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SHALLOW LAND BURIAL AS AN OPTION FOR THE DISPOSAL OF MINERAL SANDS WASTE

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1 INTRODUCTION
Heavy minerals like ilmenite, rutile and zircon are normally recovered from deposits formed by marine, alluvial or wind concentrations. Their hardness and chemical resistance, allowing them to survive the rigours of these natural concentration mechanisms, are often those which contribute to their application in the industrial or domestic environment. The high hardness (7.5 on the Moh scale) and high melting point (2430 °C) of zircon ($ZrSiO_4$) makes it for instance suitable for use in refractories, foundry sands and ceramics.

2 PURPOSE AND SCOPE
Recent changes in legislation on the control of hazards from ionizing radiation, is causing some concern amongst both regulators and industrialists about the methods for correctly disposing of widely used mildly radioactive naturally occurring minerals.

The purpose of this paper is to demonstrate what the impact would be when disposing of various quantities of zircon in shallow landfills. Shallow land disposal can occur in many ways but most will fall into one of the three categories below:

(i) The material is placed in a natural or man-made depression without dilution or a cover of non-radioactive material
(ii) As in (i) except that the material is diluted with various amounts of other solid non-radioactive material
(iii) As in (i) except that the material is covered with a layer of non-radioactive soil or clay of varying thickness.

The total amount of zircon to be disposed of is varied from 10 to 10 000 tonnes. To compare dilution factors and burial depths, some standardized geometry is useful. It is assumed that the zircon is disposed of in a circular hole with a depth of 3 metres. Considering a density of 2.7 g/cm^3, the radius of the cylinder will hence vary from about 1 to 20 metres for the amounts of zircon stated above.

3 ASSESSMENT DETAIL
Four exposure scenarios, described by an NEA Expert Group [1], are considered to assess disposal requirements in terms of dilution factors or burial depths as to limit public exposure to a dose constraint of 250 µSv/a. These are:
(i) Road construction scenario
(ii) House construction scenario
(iii) Residential scenario
(iv) Agricultural scenario.

Parameters are presented for the following pathways:
(i) External gamma radiation
(ii) Radioactive dust inhalation
(iii) Ingestion of radionuclides either directly or indirectly from dissolution of material
(iv) Radon exposure, where requirements to keep the indoor gas concentration below 200 Bq/m^3, are investigated, but also requirements to meet the dose constraint above.

Environmental parameters defined by the Expert Group relate to typical European conditions and some are adapted in separate assessments for typical South African conditions (warmer climate, developing country, houses without basements). While detailed scenario descriptions are presented in [1], Table 1 provides a list of the fixed and scenario-specific assessment parameters used.

The radon emanation coefficient of 0.007 is slightly higher than the 0.0065 measured for Rn-222 from uncalcined and calcined zircon sands [2,3], whereas the effective diffusion relaxation length of 1.15 metre is the average measured value for mineral sand tailings [3].

Some of the input parameters vary with the dilution factor and/or cover thickness and are calculated as indicated below.

(i) Cover transmission factors are calculated from exponential functions fitted through dose rates, calculated for gamma radiation from U-series and Th-series nuclides with the QAD-CGGP and ORIGEN-S computer codes [4] for infinite slab sources covered with various thicknesses of soil [5].
(ii) The root penetration factor is calculated by assuming a linear decrease in the root penetration from 1 at the surface to zero at a thickness of 1.5 metre.
(iii) For the road and house construction scenarios, dilution factors for excavated material are calculated as the fractions of the excavation depths penetrating the waste. For the residential scenario, dilution factors are calculated by assuming that the excavated material is mixed into the top 10 cm of soil covering the residential site with a 25 metre radius. The smaller probability for residences to overlap with smaller waste sites is considered through multiplication of the dilution factor with the ratio of the waste and residential site areas if this ratio is less than 1.

ICRP- and IAEA-published internal dose assessment parameters are not regarded as particularly suitable for assessments on mineral sands because:

(i) ICRP lung clearance rates [6] are regarded as too high [7].
(ii) Age-specific public ingestion dose coefficients [8] relate to soluble material rendering them unsuitable for directly-ingested mineral sands.
(iii) Soil-to-plant transfer factors [9,10] are likely to grossly over-estimate the transfer of radioactivity, firmly trapped inside mineral sand grain structures. Very low (generally < 10 mBq/L) concentrations of radionuclides, statistically not distinguishable from background samples, were recorded for Richards Bay Minerals process and mine water [11].

***TABLE 1:* INPUT PARAMETER VALUES FOR ASSESSMENTS**

	Fixed Parameters				
Th-ppm in Waste	150	Soil Ingestion Rate (mg/d)			100
U-ppm in Waste	325	Ingestion Dose Coefficients (µSv/αBq)			Table 2
Breathing Rate (m^3/h)	Table 2	External Dose Coefficient (nSv/h per αBq/g)			53
		Cover Transmission Factor			Calculated
Inhalation Dose Coefficients (µSv/αBq)	Table 2	Soil-to-Plant Transfer Factor			0.0002
Respirable Fraction of Airborne Dust	1	Root Penetration Factor			Calculated
Scenario-dependent Parameters	**Road Construction**	**House Construction**	**Residential**	**Agricultural**	**Indoor Radon**
Exposure Period Indoors (fraction)			0.5		
Exposure Period Outdoors (h/a or fraction)	50/200*##	500/2000*#	0.25/0.5*		
Airborne Dust Concentration (mg/m^3)	1	0.1	0.01/0.05*		
Indoor Gamma Shielding Factor			2		
Excavation Depth (m)	0.7	3.0/0.7*			
Excavated Material Dilution Factor	Calculated	Calculated	Calculated		Calculated
Vegetable/Fruit Ingestion Rate (kg/a)			128/256*	310#	
Air Removal Rate (air changes/h)					0.5/3*
Cover Diffusion Relaxation Length (m)					1.15
Basement Area/House Vol. (1/m)					0.57/0.3*
Floor/Wall Permeability Factor					0.15/0.3*
Radon Decay Constant (1/s)					2.1E-06
Mass Fraction of Waste in Soil					1.0
Waste Density (g/cm^3)					2.7
Emanation Coefficient					0.007
Waste Diffusion Relaxation Length (m)					1.15

** Values for Europe/RSA # Value for largest waste site reduced proportional to site radius (##) or area (#)*

The following strategy is followed to overcome the problems above and still ensure a conservative approach:

(i) Inhalation and ingestion dose coefficients for zircon material are calculated for an 85 % nose breathing worker and adult member of the public using the NRPB-developed LUDEP computer code [12]. Through its Amerge@ option, LUDEP forces the progeny of U-238 and Th-232 into the same biokinetic behaviour as the parent nuclides (assumed to be Type S material). Adult coefficients are regarded as conservative to the extent that they will also be applicable to children (particularly as the same inhalation rates are assumed).

(ii) ICRP-72 age-specific dose coefficients [8], weighted for uranium- and thorium-series nuclides in secular equilibrium with their respective parent nuclides, are calculated for secondary ingestion pathways. Uranium and thorium soil-to-plant transfer factors [10], at the lower side of the published range are, however, used assuming an average dry weight contents for root crops of 15 % relative to the fresh crops.

The results are presented in Table 2.

TABLE 2: **WEIGHTED WORKER AND PUBLIC INHALATION AND INGESTION DOSE COEFFICIENTS FOR ZIRCON**

Exposed Group	Public Breathing Rate (m^3/h)	Relative Food Consumption Rate	Specific Alpha Activity (αBq/g)	Inhalation dose coefficient (Sv/αBq)	Ingestion dose coefficient (Sv/αBq)	Inhalation dose coefficient (Sv/αBq)	Ingestion dose coefficient (Sv/αBq)
			Calculated From ICRP-68 and ICRP-72 Values			Weighted with Relative Breathing or Consumption Rates	
Workers (5 µm)			36.9	3.7E-06	1.7E-07		
1 Year Public (1 µm)	0.21	0.4	36.9	2.2E-05	1.7E-06	4.8E-06	6.7E-07
5 Year Public (1 µm)	0.34	0.5	36.9	1.4E-05	9.4E-07	5.2E-06	4.7E-07
10 Year Public (1 µm)	0.64	0.6	36.9	8.9E-06	7.1E-07	5.9E-06	4.3E-07
15 Year Public (1 µm)	0.96	0.85	36.9	8.3E-06	6.9E-07	8.4E-06	5.9E-07
Adult Public (1 µm)	0.95	1.0	36.9	7.7E-06	3.0E-07	7.7E-06	3.0E-07
			Calculated With LUDEP				
Workers (10 µm)			35.6	7.2E-06	1.5E-08		
Adult Public (10 µm)	0.96		35.6	7.7E-06	1.5E-08		

ICRP-72 ingestion dose coefficients in Table 2 are weighted with the uranium/thorium ratio of zircon and also with relative food consumption rates for various public age groups. The highest weighted coefficient is used in the assessments to ensure that the results will apply to the critical age group.

Defined and calculated parameters are inserted in spreadsheets. Either the dilution factor (fraction of zircon in diluted material) or cover thickness is then varied until the dose constraint or radon concentration criterion is met. The results are presented in Table 3. Results of a second residential scenario, which includes the dose from radon exposure in the 250 µSv/a criterion test, are indicated in brackets in Table 3. A conversion factor of 2.45×10^{-3} µSv/h per Bq/m^3 radon gas is used [13].

4 DISCUSSION OF RESULTS

(i) The dose constraint criterion is met without dilution or a cover for all scenarios and amounts of waste up to 100 tonnes for both European and South African conditions.

(ii) For the agricultural scenario, (i) above applies for up to 1 000 tonnes. For the road and house construction scenarios, (i) above also applies for up to 1 000 tonnes but only for European conditions due to shorter expected exposure periods.

(iii) For waste quantities of 10 000 tonnes, dilution requirements for the house construction and residential scenarios become rather restrictive (30 to 50 times).

(iv) Burial depths around 3 and 1 metres for European and South African conditions respectively, may be preferred. The thicker covers for European conditions relate to the basements usual for residences in this region.

(v) The spreadsheets allow some sensitivity analysis to be performed by changing the input parameters. From this it is evident that, for the first three scenarios in Table 3, external gamma radiation is the dominant pathway, contributing more than 90 % of the dose. Uncertainties in the inhalation and ingestion dose coefficients may hence not be a major concern for these scenarios. Soil-to-plant transfer factors for mineral sands should, however, be studied in more detail to see whether they are of any concern for agricultural scenarios.

(vi) The indoor radon concentration criterion is met without dilution or a cover for all amounts of waste studied and for both European and South African conditions. The low emanation coefficient of zircon (and mineral sands in general) is the primary reason for this. If radon exposure is, however, to be included in the dose criterion, it becomes a rather dominant pathway, requiring a dilution of up to 100 times and a burial depth of around 4 metres for European conditions.

(vii) Long-term institutional control requirements would be country-dependent and are not covered in the present study. Choosing sites with low soil erosion rates and low probability for excavations beyond those considered in this study, should reduce such control requirements to a minimum.

***TABLE 3:* RESULTS OF ASSESSMENT**

Zircon Mass (Tonnes)		10	100	1 000	10 000
Road Construction Scenario					
Dilution Required	Europe	1	1	1	1
	RSA	1	1	0.9	0.3
Cover Thickness Required (m)	Europe	0	0	0	0
	RSA	0	0	0.1	0.8
House Construction Scenario					
Dilution Required	Europe	1	1	1	0.1
	RSA	1	1	0.3	0.03
Cover Thickness Required (m)	Europe	0	0	0	3.2
	RSA	0	0	0.8	1.1
Residential Scenario (Values in Brackets Include Radon Exposure)					
Dilution Required	Europe	1 (1)	1 (1)	0.4 (0.2)	0.03 (0.01)
	RSA	1 (1)	1(1)	0.3 (0.2)	0.02 (0.02)
Cover Thickness Required (m)	Europe	0 (0)	0 (0)	0.2 (1.4)	2.6 (3.8)
	RSA	0 (0)	0 (0)	0.2 (0.3)	0.7 (1.8)
Agricultural Scenario					
Dilution Required	Europe	1	1	1	0.15
	RSA	1	1	1	0.15
Cover Thickness Required (m)	Europe	0	0	0	1.3
	RSA	0	0	0	1.3
Radon Exposure Scenario					
Dilution Required	Europe	1	1	1	1
	RSA	0	0	0	0
Cover Thickness Required (m)	Europe	1	1	1	1
	RSA	0	0	0	0

CONCLUSION

This study shows that zircon sand may be safely disposed of in shallow landfills, without dilution or cover, in quantities up to a 100 tonnes.

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