101

AN ASSESSMENT OF THE ENVIRONMENTAL RADIATION DOSE FOR RESIDENTS OF THE PERTH METROPOLITAN AREA

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ABSTRACT

The total environmental radiation dose for residents of the Perth Metropolitan Area is assessed. This dose is assumed to come from a variety of sources, including indoor Rn(222) and Rn(220) daughters, radioactivity of building materials and radioactivity in drinking water. Based of the results of measurements of these sources, the average total estimated annual effective dose equivalent for residents of the Perth Metropolitan Area is 2.3 mSv. This is more than twice the public limit for artificial sources (1 mSv) recommended by the ICRP (1990). 76 % of the average total dose is contributed by indoor Rn (222) and Rn(220) daughters with Rn(222) daughters contributing 48 % (1.2 mSv) and Rn(220) daughters 28 % (0.6 mSv) of the average total dose. Radioactivity of local building materials contributed approximately 19 % (0.4 mSv), while radon, radium and solid isotopes in groundwater contributed only 3 % (0.07 mSv), 0.3 % (0.006 mSv) and 2%(0.04 mSv) to the average total annual effective dose equivalent respectively. The average total annual effective dose equivalent from all sources in this study could be overestimated since the sampling procedure was not truly random.

INTRODUCTION

Rn(222) and Rn(220) and their progeny are well known as health hazards for causing lung cancer in humans. This is based on the epidemiological evidence of a higher probability of mortality from lung cancer caused by Rn(222) among uranium miners (Archer et al, 1973; Kunt et al,1979; Howe,1988; Harley,1988; Fabrikant, 1990; Steinhausler, 1989) as well as non-uranium miners (Lundin, 1969; Radford et al, 1984). These gases are common contaminants of the air in mines. Significantly elevated levels of Rn(222) have also been found in dwellings in America, Canada and Europe (Edling et al, 1979; Eaton,1987; James, 1987). Rn(222) occurs naturally as a result of the decay of uranium in the rocks and the decay products of the gas are solid radioactive elements which occur in the atmosphere in the form of attached and non-attached fractions. Since the gas is continuously inhaled by humans, both of these fractions will decay in the lung and will be deposited in the bronchial tree where they irradiate the nearby tissues with alpha, beta and gamma radiation. A serious risk occurs from irradiation by alpha particles emitted by those solid isotopes, which may cause the induction of lung cancer. The risk of lung cancer from Rn(222) and its progeny is typically thousands of times larger than that from other enviromental pollutants. In fact, millions of

Americans are exposed to more radiation in their homes than underground miners experience in the workplace (Nero, 1986).

Rn(222) and its daughters, as well as Ra(226), are also found as common water contaminants, particularly if the water supply used is derived from groundwater from a geological structure containing rocks with a high uranium content. In addition significant Rn(222) concentrations in the groundwater could contribute substantially to indoor air pollution if such water is used for various domestic purposes such as washing, cooking, showers, etc. In the USA, nearly 60,000 (80 %) public water supplies use groundwater sources (Hess, 1985). The mean Rn(222) concentration in public wells is about 40 Bq L^{-1} (King et al (1982; Krisnawani et al, 1982). In Italy, some mineral waters have a Ra(226) concentration > 0.04 Bq L^{-1} to < 0.70 Bq L^{-1} and no definite correlation was found between the Ra(226) concentration measured and high natural background radiation (Mastinu, 1982). The mean concentrations of Rn(222) and Ra(226) found in drill wells in Finland were 629 Bq L^{-1} and 0.11 Bq L^{-1}, respectively (Asikeinen, 1980).

The radioactivity of building materials is primarily due to the presence of radionuclides, Ra(226), Th(232) and K(40). These materials contain small amounts of these isotopes. In recent years, some construction materials, used for building houses, have been found to contain materials which have a high radium content, such as the use of uranium mill tailings and phosphate industry waste in America (OECD, 1979; UNSCEAR, 1982), alumshale in Sweden (Akerblom and Wilson, 1981), and also the use of fly ash from coal-fired power plants (Stranden, 1982). These materials not only generate high gamma levels but also contribute significantly to indoor Rn(222) and Rn(220) levels, particularly when houses are built using these materials. In Europe, especially in Sweden and Denmark, the indoor Rn(222) concentrations are often determined by building materials.

This study aimed to develop the techniques and provide some data for assessing background radiation doses in the Perth Metropolitan Area.

METHODS

1. Indoor Rn(222) and Rn(220) Daughters

To measure indoor Rn(222) and Rn(220) daughter working levels, a flexible version of the two count method was developed and adapted for use with a simple " Radon Sniffer " based on a low speed pump and alpha counter (Stranden,1980). The method was used to determine relative concentrations of RaA,RaB, RaC, ThA, ThB, and ThC in the atmosphere by measuring the alpha activity of a mixture of these isotopes on a filter paper through which air is sucked for a period of 1 or 2 hours. By observing the integrated alpha counts for a period of 0 - 30 minutes and 300 - 600 minutes after sampling, the Rn(222) and Rn(220) daughter working levels were calculated. The delayed observation of integrated alpha counts (300 minutes after sampling) is intended to eliminate Rn(222) daughters from the determination of Rn(220) daughter working levels, since the relatively

short-lived Rn(222) daughters will have almost completely decayed during that period. Before applying this method to analyse field data, the Radon Sniffer was calibrated and tested using standard samples prepared in the laboratory. A computer program has been written to analyse integrated alpha counts observed after sampling. The method was found to give consistently reliable results over a wide range of working levels (Zainuddin and Jennings, 1992). It provides an inexpensive approach to surveying indoor Rn(222) and Rn(220) daughter levels in a variety of domestic and industrial premises.

2. Measurement of Rn(222), radium and Other Solid Isotopes in Groundwater

The modified version of the liquid scintillation technique developed by Prichard (1977) was used to determine the activity of radon, radium and other solid isotopes in groundwater collected from different parts of the Perth Metropolitan Area (Zainuddin and Jennings, 1992). In this study, Rn(222) gas in water samples was separated from radium and other solid isotopes using an outgassing technique. This technique allowed us to determine radium and solid isotopes in water without interference from Rn(222) gas. The activity due to Rn(222) itself is obtained by substracting the activities measured for untreated and outgassed samples. The liquid scintillation counter (MINAXI TRI-CARB 4000 series model 4430 & 4450 made by United Technologies Packard Ltd) was employed in this study. The activity of radium is estimated by assuming that the solid radioactive isotopes are in secular equilibrium. Since there are 6 solid isotopes in secular equilibrium, the radium activity is calculated by using the following relationship;

$$Ra(c) = S(c)/6$$

where $Ra(c)$ = radium activity in units of Bq L^{-1}
$S(c)$ = solid isotope activity in units of Bq L^{-1}

3. Spesific Activity of Local Building Materials

The specific activity of building materials was measured by gamma spectrometry using a 2x2 cm NaI(Tl) detector. This detector was conected to a multichannel analyser through a standard preamplifier-amplifier chain. The instrument shift is 1% daily, therefore it is recalibrated every time after sampling. Two standard sources Co(60) and Cs(137) were used for energy calibration of the gamma spectrometer. The Ra(226) content of the samples was determined from the intensity in the range of energy 1.64 to 1.88 MeV (gamma peak of Bi(214)). The Th content from the 2.48 to 2.76 MeV range (gamma peak of Tl(208)) and the potassium content from the 1.34 to 1.58 MeV range (gamma peak of K(40)).

Local concrete and brick building materials, manufactured around Perth, are the most typical materials used to construct houses in Western Australia. These materials, together with soil samples collected from the houses, were analysed. Before counting, the samples were crushed to ensure their homogeneity. An average of 400

g of each sample and a counting time of 4 hr per sample were employed.

RESULTS

The total annual effective dose equivalent was estimated by summing all annual effective dose equivalents from inhalation of indoor radon and thoron daughters, external gamma radiation from local building materials and ingestion of groundwater containing Rn(222), radium and other solid isotopes. This total annual effective dose equivalent can be used to estimate of the total effect on the human body.

Table1. shows Rn(222) and Rn(220) daughter working levels. From 104 indoor radon daughter concentrations measured, the mean concentration was found to be 5.2 mWL (20.83 Bq m^{-3} (EEC)) and the concentrations were in the range of 0.6 to 23.3 mWL (2.22 to 86.36 Bq m^{-3} (EEC)). The annual effective dose equivalent delivered to the lung from inhalation of Rn(222) daughters was estimated using conversion factor of 0.061 mSv/Bq m^{-3} (UNSCEAR,1982). This factor based on occupancy factor of 0.8 and average breathing rate was assumed of 0.8 m^3 h^{-1}. It was estimated that the contribution of indoor Rn(222) daughter concentrations is in the range of 0.13 to 5.27 mSv y^{-1} and the mean value is 1.10 mSv y^{-1}. It can be seen that 47.4 % of the total annual effective dose equivalent arises from the inhalation of Rn(222) daughters. Thus the inhalation of Rn(222) daughter is a major contributor to the total annual effective dose equivalent for the public.

The second major contributor to the total effective dose equivalent is indoor Rn(220) daughters. From 104 indoor Rn(220) daughter measurements, the mean concentration was found to be 8.6 mWL (2.36 Bq m^{-3} (EEC)) and the concentration is in the range of 1.0 to 64.5 mWL (0.27 to 17.73 Bq m^{-3} (EEC)) as shown in Table 1. The annual effective dose equivalent delivered to the lung from inhalation of Rn(220) daughters was estimated using a conversion factor of 0.29 mSv/Bq m^{-3} (UNSCEAR,1982). This factor based on similar occupancy factor and average breathing rate applied for Rn(222) daughters dose estimation. The total annual effective dose equivalent from Rn(220) daughters was in the range of 0.01 to 5.27 mSv y^{-1} with a mean value of 0.66 mSv y^{-1}. It appears that 28.4 % of the total annual effective dose equivalent is contributed by Rn(220) daughters.

Table 2. shows the results of (measurements of specific activity) on 8 different samples of local building materials. The mean values of specific activity of three isotopes Ra(226), Rn(232) and K(40) found in local brick building materials were 31.2, 69.3 and 601.9 Bq kg^{-1}, respectively. Whereas the mean value of the specific activity of concrete was found to be 25.2 and 24.9 Bq kg^{-1} for Rn(226) and Rn(232) respectively, and 694.7 Bq kg^{-1} for K(40). The total annual effective dose equivalent resulting from external irradiation indoors due to these isotopes in building materials was estimated using Acker's model (1985), assuming that a major part of the house is made of concrete and brick in the proportion of 60 % and 40 %. This

assumption was considered close enough to the typical Western Australian home. It was estimated that an average of the external gamma radiation from local building materials contributes 0.44 mSv y^{-1}, which is about 19 % of the total annual effective dose equivalent.

Solid isotopes in groundwater were found to be in the range of 0.1 to 2.2 Bq L^{-1} and the mean value is 0.62 Bq L^{-1} as shown in Table 3. The total annual effective dose equivalent was estimated using a conversion factor for annual effective dose equivalent given by the radium concentration multiplied by factor of 6, since there are 6 solid isotopes are in secular equilibrium in the water samples. The dose was estimated to be in the range of 0.006 to 0.12 mSv and the mean value is 0.04 mSv. It appears that the contribution of solids in groundwater to the total annual effective dose equivalent is a relatively small fraction compared to other sources. It accounts for 2 % of the total dose.

The Rn(222) concentration in groundwater was found to be in the range of 0.5 to 182.5 Bq L^{-1} and the mean value is 20.8 Bq L^{-1} as shown in Table 4. Based on quality factor Q= 20, the dose equivalent to the stomach was estimated in the range of 108 to 216 nSv Bq^{-1}(Suomala and Kahlos, 1972), with mean value is 162 nSv Bq^{-1}. To convert dose equivalent to effective dose equivalent, the weighting factor 0.12 is applied for stomach as recomended by ICRP(1990). The conversion factor will be in the range of 12 to 26 nSv Bq^{-1} with a mean value of 19 nSv Bq^{-1}. This mean value was applied to estimate the annual effective dose equivalent due to Rn(222) in the samples. The amount of water consumed was assumed to be 0.5 L d^{-1}. The total annual effective dose equivalent was estimated to be in the range of 0.002 to 0.63 mSv and mean value is 0.071 mSv. This dose is delivered to the stomach which is considered as the critical organ and receives the highest dose. It appears that contribution of Rn(222) in groundwater to the total annual effective dose equivalent is a relatively small fraction compared to other sources. It accounts for only 3 % of the total dose.

The radium concentration in groundwater was found to be in the range of 0.02 to 0.37 Bq L^{-1} and the mean value is 0.11 Bq L^{-1} as shown in Table 4. The total annual effective dose equivalent was estimated using a conversion factor of 310 nSv Bq^{-1} (Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores, 1987). This factor correspond to that given by ICRP Publication 30 (ICRP, 1979) for the longest pulmonary retention class for an AMAD of 1 μm. The total annual effective dose equivalent was estimated to be in the range of 0.001 to 0.02 mSv and the mean value is 0.006 mSv. It appears that the contribution of radium in groundwater to the total annual effective dose equivalent is a relatively small fraction compared to other sources. It accounts for only 0.3 % of the total dose.

Table 5. shows a summary of the results for the estimated annual effective dose equivalent from six natural radiation sources and Figure 1. shows the percentage which each source contributed to the total annual effective dose equivalent.

The total average annual effective dose equivalent (2.32 mSv) estimated in this study is higher than those estimated by ICRP publication 39 (2.04 mSv)(ICRP, 1983) and UNSCEAR (1988) (2.01 mSv). The ingested dose delivered by the U(238) decay series, mainly due to Ra(226) decay products, is estimated at approximately 5 % of the total annual effective dose equivalent as shown in Figure 1. While, ICRP (1983) estimated approximately a 7% contribution from the ingestion of U(238) decay series. The higher dose estimate is caused mainly by the dose to the lung resulting from inhalation of indoor Rn(222) and Rn(220) daughters. Approximately 75 % of total annual effective dose equivalent is caused by Rn(222) and Rn(220) daughters, while ICRP (1983) estimated 47 % of the total annual effective dose equivalent from inhalation of U(238) and Th(232) decay series mainly due to Rn(222) and Rn(220) daughters. UNSCEAR (1988) estimated appoximately 70 % of the total annual effective dose equivalent from internal irradiation of U(238) and Th(232) decay series.

CONCLUSIONS

The annual effective dose equivalent limit for members of the public from artificial sources of radiation was set at 1 mSv (ICRP,1990). It appears that the mean annual effective dose equivalent resulting from 6 natural radiation sources in this studies is more than twice than the public limit set by the ICRP. However, this mean dose could be overestimated since the relatively high dose contributed by indoor Rn(222) and Rn(220) were found in an area of granite and laterite formation, where more indoor Rn(222) and Rn(220) and groundwater water measurements were taken. These areas are relatively high in uranium and thorium decay series products in the rocks and soils. Also the ICRP limit applies to enhanced radiation and not to background radiation. Whether groundwater and building materials can be regarded as background or enhanced sources is a debatable point. In any case it is difficult to see how these doses could be reduced other than by restricting housing sites and materials.

Table 1.
Results of Rn(222) and Rn(220) Daughter Working Levels, Surveyed in the Perth Metropolitan Area

Variable	Arithmetic mean	geometric mean	Minimum value	Maximum value
WL Rn(222) (mWL)	5.2	4.0	0.6	23.3
WL Rn(220) (mWL)	8.6	5.5	1.0	64.5

Number of dwellings (n) = 104

Table 2. Average concentration of radioactive nuclides and Radium Equivalents in some local building materials and other materials collected around Perth.

Samples	No.of samples	Mean activity concentration (Bq kg^{-1}) Ra(226)	Th(232)	K(40)	Radium Equivalent (Bq kg^{-1})
Redbrick	8	26.5	57.3	414.6	139.9
Brownbrick	4	22.7	81.9	567.8	160.2
Whitebrick	5	44.9	68.7	823.3	206.6
Concrete	6	25.2	24.9	694.7	162.3
Sand	2	12.3	35.9	88.9	70.4
Granites	6	69.1	78.3	1232.7	276.0
Laterites	2	59.1	116.9	304.4	249.6
Redmud	2	84.3	324.8	18.8	550.2

Table 3.

AVERAGE TOTAL ALPHA AND SOLID RADIOACTIVE CONCENTRATIONS IN WATER SAMPLES FROM BORES AND WELLS, SURVEYED IN THE PERTH METROPOLITAN AREA

Soil type	No. of Samples	Mean Total Alpha Counts (Bq L^{-1})	Range	Mean Solids (Bq L^{-1})	Range
Granites and Laterites	16	74.5	6.4 - 183.6	1.0	0.1-2.2
Coastal Plain (Clay and Loam overlain with lateritic and granitic)	4	5.1	3.3 - 7.8	0.7	0.5-0.8
Coastal Plain (quartz sand leached)	6	3.7	2.5 - 4.7	0.5	0.2-0.8
Lime beach sand,	8	2.0	0.8 - 3.3	0.3	0.2-0.5

Table 4.

AVERAGE RADON AND CALCULATED RADIUM CONCENTRATIONS IN WATER SAMPLES FROM BORES AND WELLS, SURVEYED IN THE PERTH METROPOLITAN AREA.

Soil type	No. of Samples	Mean Radon ($Bq\ L^{-1}$)	Range	Mean radium ($Bq\ L^{-1}$)	Range
Granites and Laterites	16	73.1	6.3 - 182.5	0.2	0.02 - 0.37
Coastal Plain (Clay and Loam overlain with lateritic and granitic)	4	4.6	3.3 - 6.9	0.1	0.09 - 0.14
Coastal Plain (quartz sand leached)	6	3.8	1.9 - 4.2	0.09	0.04 - 0.14
Lime beach sand,	8	1.7	0.5 - 3.0	0.05	0.03 - 0.09

Table 5. Estimated annual effective dose equivalent from six natural radiation sources in the Perth Metropolitan Area.

	Annual Effective dose equivalent	
Source	Mean (mSv)	Range (mSv)
Indoor Rn(222) daughter	1.100	0.130 - 5.270
Indoor Rn(220) daughter	0.660	0.010 - 5.140
Building Materials	0.440	-
Rn(222) in groundwater	0.071	0.002 - 0.063
Radium in groundwater	0.006	0.001 - 0.020
Solids in groundwater	0.040	0.060 - 0.120
Total	2.320	0.001 - 5.270

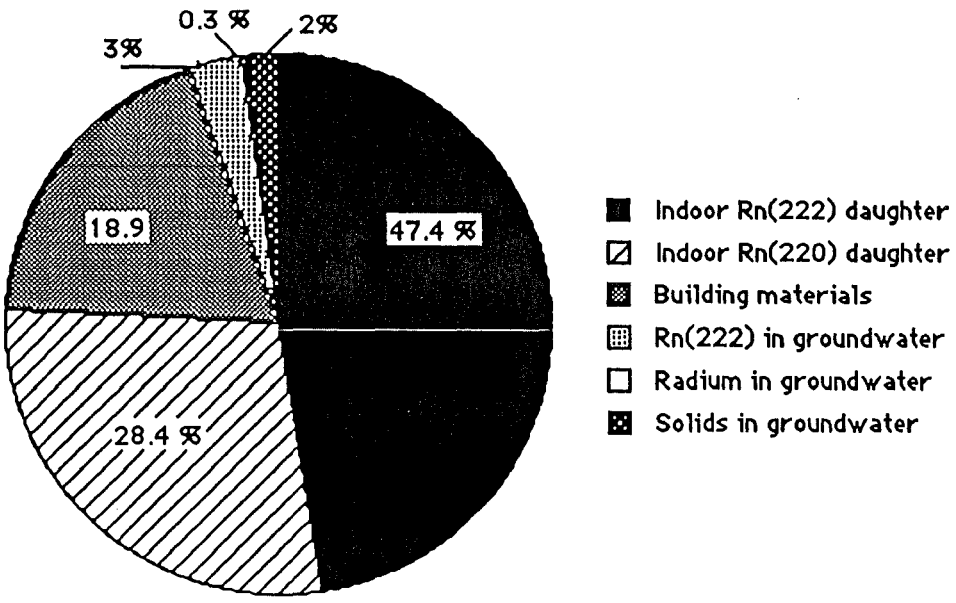

Figure 1. Contribution of six different sources of radiation to the total annual effective dose equivalent in the Perth Metropolitan Area.

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