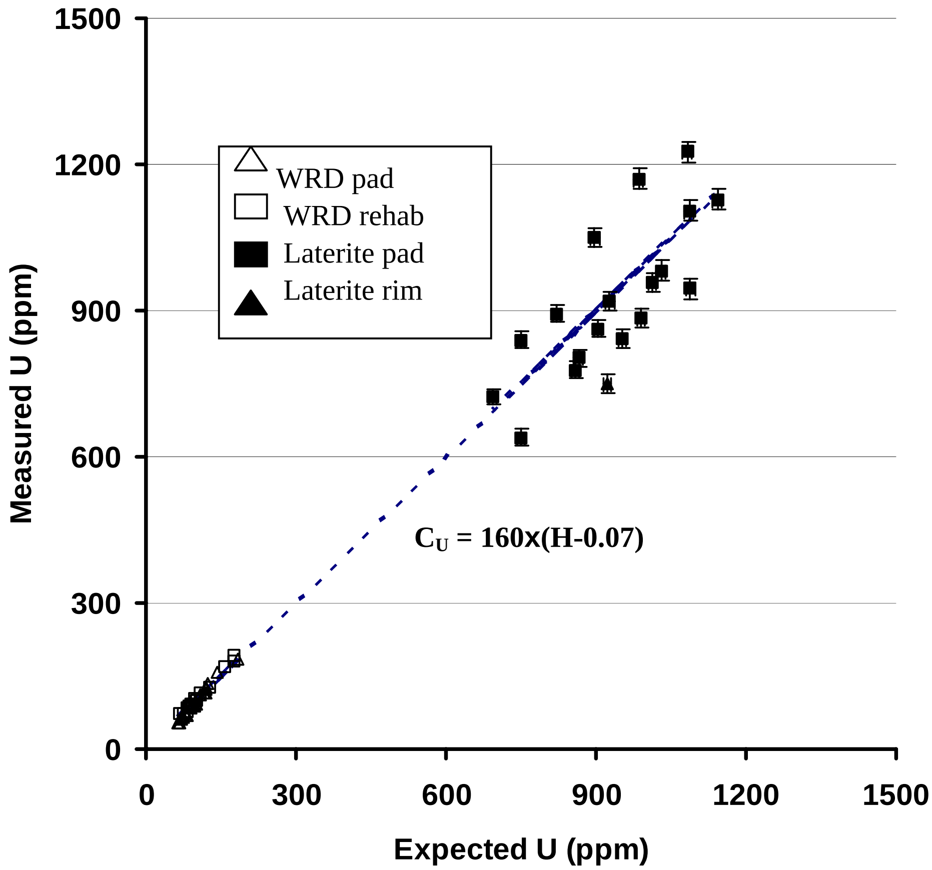

Figure 1 Measured uranium concentration using in situ gamma spectroscopy at the waste rock dump and laterite pile vs. the expected value from Equation 2 and external gamma dose rate measurement

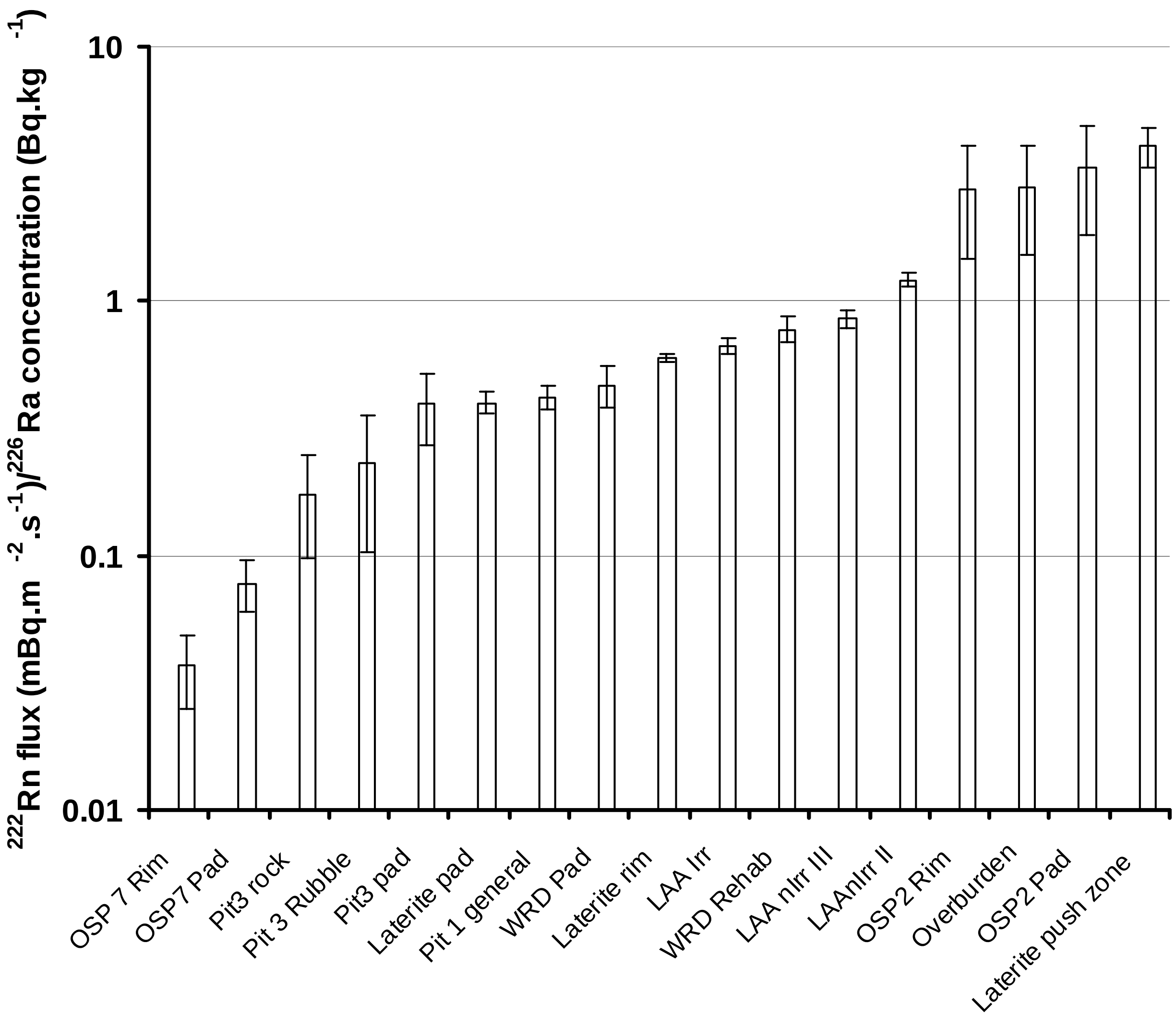

Figure 2 Ratio of radon activity flux and ^{226}Ra activity concentration for various locations at Ranger Uranium Mine

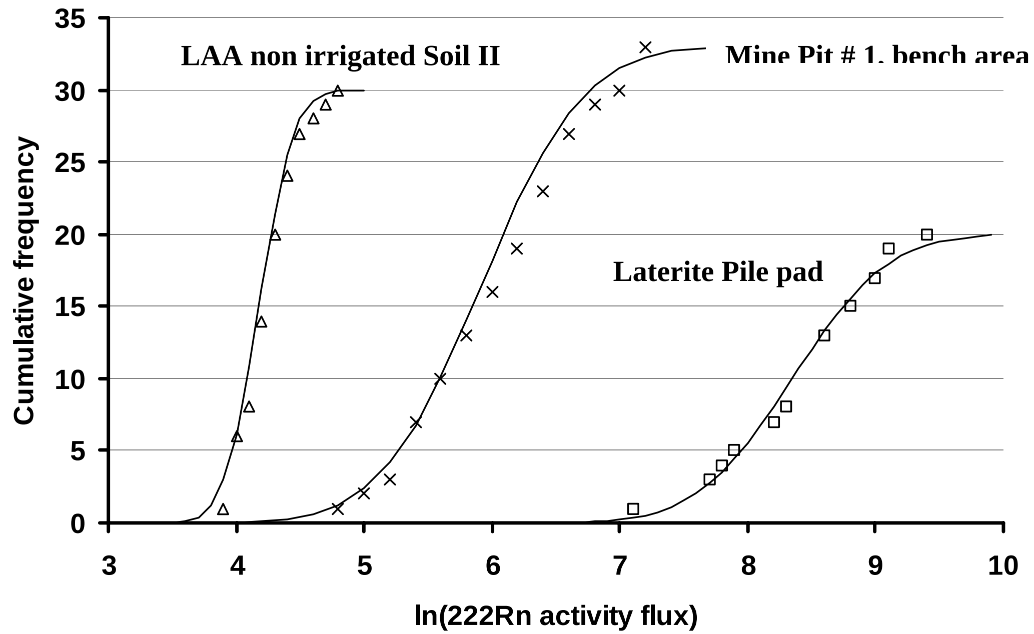

Figure 3 ^{222}Rn activity flux frequency distribution for measurements at three different locations. The continuous line is the statistically expected cumulative frequency for log-normal distribution.

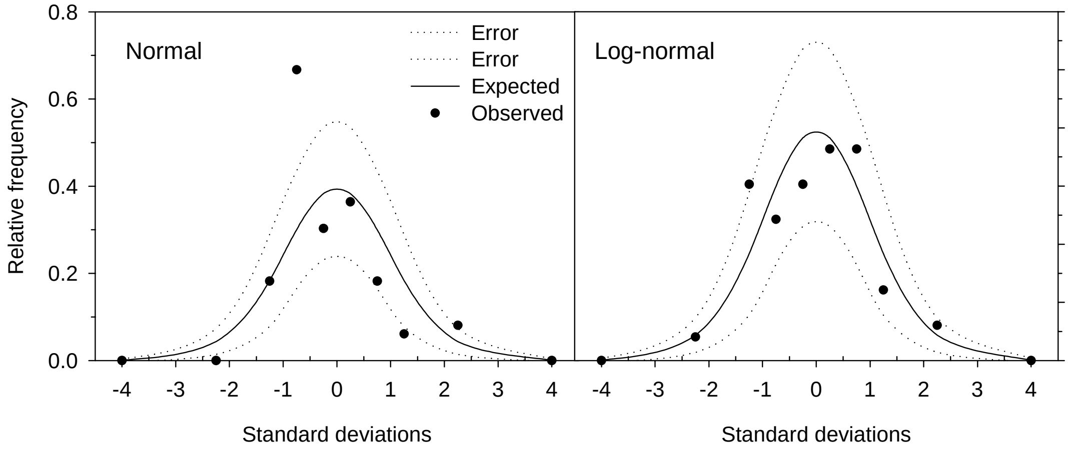

Figure 4 Expected and observed Rn exhalation rate distributions for pit 1 general area

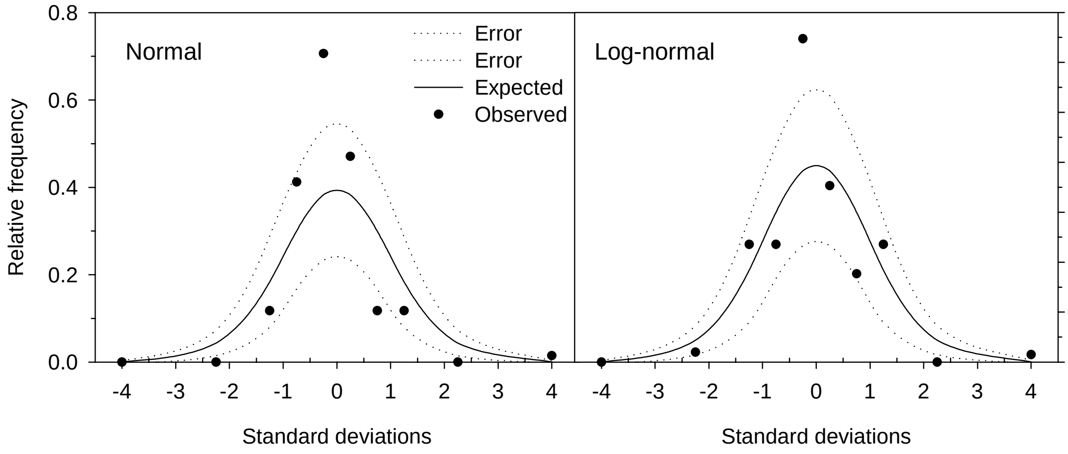

Figure 5 Expected and observed Rn exhalation rate distributions for LAA irrigated area

Table 1 Radon activity flux at various points at ERA Ranger

Site: **Mine pit # 3 - Pad**

Period of measurement: **October 2003**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux (mBq m^{-2} s^{-1})		
3694	7778	Charcoal	518	±	33
3721	7768	Charcoal	10559	±	493
3702	7770	Charcoal	294	±	21
3716	7786	Charcoal	839	±	49
3684	7790	Charcoal	1122	±	63
3664	7794	Charcoal	7125	±	338
3687	7772	Charcoal	2722	±	137
3713	7774	Charcoal	7675	±	366
3696	7780	Charcoal	956	±	55
3690	7768	Charcoal	523	±	33
3666	7794	Charcoal	841	±	48
3669	7772	Charcoal	3181	±	158
3696	7774	Charcoal	684	±	42
3694	7788	Charcoal	282	±	21
3684	7780	Charcoal	308	±	23
3703	7762	Charcoal	623	±	37
3724	7788	Charcoal	2162	±	112
3713	7784	Charcoal	725	±	44
3714	7768	Charcoal	9438	±	442
3703	7788	Charcoal	235	±	19
3703	7772	Charcoal	359	±	24
3715	7772	Emanometer	2211	±	241
3711	7774	Emanometer	5003	±	494
3705	7764	Emanometer	286	±	45
3664	7744	Emanometer	4662	±	463

Number of measurement locations	25
Arithmetic mean	2533
Standard deviation	3094
Standard error	619

Geometric mean	1237
Geometric deviation	3

Site: **Mine pit # 3 - Rubble**

Period of measurement: **October 2003**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux ($mBq\ m^{-2}\ s^{-1}$)
3718	7762	Charcoal	5743 ± 275
3690	7772	Charcoal	246 ± 19
3687	7768	Charcoal	892 ± 51
3676	7778	Charcoal	409 ± 27
3708	7766	Charcoal	353 ± 24
3669	7776	Charcoal	479 ± 30
3712	7764	Charcoal	3643 ± 179
3708	7766	Emanometer	477 ± 70
3691	7804	Emanometer	2874 ± 289
3718	7762	Charcoal	5743 ± 275

Number of measurement locations	9
Arithmetic mean	1670
Standard deviation	1960
Standard error	653

Geometric mean	912
Geometric deviation	3

Site: **Mine pit # 3 – Rocks**

Period of measurement: **October 2003**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux ($mBq\ m^{-2}\ s^{-1}$)
3694	7766	Charcoal	26 ± 7
3669	7778	Charcoal	2039 ± 105

Number of measurement locations	2
Arithmetic mean	1033
Standard deviation	1423
Standard error	1007

Geometric mean	232
Geometric deviation	22

Site: **Waste Rock – Rehabilitated area**

Period of measurement: **July 2002**

Location coordinates 53L027	**UTM859**	**Method**	**^{222}Rn activity flux (mBq m^{-2} s^{-1})**		
272930	8597069	Emanometer	488	±	42
272915	8597065	Emanometer	551	±	47
272916	8597073	Emanometer	611	±	53
272915	8597084	Emanometer	1254	±	108
272903	8597092	Emanometer	1277	±	110
272900	8597080	Emanometer	1449	±	99
272850	8597039	Emanometer	506	±	35
272887	8597009	Emanometer	1067	±	73
272893	8597012	Emanometer	675	±	46
272943	8597112	Emanometer	1074	±	73
272895	8597070	Charcoal	1130	±	61
272930	8597058	Charcoal	699	±	40
272928	8597082	Charcoal	799	±	45
272946	8597111	Charcoal	986	±	54
272861	8597060	Charcoal	823	±	46
272899	8597046	Charcoal	912	±	50
272868	8597035	Charcoal	1154	±	62
272912	8597050	Charcoal	194	±	15
272878	8597065	Charcoal	1661	±	86
272884	8597040	Charcoal	342	±	22
272909	8597077	Charcoal	2035	±	103

Number of measurement locations	21
Arithmetic mean	937
Standard deviation	449
Standard error	98

Geometric mean	826
Geometric deviation	2

Site: **Waste Rock – Pad area**

Period of measurement: **July 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux ($mBq\ m^{-2}\ s^{-1}$)		
273010	8597072	Emanometer	665	±	60
273007	8597059	Emanometer	367	±	39
273001	8597072	Emanometer	1160	±	101
272989	8597063	Emanometer	559	±	57
272977	8597048	Emanometer	462	±	48
272973	8597054	Emanometer	312	±	36
272964	8597052	Emanometer	636	±	71
272937	8597030	Emanometer	702	±	78
272940	8597028	Emanometer	130	±	25
272971	8597082	Emanometer	539	±	62
272986	8597084	Charcoal	286	±	20
272984	8597131	Charcoal	211	±	16
273006	8597114	Charcoal	455	±	29
273020	8597094	Charcoal	353	±	24
273004	8597089	Charcoal	227	±	17
273026	8597112	Charcoal	229	±	17
272971	8597107	Charcoal	217	±	23
272973	8597082	Charcoal	620	±	36
272989	8597112	Charcoal	2181	±	111
272969	8597128	Charcoal	215	±	21

Number of measurement locations	20
Arithmetic mean	526
Standard deviation	459
Standard error	103

Geometric mean	415
Geometric deviation	2

Site: **Ore Stock Pile 7 – Pile area**

Period of measurement: **July 2002**

Location coordinates		**Method**	**^{222}Rn activity flux (mBq m^{-2} s^{-1})**		
53L027	**UTM859**				
		Charcoal	4576	±	244
		Charcoal	1358	±	86
		Charcoal	1080	±	70
		Charcoal	837	±	58
		Charcoal	577	±	44

Number of measurement locations	5
Arithmetic mean	1686
Standard deviation	1641
Standard error	734

Geometric mean	1265
Geometric deviation	2

Site: **Ore Stock Pile 7 – Rim area**

Period of measurement: **July 2002**

Location coordinates		**Method**	**^{222}Rn activity flux (mBq m^{-2} s^{-1})**		
53L027	**UTM859**				
		Emanometer	695	±	80
		Emanometer	143	±	27
		Emanometer	1718	±	177
		Emanometer	816	±	96
		Emanometer	193	±	27
		Emanometer	76	±	18
		Emanometer	2953	±	238
		Emanometer	1009	±	99

Number of measurement locations	8
Arithmetic mean	950
Standard deviation	977
Standard error	345

Geometric mean	529
Geometric deviation	4

Site: **Ore Stock Pile 7 – Pad area**

Period of measurement: **July 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux ($mBq\ m^{-2}\ s^{-1}$)		
		Emanometer	5251	±	502
		Emanometer	2521	±	265
		Emanometer	2780	±	228
		Emanometer	6958	±	535
		Charcoal	1063	±	71
		Charcoal	2132	±	124
		Charcoal	2892	±	162
		Charcoal	897	±	62
		Charcoal	3779	±	204

Number of measurement locations	9
Arithmetic mean	3141
Standard deviation	1949
Standard error	650

Geometric mean	2614
Geometric deviation	2

Site: **Ore Stock Pile 2 – Rim area**

Period of measurement: **September 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux (mBq m^{-2} s^{-1})		
3120	6556	Charcoal	1968	±	120
3126	6543	Charcoal	6227	±	326
3127	6517	Charcoal	916	±	68
3128	6493	Charcoal	5853	±	308
3126	6488	Charcoal	14003	±	686
3116	6537	Charcoal	850	±	64
3103	6473	Charcoal	2194	±	132
3106	6462	Charcoal	57354	±	2637
3113	6506	Charcoal	17710	±	856
3126	6458	Charcoal	16223	±	789

Number of measurement locations	10
Arithmetic mean	12330
Standard deviation	17080
Standard error	5401

Geometric mean	5561
Geometric deviation	4

Site: **Ore Stock Pile 2 – Pad area**

Period of measurement: **September 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux ($mBq\ m^{-2}\ s^{-1}$)		
3133	6517	Emanometer	14709	±	1085
3129	6539	Emanometer	19275	±	1421
3111	6497	Emanometer	6336	±	511
3113	6480	Emanometer	1653	±	160
3110	6469	Emanometer	2401	±	205
3122	6521	Emanometer	24649	±	2242
3142	6515	Charcoal	5714	±	300
3130	6469	Charcoal	91899	±	4166
3135	6547	Charcoal	26342	±	1246
3140	6526	Charcoal	10345	±	517
3139	6486	Charcoal	8200	±	417
3140	6502	Charcoal	5554	±	293
3099	6446	Charcoal	2104	±	127
3129	6563	Charcoal	13245	±	651
3110	6443	Charcoal	2774	±	160

Number of measurement locations	15
Arithmetic mean	15680
Standard deviation	22553
Standard error	5823

Geometric mean	8508
Geometric deviation	3

Site: **Land Application Area – Non irrigated Soil Type II**
Period of measurement: **July 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux (mBq m^{-2} s^{-1})
5042	7390	Char+Eman	52 ± 4
5042	7386	Charcoal	52 ± 5
5027	7380	Charcoal	53 ± 5
5007	7353	Charcoal	52 ± 5
4992	7343	Charcoal	62 ± 5
4961	7325	Charcoal	67 ± 5
4949	7312	Charcoal	61 ± 5
4934	7297	Charcoal	73 ± 6
4887	7312	Charcoal	56 ± 5
4905	7318	Charcoal	77 ± 6
4925	7333	Char+Eman	106 ± 8
4953	7348	Charcoal	73 ± 6
4978	7369	Charcoal	76 ± 6
4996	7386	Charcoal	53 ± 5
5012	7405	Charcoal	72 ± 6
5031	7422	Charcoal	64 ± 5
4826	7258	Char+Eman	79 ± 7
4832	7284	Charcoal	55 ± 5
4827	7324	Charcoal	62 ± 5
4833	7348	Charcoal	72 ± 6
4827	7368	Charcoal	84 ± 6
4901	7458	Char+Eman	84 ± 7
4887	7451	Charcoal	93 ± 7
4873	7433	Char+Eman	112 ± 8
4858	7422	Charcoal	65 ± 6
4842	7412	Charcoal	65 ± 6
4818	7395	Charcoal	79 ± 6
4803	7391	Charcoal	72 ± 6
4790	7389	Charcoal	86 ± 7
4776	7377	Charcoal	48 ± 5

Number of measurement locations	30
Arithmetic mean	70
Standard deviation	16
Standard error	3

Geometric mean	69
Geometric deviation	1

Site: **Land Application Area - Non irrigated Soil Type III**
Period of measurement: **July 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux (mBq m^{-2} s^{-1})
5118	7507	Char+Eman	56 ± 4
5124	7540	Charcoal	46 ± 7
5124	7573	Charcoal	57 ± 7
5122	7605	Charcoal	91 ± 8
5117	7630	Charcoal	91 ± 9
5083	7510	Charcoal	69 ± 8
5094	7519	Charcoal	54 ± 6
5109	7534	Charcoal	66 ± 6
5079	7533	Charcoal	65 ± 8
5091	7543	Char+Eman	38 ± 3
5100	7554	Charcoal	55 ± 6
5099	7564	Charcoal	56 ± 7
5053	7551	Char+Eman	62 ± 4
5066	7555	Charcoal	61 ± 6
5064	7566	Charcoal	70 ± 7
5084	7576	Charcoal	65 ± 6
5091	7589	Charcoal	158 ± 11
5075	7592	Charcoal	78 ± 7
5055	7570	Char+Eman	67 ± 4
5041	7563	Charcoal	69 ± 6
5024	7546	Charcoal	63 ± 6
5011	7538	Charcoal	71 ± 7
4954	7505	Charcoal	107 ± 9
4962	7513	Char+Eman	84 ± 4
4973	7527	Charcoal	67 ± 6
4977	7544	Charcoal	75 ± 7
4992	7530	Charcoal	54 ± 6
4988	7513	Charcoal	52 ± 6
4995	7566	Charcoal	75 ± 7
5005	7572	Charcoal	67 ± 6

Number of measurement locations	30
Arithmetic mean	70
Standard deviation	22
Standard error	4

Geometric mean	67
Geometric deviation	1

Site: **Land Application Area - Irrigated**
Period of measurement: **June-August 2002**

Location coordinates 53L027	**UTM859**	**Method**	**^{222}Rn activity flux (mBq m^{-2} s^{-1})**		
4878	7344	Charcoal	72	±	7
4898	7375	Charcoal	86	±	10
4925	7397	Char+Eman	95	±	12
4938	7401	Charcoal	96	±	11
4969	7424	Charcoal	123	±	12
5000	7447	Charcoal	83	±	8
5028	7466	Char+Eman	99	±	13
5056	7489	Charcoal	133	±	12
5062	7526	Charcoal	73	±	9
5037	7505	Char+Eman	67	±	10
5004	7485	Charcoal	122	±	11
4973	7461	Charcoal	166	±	12
4948	7442	Charcoal	148	±	12
4919	7422	Charcoal	167	±	14
4888	7395	Charcoal	102	±	11
4861	7385	Char+Eman	129	±	15
4846	7360	Charcoal	104	±	9
4839	7385	Charcoal	105	±	11
4867	7408	Charcoal	87	±	10
4895	7432	Char+Eman	79	±	13
4915	7446	Charcoal	101	±	11
4960	7467	Charcoal	115	±	11
4874	7488	Char+Eman	118	±	14
5001	7503	Charcoal	153	±	13
5031	7527	Charcoal	124	±	10
5048	7540	Charcoal	315	±	19
5050	7458	Char+Eman	94	±	13
5021	7431	Charcoal	56	±	8
4991	7411	Charcoal	99	±	11
4980	7404	Charcoal	69	±	9
4955	7377	Charcoal	92	±	8
4918	7362	Charcoal	110	±	10
4887	7337	Char+Eman	106	±	12
4878	7344	Emanometer	132	±	8

Number of measurement locations	34
Arithmetic mean	112
Standard deviation	45
Standard error	8

Geometric mean	106
Geometric deviation	1

Site: **Mine Pit 1 – general area**

Period of measurement: **October 2003**

Location coordinates 53L027	**UTM859**	**Method**	**^{222}Rn activity flux (mBq m^{-2} s^{-1})**		
3444	6166	Charcoal	314	±	20
3434	6132	Charcoal	236	±	17
3433	6106	Charcoal	1103	±	43
3433	6118	Charcoal	624	±	30
3431	6118	Charcoal	630	±	30
3439	6110	Charcoal	745	±	33
3439	6116	Charcoal	560	±	27
3422	6142	Charcoal	671	±	31
3440	6106	Charcoal	517	±	26
3424	6136	Charcoal	577	±	28
3428	6146	Charcoal	656	±	31
3441	6154	Charcoal	107	±	13
3444	6166	Charcoal	175	±	15
3442	6136	Charcoal	280	±	19
3440	6126	Charcoal	480	±	25
3428	6112	Charcoal	470	±	24
3427	6126	Charcoal	1190	±	46
3442	6132	Charcoal	1007	±	41
3442	6142	Charcoal	208	±	16
3434	6150	Charcoal	217	±	17
3425	6132	Charcoal	395	±	23
3437	6142	Charcoal	319	±	20
3434	6150	Charcoal	451	±	24
3430	6152	Charcoal	148	±	14
3433	6140	Charcoal	398	±	23
3436	6138	Charcoal	850	±	36
3442	6138	Charcoal	1265	±	48
3430	6120	Emanometer	189	±	26
3430	6116	Emanometer	337	±	45
3431	6124	Emanometer	258	±	40
3434	6150	Emanometer	502	±	63
3439	6144	Emanometer	210	±	34
3437	6140	Emanometer	247	±	37

Number of measurement locations	33
Arithmetic mean	495
Standard deviation	309
Standard error	54

Geometric mean	410
Geometric deviation	2

Site: **Mine Pit 1 – Wall**

Period of measurement: **October 2003**

Location coordinates 53L027	**UTM859**	**Method**	**^{222}Rn activity flux (mBq m^{-2} s^{-1})**		
		Charcoal	395	±	22
		Charcoal	291	±	19
		Charcoal	227	±	17

Number of measurement locations	3
Arithmetic mean	304
Standard deviation	85
Standard error	49

Geometric mean	297
Geometric deviation	1

Site: **Laterite Pile – Pad area**

Period of measurement: **August 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux ($mBq\ m^{-2}\ s^{-1}$)		
3309	6741	Charcoal	3651	±	51
3315	6750	Charcoal	2057	±	39
3319	6759	Charcoal	1169	±	31
3302	6776	Charcoal	8642	±	77
3330	6746	Charcoal	6403	±	65
3302	6726	Charcoal	4969	±	55
3334	6757	Charcoal	4921	±	54
3293	6768	Charcoal	7808	±	74
3340	6765	Charcoal	11911	±	83
3285	6757	Charcoal	7879	±	74
3307	6786	Charcoal	3529	±	50
3317	6722	Charcoal	8820	±	76
3321	6733	Charcoal	5046	±	59
3324	6770	Charcoal	2100	±	37
3315	6792	Charcoal	6059	±	65
3321	6789	Emanometer	4965	±	393
3315	6790	Emanometer	4933	±	398
3319	6797	Emanometer	2308	±	207
3310	6769	Emanometer	3427	±	281
3316	6767	Emanometer	2566	±	221

Number of measurement locations	20
Arithmetic mean	5158
Standard deviation	2770
Standard error	619

Geometric mean	4434
Geometric deviation	2

Site: **Laterite Pile – Push Zone**

Period of measurement: **August 2002**

Location coordinates		**Method**	**^{222}Rn activity flux (mBq m^{-2} s^{-1})**		
53L027	**UTM859**				
3344	6785	Charcoal	50680	±	182
3349	6762	Charcoal	99606	±	255
3348	6742	Charcoal	64044	±	204
3346	6779	Charcoal	126502	±	291
3342	6726	Charcoal	90825	±	241
3340	6793	Charcoal	120334	±	285
3336	6795	Emanometer	12143	±	1157

Number of measurement locations	7
Arithmetic mean	80591
Standard deviation	40840
Standard error	15436

Geometric mean	65953
Geometric deviation	2

Site: **Laterite Pile – Rim**

Period of measurement: **August 2002**

Location coordinates 53L027	UTM859	**Method**	^{222}Rn activity flux (mBq m^{-2} s^{-1})		
3345	6730	Charcoal	23967	±	124
3340	6797	Charcoal	58189	±	196
3352	6747	Charcoal	46717	±	174
3349	6775	Charcoal	66654	±	209
3351	6765	Charcoal	36358	±	154
3342	6720	Charcoal	27583	±	133
3315	6808	Charcoal	25080	±	128
3349	6736	Charcoal	5586	±	62
3352	6756	Charcoal	55434	±	191
3330	6804	Emanometer	22346	±	2035
3334	6803	Emanometer	23276	±	2134
3349	6780	Emanometer	50275	±	4495
3348	6776	Emanometer	57792	±	5175

Number of measurement locations	13
Arithmetic mean	38404
Standard deviation	18566
Standard error	5149

Geometric mean	32813
Geometric deviation	2

Site: **Overburden**

Period of measurement: **July 2002**

Location coordinates 53L027	UTM859	Method	^{222}Rn activity flux (mBq m^{-2} s^{-1})		
3154	7247	Emanometer	954	±	87
3167	7241	Emanometer	1424	±	123
3197	7262	Emanometer	575	±	67
3182	7268	Emanometer	931	±	102

Number of measurement locations	4
Arithmetic mean	971
Standard deviation	348
Standard error	174

Geometric mean	923
Geometric deviation	1

Table 2 Statistical summary of radon exhalation rate data (mBq m^{-2} s^{-1})

Location		Month of measurement	Number of readings	Average	Standard Deviation	Standard Error	Geometric Mean	Geometric Deviation
Waste Rock Dump	Rehabilitated area	July 2002	21	937	449	98	826	1.7
	Pad area		20	526	459	103	415	2.0
Ore Stock Pile 7	Rock pile	July 2002	5	1686	1641	734	1265	2.2
	Rim		8	950	977	345	529	3.6
	Pad area		9	3141	1949	650	2614	2.0
Ore Stock Pile 2	Rim	September 2002	10	12330	17080	5401	5561	4.0
	Pad area		15	15680	22553	5823	8508	3.0
Land application area	Non irrigated soil type II	July 2002	30	70	16	3	69	1.2
	Non irrigated soil type III		30	70	22	4	67	1.3
LAA	Irrigated area	June-August 2002	34	112	45	8	106	1.4
Mine Pit 3	Rubble	October 2003	9	1680	1960	653	912	3.2
	Rocks		2	1033	1423	1007	232	21.7
	Pad area		25	2533	3094	619	1237	3.4
Mine Pit 1	Walls	October 2003	3	304	85	49	297	1.3
Pit 1	General area		33	495	309	54	410	1.9
Laterite	Rim	August 2002	13	38404	18566	5149	32813	1.9
Laterite	Push zone		7	80591	40840	15436	65953	2.3
Laterite	Pad area		20	5158	2770	619	4434	1.8
Overburden		July 2002	4	971	348	174	923	1.4
		Total	298					

Table 3 Classification of ore grades and uranium concentration (%) at Ranger uranium mine

Ore Grade Number	Uranium Concentration (%)
1	0-0.02
2	0.02-0.08
3	0.08-0.12
4	0.12-0.2
5	0.2-0.35
6	0.35-0.5
7	>0.5

Table 4 eU, eTh and K concentrations, corresponding external gamma dose rate estimates, measured gamma dose rates and measured to calculated dose rate ratios

Measured concentration			Equivalent external gamma dose rate (μSv.h^{-1})					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(a) Laterite Pile – pad area								
863 ± 18	235 ± 16	32 ± 3	4.88	0.57	0.35	5.86 ± 0.11	5.71 ± 0.06	0.97 ± 0.03
802 ± 18	245 ± 16	31 ± 3	4.53	0.60	0.34	5.54 ± 0.11	5.47 ± 0.06	0.99 ± 0.03
778 ± 18	255 ± 16	40 ± 3	4.40	0.62	0.43	5.51 ± 0.11	5.44 ± 0.06	0.99 ± 0.03
958 ± 20	367 ± 19	52 ± 3	5.41	0.90	0.56	6.93 ± 0.13	6.40 ± 0.06	0.92 ± 0.03
1170 ± 21	189 ± 15	18 ± 3	6.61	0.46	0.19	7.33 ± 0.13	6.22 ± 0.06	0.85 ± 0.02
883 ± 19	309 ± 18	44 ± 3	4.99	0.75	0.48	6.29 ± 0.12	6.25 ± 0.06	0.99 ± 0.03
920 ± 19	211 ± 15	37 ± 3	5.20	0.52	0.40	6.18 ± 0.12	5.87 ± 0.06	0.95 ± 0.03
1128 ± 21	349 ± 19	50 ± 3	6.38	0.85	0.54	7.83 ± 0.13	7.22 ± 0.07	0.92 ± 0.02
1226 ± 22	256 ± 17	31 ± 3	6.93	0.62	0.34	7.96 ± 0.13	6.84 ± 0.06	0.86 ± 0.02
1051 ± 20	168 ± 14	16 ± 3	5.94	0.41	0.17	6.59 ± 0.12	5.68 ± 0.06	0.86 ± 0.02
1104 ± 21	273 ± 17	37 ± 3	6.24	0.67	0.40	7.37 ± 0.13	6.86 ± 0.06	0.93 ± 0.02
841 ± 19	364 ± 19	50 ± 3	4.75	0.89	0.53	6.24 ± 0.12	6.02 ± 0.06	0.96 ± 0.03
840 ± 18	132 ± 13	14 ± 2	4.74	0.32	0.15	5.28 ± 0.11	4.76 ± 0.05	0.90 ± 0.03
750 ± 18	399 ± 19	50 ± 3	4.24	0.97	0.54	5.82 ± 0.12	5.83 ± 0.06	1.00 ± 0.03
945 ± 20	529 ± 22	70 ± 3	5.34	1.29	0.75	7.45 ± 0.13	6.88 ± 0.06	0.92 ± 0.02
639 ± 17	353 ± 18	47 ± 2	3.61	0.86	0.51	5.05 ± 0.11	4.77 ± 0.05	0.94 ± 0.03
982 ± 20	336 ± 18	45 ± 3	5.55	0.82	0.49	6.93 ± 0.13	6.51 ± 0.06	0.94 ± 0.03
894 ± 18	158 ± 14	17 ± 3	5.05	0.39	0.19	5.69 ± 0.11	5.19 ± 0.06	0.91 ± 0.03
723 ± 17	129 ± 12	18 ± 2	4.08	0.32	0.19	4.66 ± 0.10	4.41 ± 0.05	0.95 ± 0.03
Average			*5.20*	*0.68*	*0.40*	*6.34*	*5.91*	*0.94*
Standard Deviation			*0.90*	*0.25*	*0.17*	*0.95*	*0.79*	*0.05*

Measured concentration			Equivalent external gamma dose rate (μSv.h^{-1})					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(c) Laterite Pile – push zone								
							11.2 ± 0.1	
							11.2 ± 0.1	
							11.9 ± 0.1	
							9.0 ± 0.1	
							12.0 ± 0.1	
							9.5 ± 0.1	
Average							*10.8*	
Standard Deviation							*1.3*	

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(b) Laterite Pile - rim								
							5.8 ± 0.1	
							12.0 ± 0.1	
							10.5 ± 0.1	
							9.8 ± 0.1	
							9.8 ± 0.1	
							10.3 ± 0.1	
							10.4 ± 0.1	
							9.9 ± 0.1	
							10.5 ± 0.1	
							11.1 ± 0.1	
							8.8 ± 0.1	
							8.9 ± 0.1	
							10.5 ± 0.1	
							10.1 ± 0.1	
Average							*9.9*	
Standard Deviation							*1.4*	

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(d) Ore Stock Pile 2								
361 ± 12	59 ± 8	10 ± 2	2.04	0.14	0.11	2.36 ± 0.07	2.34 ± 0.02	0.99 ± 0.03
340 ± 11	61 ± 8	11 ± 2	1.92	0.15	0.12	2.26 ± 0.07	2.26 ± 0.02	1.00 ± 0.03
340 ± 11	56 ± 8	11 ± 2	1.92	0.14	0.12	2.25 ± 0.07	2.26 ± 0.02	1.00 ± 0.03
415 ± 13	78 ± 9	6 ± 2	2.34	0.19	0.06	2.66 ± 0.08	2.43 ± 0.02	0.91 ± 0.03
470 ± 13	79 ± 10	7 ± 2	2.66	0.19	0.08	2.99 ± 0.08	2.68 ± 0.03	0.90 ± 0.03
550 ± 14	79 ± 10	12 ± 2	3.11	0.19	0.13	3.50 ± 0.09	3.17 ± 0.03	0.91 ± 0.03
491 ± 14	75 ± 10	6 ± 2	2.77	0.18	0.06	3.08 ± 0.08	2.83 ± 0.03	0.92 ± 0.03
452 ± 13	66 ± 9	10 ± 2	2.55	0.16	0.11	2.89 ± 0.08	2.64 ± 0.03	0.91 ± 0.03
378 ± 12	52 ± 8	6 ± 2	2.14	0.13	0.07	2.40 ± 0.07	2.2 ± 0.02	0.92 ± 0.03
452 ± 13	72 ± 9	12 ± 2	2.56	0.18	0.12	2.92 ± 0.08	2.85 ± 0.03	0.98 ± 0.03
340 ± 11	49 ± 8	7 ± 2	1.92	0.12	0.08	2.19 ± 0.07	2.23 ± 0.02	1.02 ± 0.03
266 ± 10	46 ± 7	6 ± 1	1.50	0.11	0.06	1.74 ± 0.06	1.69 ± 0.02	0.97 ± 0.04
470 ± 13	62 ± 9	6 ± 2	2.65	0.15	0.07	2.94 ± 0.08	2.77 ± 0.03	0.94 ± 0.03
1080 ± 20	119 ± 13	11 ± 3	6.11	0.29	0.12	6.59 ± 0.12	5.21 ± 0.05	0.79 ± 0.02
189 ± 9	46 ± 7	6 ± 1	1.07	0.11	0.06	1.31 ± 0.05	1.39 ± 0.01	1.06 ± 0.04
487 ± 13	62 ± 9	4 ± 2	2.75	0.15	0.04	3.01 ± 0.08	2.79 ± 0.03	0.93 ± 0.03
395 ± 12	29 ± 7	4 ± 2	2.23	0.07	0.05	2.42 ± 0.07		
Average			*2.49*	*0.16*	*0.09*	*2.79*	*2.61*	*0.95*
Standard deviation			*1.06*	*0.05*	*0.03*	*1.06*	*0.83*	*0.06*

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(e) Waste Rock Dump – pad area								
133 ± 1	20 ± 1	2 ± 0	0.75	0.05	0.02	0.88 ± 0.01	0.85 ± 0.01	0.96 ± 0.02
115 ± 1	23 ± 1	3 ± 0	0.65	0.06	0.03	0.80 ± 0.01	0.79 ± 0.01	0.99 ± 0.02
67 ± 1	20 ± 1	3 ± 0	0.38	0.05	0.03	0.52 ± 0.01	0.53 ± 0.01	1.01 ± 0.02
93 ± 1	14 ± 1	2 ± 0	0.52	0.03	0.02	0.65 ± 0.01	0.66 ± 0.01	1.02 ± 0.02
94 ± 1	24 ± 1	2 ± 0	0.53	0.06	0.03	0.68 ± 0.01	0.70 ± 0.01	1.03 ± 0.02
113 ± 1	23 ± 1	2 ± 0	0.64	0.06	0.02	0.79 ± 0.01	0.76 ± 0.01	0.96 ± 0.02
87 ± 1	21 ± 1	3 ± 0	0.49	0.05	0.03	0.64 ± 0.01	0.63 ± 0.01	0.98 ± 0.02
158 ± 1	21 ± 1	2 ± 0	0.89	0.05	0.02	1.03 ± 0.01	0.96 ± 0.01	0.93 ± 0.02
183 ± 1	27 ± 1	3 ± 0	1.04	0.06	0.03	1.20 ± 0.01	1.21 ± 0.01	1.01 ± 0.02
126 ± 1	17 ± 1	2 ± 0	0.71	0.04	0.02	0.84 ± 0.01	0.83 ± 0.01	0.98 ± 0.02
90 ± 1	21 ± 1	3 ± 0	0.51	0.05	0.03	0.66 ± 0.01	0.68 ± 0.01	1.04 ± 0.02
122 ± 1	21 ± 1	3 ± 0	0.69	0.05	0.03	0.84 ± 0.01	0.82 ± 0.01	0.98 ± 0.02
117 ± 1	19 ± 1	3 ± 0	0.66	0.05	0.03	0.80 ± 0.01	0.82 ± 0.01	1.02 ± 0.02
73 ± 1	22 ± 1	2 ± 0	0.41	0.05	0.02	0.56 ± 0.01	0.56 ± 0.01	1.00 ± 0.02
65 ± 1	21 ± 1	3 ± 0	0.37	0.05	0.03	0.51 ± 0.01	0.54 ± 0.01	1.06 ± 0.03
55 ± 1	20 ± 1	3 ± 0	0.31	0.05	0.03	0.45 ± 0.01	0.48 ± 0.01	1.05 ± 0.03
70 ± 1	19 ± 1	3 ± 0	0.40	0.05	0.03	0.54 ± 0.01	0.58 ± 0.01	1.07 ± 0.03
54 ± 1	14 ± 1	3 ± 0	0.31	0.03	0.03	0.44 ± 0.00	0.49 ± 0.01	1.12 ± 0.03
60 ± 1	15 ± 1	3 ± 0	0.34	0.04	0.03	0.48 ± 0.01	0.52 ± 0.01	1.09 ± 0.03
Average			*0.56*	*0.05*	*0.03*	*0.70*	*0.71*	*1.02*
Standard deviation			*0.20*	*0.01*	*0.00*	*0.20*	*0.19*	*0.05*

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(f) Waste Rock Dump – rehabilitated area								
102 ± 1	13 ± 1	2 ± 0	0.57	0.03	0.02	0.69 ± 0.01	0.71 ± 0.01	1.02 ± 0.02
83 ± 1	11 ± 1	2 ± 0	0.47	0.03	0.02	0.58 ± 0.01	0.60 ± 0.01	1.04 ± 0.02
78 ± 1	16 ± 1	1 ± 0	0.44	0.04	0.01	0.56 ± 0.01	0.58 ± 0.01	1.03 ± 0.02
94 ± 1	14 ± 1	2 ± 0	0.53	0.03	0.02	0.65 ± 0.01	0.67 ± 0.01	1.03 ± 0.02
126 ± 1	16 ± 1	3 ± 0	0.71	0.04	0.04	0.85 ± 0.01	0.86 ± 0.01	1.01 ± 0.02
90 ± 1	14 ± 1	2 ± 0	0.51	0.03	0.02	0.62 ± 0.01	0.62 ± 0.01	1.00 ± 0.02
75 ± 1	14 ± 1	2 ± 0	0.42	0.03	0.02	0.54 ± 0.01	0.53 ± 0.01	0.99 ± 0.02
87 ± 1	11 ± 1	2 ± 0	0.49	0.03	0.02	0.60 ± 0.01	0.62 ± 0.01	1.03 ± 0.02
168 ± 1	18 ± 1	2 ± 0	0.95	0.04	0.02	1.08 ± 0.01	1.04 ± 0.01	0.97 ± 0.02
91 ± 1	11 ± 1	2 ± 0	0.51	0.03	0.02	0.62 ± 0.01	0.64 ± 0.01	1.03 ± 0.02
84 ± 1	13 ± 1	2 ± 0	0.47	0.03	0.02	0.59 ± 0.01	0.58 ± 0.01	0.98 ± 0.02
180 ± 1	38 ± 1	4 ± 0	1.02	0.09	0.04	1.22 ± 0.01	1.18 ± 0.01	0.97 ± 0.02
90 ± 1	14 ± 1	2 ± 0	0.51	0.03	0.02	0.63 ± 0.01	0.64 ± 0.01	1.01 ± 0.02
114 ± 1	19 ± 1	2 ± 0	0.65	0.05	0.02	0.78 ± 0.01	0.75 ± 0.01	0.96 ± 0.02
99 ± 1	14 ± 1	2 ± 0	0.56	0.03	0.02	0.68 ± 0.01	0.70 ± 0.01	1.03 ± 0.02
86 ± 1	10 ± 1	2 ± 0	0.48	0.02	0.02	0.59 ± 0.01	0.62 ± 0.01	1.04 ± 0.02
194 ± 1	23 ± 1	2 ± 0	1.09	0.06	0.03	1.24 ± 0.01	1.17 ± 0.01	0.94 ± 0.02
73 ± 1	13 ± 1	1 ± 0	0.41	0.03	0.01	0.52 ± 0.01	0.49 ± 0.01	0.94 ± 0.02
93 ± 1	12 ± 1	2 ± 0	0.52	0.03	0.02	0.64 ± 0.01	0.68 ± 0.01	1.07 ± 0.02
104 ± 1	14 ± 1	2 ± 0	0.58	0.03	0.02	0.71 ± 0.01	0.68 ± 0.01	0.97 ± 0.02
Average			*0.60*	*0.04*	*0.02*	*0.72*	*0.72*	*1.00*
Standard Deviation			*0.20*	*0.02*	*0.01*	*0.20*	*0.20*	*0.04*

Measured concentration			Equivalent external gamma dose rate (μSv.h^{-1})					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(g) Overburden								
70 ± 1	17 ± 1	2 ± 0	0.40	0.04	0.02	0.53 ± 0.01	0.54 ± 0.02	1.03 ± 0.04
76 ± 1	17 ± 1	2 ± 0	0.43	0.04	0.02	0.56 ± 0.01	0.59 ± 0.02	1.06 ± 0.04
23 ± 1	15 ± 1	2 ± 0	0.13	0.04	0.02	0.25 ± 0.00	0.29 ± 0.01	1.16 ± 0.07
19 ± 1	19 ± 1	2 ± 0	0.11	0.05	0.02	0.23 ± 0.00	0.29 ± 0.01	1.24 ± 0.08
Average			*0.26*	*0.04*	*0.02*	*0.39*	*0.43*	*1.12*
Standard Deviation			*0.17*	*0.00*	*0.00*	*0.17*	*0.16*	*0.10*
(h) Ore Stock Pile 7 – rim								
							23.03 ± 0.12	
							21.85 ± 0.11	
							26.82 ± 0.13	
Average							*23.90*	
Standard Deviation							*2.60*	
(i) Ore Stock Pile 7 - pad								
							13.42 ± 0.09	
							14.36 ± 0.09	
							17.17 ± 0.10	
							9.16 ± 0.07	
							13.61 0.09	
Average							*13.54*	
Standard Deviation							*2.87*	

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(j) Land Application Area – non irrigated soil type 2								
5	18	1	0.03	0.04	0.01	0.14	0.14 ± 0.00	1.02 ± 0.13
5	18	1	0.03	0.04	0.01	0.14	0.14 ± 0.00	1.02 ± 0.13
5	18	1	0.03	0.04	0.01	0.14	0.14 ± 0.00	1.02 ± 0.13
8	17	1	0.04	0.04	0.01	0.16	0.18 ± 0.00	1.12 ± 0.14
							0.18 ± 0.00	
							0.16 ± 0.00	
							0.17 ± 0.00	
							0.17 ± 0.00	
							0.16 ± 0.00	
Average			*0.03*	*0.04*	*0.01*	*0.15*	*0.16*	*1.05*
Standard Deviation			*0.01*	*0.00*	*0.00*	*0.01*	*0.01*	*0.05*
(k) Land Application Area – non irrigated soil type 3								
5	18	1	0.03	0.04	0.01	0.14	0.17 ± 0.00	1.17 ± 0.15
4	17	0	0.02	0.04	0.01	0.13	0.16 ± 0.00	1.19 ± 0.15
6	19	0	0.03	0.05	0.00	0.15	0.18 ± 0.00	1.16 ± 0.14
8	10	0	0.05	0.03	0.00	0.14	0.17 ± 0.00	1.19 ± 0.15
7	16	1	0.04	0.04	0.01	0.15	0.18 ± 0.00	1.17 ± 0.14
							0.17 ± 0.00	
							0.16 ± 0.00	
							0.18 ± 0.00	
							0.17 ± 0.00	
							0.18 ± 0.00	
Average			*0.03*	*0.04*	*0.01*	*0.14*	*0.17*	*1.18*
Standard Deviation			*0.01*	*0.01*	*0.00*	*0.01*	*0.01*	*0.01*

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)						
			Calculated				Measured		Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total			
(l) Land Application Area – irrigated									
12	19	1	0.07	0.05	0.01	0.18	0.22 ± 0.00		1.20 ± 0.15
14	18	1	0.08	0.04	0.01	0.19	0.26 ± 0.01		1.32 ± 0.16
12	16	1	0.07	0.04	0.01	0.18	0.21 ± 0.00		1.19 ± 0.14
13	17	1	0.07	0.04	0.01	0.19	0.24 ± 0.00		1.27 ± 0.15
10	15	0	0.06	0.04	0.00	0.16	0.21 ± 0.00		1.27 ± 0.15
13	18	0	0.07	0.04	0.01	0.19	0.23 ± 0.00		1.21 ± 0.15
11	17	1	0.06	0.04	0.01	0.18	0.23 ± 0.00		1.30 ± 0.16
10	18	1	0.06	0.04	0.01	0.18	0.24 ± 0.00		1.35 ± 0.16
Average			*0.07*	*0.04*	*0.01*	*0.18*	*0.23*		*1.27*
Standard Deviation			*0.01*	*0.00*	*0.00*	*0.01*	*0.02*		*0.06*
(m) Mine Pit # 1									
							0.45 ± 0.01		
							0.86 ± 0.01		
							0.95 ± 0.01		
							1.01 ± 0.01		
							1.07 ± 0.01		
							0.86 ± 0.01		
							0.71 ± 0.01		
							1.23 ± 0.01		
							0.99 ± 0.01		
							1.04 ± 0.01		
							0.65 ± 0.01		
							0.36 ± 0.01		
							0.43 ± 0.01		

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
Mine Pit # 1 (continued)								
							0.52 ± 0.01	
							0.71 ± 0.01	
							0.86 ± 0.01	
							1.09 ± 0.01	
							0.77 ± 0.01	
							0.56 ± 0.01	
							0.59 ± 0.01	
							0.88 ± 0.01	
							0.64 ± 0.01	
							0.60 ± 0.01	
							0.53 ± 0.01	
							0.72 ± 0.01	
							0.84 ± 0.01	
							0.65 ± 0.01	
Average							*0.76*	
Standard Deviation							*0.23*	
(n) Mine Pit # 3 – rocks								
							4.33 ± 0.02	
							3.41 ± 0.02	
Average							*3.87*	
Standard Deviation							*0.65*	

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(o) Mine Pit # 3 (pad area)								
							2.92 ± 0.02	
							3.08 ± 0.02	
							2.75 ± 0.02	
							3.15 ± 0.02	
							3.05 ± 0.02	
							3.69 ± 0.02	
							3.75 ± 0.02	
							3.04 ± 0.02	
							2.69 ± 0.02	
							4.11 ± 0.02	
							4.10 ± 0.02	
							6.40 ± 0.03	
							4.49 ± 0.02	
							3.56 ± 0.02	
							4.36 ± 0.02	
							7.29 ± 0.03	
							3.46 ± 0.02	
							4.59 ± 0.02	
							3.80 ± 0.02	
							21.26 ± 0.05	
Average							*4.78*	
Standard Deviation							*4.05*	

Measured concentration			Equivalent external gamma dose rate ($\mu Sv.h^{-1}$)					
			Calculated				Measured	Ratio
U(ppm)	Th(ppm)	K(%)	H_U	H_{Th}	H_K	Total		
(p) Mine Pit # 3 – rubble								
							3.77 ± 0.02	
							3.42 ± 0.02	
							3.05 ± 0.02	
							3.04 ± 0.02	
							3.82 ± 0.02	
							3.48 ± 0.02	
							7.00 ± 0.03	
							7.58 ± 0.03	
Average							*4.39*	
Standard Deviation							*1.82*	

Table 5 Average U, Th and K concentrations

Location	Number of readings	U(ppm)	Th (ppm)	K (%)
Laterite Pile pad area	19	930 ± 37	270 ± 24	36 ± 4
push zone				
Rim	1	750 ± 18	399 ± 19	50 ± 3
Ore Stock Pile 2	17	440 ± 46	64 ± 5	8 ± 1
Waste Rock Dump pad area	19	99 ± 8	20 ± 1	3 ± 0
rehabilitated	20	105 ± 8	15 ± 1	2 ± 0
Overburden	4	47 ± 15	17 ± 1	2 ± 0
Ore Stock Pile 7 rim				
pad				
Land Application Area				
Non Irrigated Soil Type II	4	5 ± 1	17 ± 0	1 ± 0
Non Irrigated Soil Type II	5	6 ± 1	16 ± 1	0 ± 0
Irrigated	8	12 ± 0	17 ± 0	1 ± 0
Mine Pit 1				
Mine Pit 3 rocks				
pad				
rubble				

Table 6 Dose conversion coefficients for U, Th and K activity concentrations

Isotope	Conversion coefficient ($nGy.h^{-1}/Bq.kg^{-1}$)
^{238}U in equilibrium with series	0.462
^{232}Th in equilibrium with series	0.604
^{40}K	0.0417

Table 7 Estimated average external gamma radiation rate at various locations

Location	Estimated external gamma dose rate(μSv.h^{-1})			
	H_U	H_{Th}	H_K	Total
Laterite Pile pad area	5.26 ± 0.21	0.66 ± 0.06	0.39 ± 0.04	6.37 ± 0.23
push zone				
Rim	4.24 ± 0.10	0.97 ± 0.05	0.54 ± 0.03	5.82 ± 0.12
Ore Stock Pile 2	2.49 0.26	0.16 0.01	0.09 0.01	2.79 0.27
Waste Rock Dump pad area	0.56 ± 0.05	0.05 ± 0.00	0.03 ± 0.00	0.70 ± 0.05
rehabilitated	0.60 ± 0.04	0.04 ± 0.00	0.02 ± 0.00	0.72 ± 0.05
Overburden	0.26 ± 0.09	0.04 ± 0.00	0.02 ± 0.00	0.39 ± 0.09
Ore Stock Pile 7 rim				
pad				
Land Application Area				
Non Irrigated Soil Type II	0.03 ± 0.00	0.04 ± 0.00	0.01 ± 0.00	0.15 ± 0.00
Non Irrigated Soil Type II	0.03 ± 0.00	0.04 ± 0.00	0.01 ± 0.00	0.14 ± 0.00
Irrigated	0.07 ± 0.00	0.04 ± 0.00	0.01 ± 0.00	0.18 ± 0.00
Mine Pit 1				
Mine Pit 3 rocks				
pad				
rubble				

Table 8 Measured average external gamma radiation dose rate at various locations and a comparison of estimated and measured values

Location	Measured external gamma dose rate Points	(μSv.h^{-1})	Ratio Points	(Measured/Calculated)
Laterite Pile pad area	19	5.92 ± 0.19	19	0.93 ± 0.01
push zone	6	10.80 ± 0.51		
Rim	14	9.88 ± 0.38	1	1.00 ± 0.03
Ore Stock Pile 2	16	2.61 ± 0.83	16	0.95 ± 0.06
Waste Rock Dump pad area	19	0.71 ± 0.04	19	1.02 ± 0.01
rehabilitated	20	0.72 ± 0.04	20	1.00 ± 0.01
Overburden	4	0.43 ± 0.08	4	1.12 ± 0.05
Ore Stock Pile 7 rim	3	23.90 ± 1.50		
pad	5	13.54 ± 1.29		
Land Application Area				
Non Irrigated Soil Type II	9	0.16 ± 0.00	4	1.05 ± 0.02
Non Irrigated Soil Type II	10	0.17 ± 0.00	5	1.18 ± 0.01
Irrigated	8	0.23 ± 0.01	8	1.27 ± 0.02
Mine Pit 1	27	0.76 ± 0.04		
Mine Pit 3 rocks	2	3.87 ± 0.46		
pad	20	4.78 ± 0.91		
rubble	8	4.39 ± 0.64		
Total	174		80	1.03 ± 0.01

Table 9 ^{222}Rn activity flux to ^{226}Ra activity concentration ratio for different areas

Location	**Points**	**^{222}Rn activity flux (mBq.m^{-2}.s^{-1}) / ^{226}Ra activity concentration (Bq.kg^{-1})**
Laterite Pile pad area	18	0.40 ± 0.04
push zone	7	4.06 ± 0.72
Rim	1	0.60 ± 0.02
Ore Stock Pile 2 pad	15	3.35 ± 1.53
rim	10	2.75 ± 1.29
Waste Rock Dump pad area	19	0.47 ± 0.09
rehabilitated	20	0.77 ± 0.09
Overburden	4	2.80 ± 1.28
Ore Stock Pile 7 rim	3	0.04 ± 0.01
pad	5	0.08 ± 0.02
Land Application Area		
Non Irrigated Soil Type II	4	1.21 ± 0.07
Non Irrigated Soil Type III	5	0.85 ± 0.07
Irrigated	8	0.67 ± 0.04
Mine Pit 1	27	0.42 ± 0.04
Mine Pit 3 rocks	2	0.17 ± 0.08
pad	21	0.40 ± 0.12
rubble	7	0.23 ± 0.13
Total	176	

Table 10 Statistical parameters for pit 1 general area Rn exhalation rate data

Statistical parameter	Normal	Log-normal
N	33	33
Mean	495 ± 54	502 ± 61
Standard deviation	309 ± 38	353 ± 43
Skewness	1.04	-0.07
χ^2 per degree of freedom	3.4	0.55
Error probability ζ	0.99	0.99

Table 11 Statistical parameters for LAA irrigated area Rn exhalation rate data

Statistical parameter	Normal	Log-normal
N	34	34
Mean	112 ± 8	112 ± 6
Standard deviation	45 ± 5	37 ± 5
Skewness	2.9	0.93
χ^2 per degree of freedom	8.2	5.5
Error probability ζ	0.97	0.97