AN ASSESSMENT OF THE POPULATION DOSE DUE TO RADON-222 FROM MINE TAILINGS ON THE WITWATERSRAND

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1. Introduction

The contribution of radon as a source of radiation exposure to man is well established. At higher concentrations, such as is experienced in underground mines, epidemiological evidence of radiogenic lung cancer has been found and a quantitative life-time risk of 1,5 to 4,5 x 10^{-4} cases per Working Level Month (WLM) has been calculated [1]. Natural concentrations of radon in the atmosphere normally vary around 200 $pCi.m^{-3}$ but could be an order of magnitude or more higher indoors, depending on factors such as ventilation and the type of building materials used. The effective dose equivalent to the average global population from inhalation of radon daughter products is 80 $mrem.a^{-1}$ [2] with approximately 90 % of this due to indoor exposure and 10 % from outdoor exposure. The radon exposure pathway accounts for almost 40 % of the total dose from natural radiation sources to the population.

Enhanced radon releases from disposed mining wastes result in an additional radiation exposure. The population of 3,8 million presently living in and around Johannesburg, situated on the Witwatersrand, the centre of the South African gold/uranium mining industry, is exposed to these accumulated wastes, the product of a century of mining activities.

In this study the radium content of individual tailings dams on the Witwatersrand is determined and resultant radon emanation calculated. The dispersion of radon from this source is predicted by means of an atmospheric dispersion model using average meteorological conditions, and is verified by measurement. With knowledge of the population distribution, individual and collective doses are calculated.

2. Distribution of Mine Tailings

Since the discovery of gold on the Central Witwatersrand in 1886, 19 million kg of gold has been produced from 2,4 x 10^9 t of ore [3]. Although uranium occurs as a byproduct of gold it has only been exploited since 1952 with approximately 30 000 t of U_3O_8 produced to date from the Central Witwatersrand area. Known reserves of uranium in tailings amount to 70 000 t while a further 50 000 t are estimated to be present [4].

The total radium associated with these tailings amounts to 50 000 Ci and is contained in 250 tailings dams with a total area of 6 475 ha. These dams are spread over a distance of 80 kms from the town of Springs in the east, to Randfontein in the west, with the metropolis of Johannesburg roughly in the centre of this east-west strip.

Uranium, and therefore radium concentrations, increase from east (10 pCi $Ra.g^{-1}$) to west (>100 pCi $Ra.g^{-1}$) with an average value of 20 $pCi.g^{-1}$, which is low compared to uranium mines in other parts of the world. However, factors such as the population of 3,8 million people living within 20 km of the strip, the large total quantity of radium and the extensive period over which this situation has lasted, result in a significant contribution of mine tailings to the collective dose exposure of the surrounding population.

3. Distribution of Radium

Results available from an airborne radiometric survey of an extensive part of the mining area conducted by the South African Geological Survey during 1976 provided a useful data base of radiometric anomalies which were used to determine the average radium concentration of individual tailings dams. The data from the airborne survey was calibrated by judicious sampling of a few selected tailings dams for which the radium content was determined. By applying corrections for the geometrical shape of the dam and the intersection with the flight line, a calibration curve of radiometric values versus radium concentration was obtained.

Tailings dams not showing an anomaly in the airborne survey were allocated a value of 20 $pCi.g^{-1}$. In areas not covered by the radiometric survey, major tailings dams were surveyed on foot with scintillation detectors, and representative samples were collected and combined for radium analyses.

4. Radon Emanation

The emanation of radon from different soil types has been studied in great detail by various authors both theoretically and experimentally [5,6,7] and it is well established that external factors such as barometric pressure, precipitation, wind and atmospheric stability conditions affect the escape of radon to the atmosphere. Diffusion appears to be dominant in deeper layers and can be described theoretically, but in shallow layers close to the surface convective processes, caused by external influences, modify theoretical predictions. In an extensive review, Wilkening [8] proposes a mean value of 0,42 $pCi.m^{-2}.s^{-1}$ for Radon flux from natural soils with a mean radium concentration of 1 $pCi.g^{-1}$.

Momeni <u>et al</u> [5] give the following specific radon fluxes for different tailings materials - acid tailings 0,63, alkaline tailings 0,30, loose sediments rich in clay 0,37, sandy soil 0,18, mixture of clays and heavy loams 0,28, and abandoned vitreous tailings 1,6. They suggest 1 as an average value for radiological assessment purposes.

The radon flux from the surface of different tailings dams on the Central Witwatersrand was measured experimentally and the results normalised to a unit radium concentration (Table 1). Applying a specific emanation rate of 0,4 $pCi.m^{-2}.s^{-1}$ to the 250 tailings dams, an annual release of 16 000 Ci. ^{222}Rn. results. More than 50 % of this total originates from 27 tailings dams and 90 % from 120 tailings dams.

5. Atmospheric Dispersion Modelling

The atmospheric dispersion model [9] was adapted for use with multiple sources and the radon distributions from numerous tailings dams were integrated for grid points at 1 km intervals to a distance of 20 km from each source. An additional source of radon was the ventilation air from shafts at active mines. This was calculated from a knowledge of down-draught air into the mines, by assuming ambient underground radon levels of 0,3 WL, and amounted to 3 000 $Ci.a^{-1}$. All shafts at a particular mine were considered as a single source and the distribution of radon for these sources were integrated with that of the tailings dams. Additional sources, such as releases from abandoned shafts, sand dumps and uranium mills, were not considered.

The individual areas of the tailings dams varied between 1 and 450 ha and their average height was taken as 5 m. For the purpose of the model, releases were considered to be 5 m above ground level and resultant concentrations at ground level were calculated.

The area under consideration is at an altitude of between 1500 and 1700 meters above mean sea level and is traversed from east to west by a principal watershed. The major topography is a series of parallel longitudinal valleys, orientated east-west, separated by rocky ridges. Over the tailings dams, generally situated on the southern slope of the watershed, a southward drainage of air is experienced under stable atmospheric conditions.

Meteorological data from 2 stations within a 50 km radius of the area, one to the east (Jan Smuts Airport) and one to the west (National Nuclear Research Centre, Pelindaba) were found to have comparable wind patterns and stability conditions. Using a modified Star method, [10] data from Jan Smuts Airport were used to provide correlations of wind speed, direction and Pasquill stability category.

Model predictions were verified at 12 measuring points around the Crown Mines site over a period of 1 month using site-specific source and meteorological data. Radon concentrations were measured with passive radon monitors and satisfactory comparison with predicted values was obtained.

6. Radiation Exposures

From the 1 km grid-pattern of radon concentrations, predicted by the model, average radon concentrations for each designated suburb in the region were calculated. Using population census data from 1980 it was possible to determine collective exposures in pCi-man.m^{-3}.

Exposure-dose relationships have been calculated by various groups. McDowell-Boyer et al [11] proposes a value of 4 rem.WLM^{-1} to bronchial epithelium of members of the public. The weighting factor (W_{TB}) to calculate the effective dose equivalent equals 0,06 resulting in a value of 0,24 rem.WLM^{-1} .The ICRP [1] recommends a value of 1 rem.WLM^{-1} for the effective dose equivalent to workers. Varying environmental conditions and behaviour patterns will result in a lower value for the population.

However, UNSCEAR [12] proposes values of 0,55 rem.WLM^{-1} and 1,1 rem WLM^{-1} for members of the public, for in-door and out-door conditions respectively. These values correspond to 0,28 and 0,55 mrem.a^{-1} per pCi.m^{-3}. A value of 0,37 for an average occupancy distribution of 16 hours indoors and 8 hours outdoors is used in this report. Assuming an equilibrium factor of 0,5 between radon and its short-lived progeny the collective exposures in pCi.man.m^{-3} were converted to man-rem.a (Table 2).

7. Conclusions

The annual release of radon from the tailings dams in the Witwatersrand area amounts to 19 000 Ci with peak concentration of 3 000 pCi.m^{-3} being predicted in the Randfontein area, which could result in an annual effective dose equivalent of 500 mrem to individuals. However, the average annual dose for the entire area is predicted as 70 mrem which is of the same order as that due to the radon contribution from natural sources. The annual collective effective dose equivalent to the population of the Witwatersrand due to enhanced radon releases from mine tailings is calculated as 2,6 x 10^{5} man-rem.

7. References

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TABLE 1

Measured Radon Emanation from Tailings dams.

Tailings dam	Radium concentration pCi/g	Emanation pCi.m.$^{-2}$.s^{-1}	Specific emanation pCi.m^{-2}.s^{-1}/pCi.g^{-1}
1L22	8	2,9	0,4
1L24	15	5,2	0,3
1L26	9	3,9	0,4
3L32	9	2,7	0,3
3L44	6	3,8	0,6
4L4	6	3,1	0,6
4L33	18	3,0	0,2
		AVERAGE	0,4

TABLE 2

Collective exposure to and annual effective doses from Radon.

Area	Population	Exposure pCi-man.m^{-3}	Effective dose man-rem.a^{-1}
West Witwatersrand	317 880	215x10^{6}	0,4x10^{5}
Johannesburg	2 296 300	846x10^{6}	1,6x10^{5}
East Witwatersrand	1 183 960	333x10^{6}	0,6x10^{5}
TOTAL	3 798 140	1 394x10^{6}	2,6x10^{5}