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A study of airborne radon levels in Paarl houses (South Africa) and associated source terms, using electret ion chambers and gamma-ray spectrometry

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ABSTRACT

Indoor radon (^{222}Rn) concentrations were measured in Paarl homes by means of electret ion chambers. The concentrations varied between 28 and 465 Bq m^{-3}. The average values (Bq m^{-3}) found in houses on the west and east side of the Berg River, which bisects Paarl, were 132 (±11) and 37 (±3), respectively. Radiometric analyses of soils show that the mean ^{226}Ra activity concentration is three times higher on the west than on the east side of the Berg River.

1. Introduction

Paarl is a town located in a valley, about 50 km northeast of Cape Town in the Western Cape Province, South Africa. Prominent topographical features of the valley, which is located in the Cape Winelands, are the Berg River and Paarl Mountain, which boasts three large granite outcrops. The Paarl granite outcrops were formed when magma from below pushed into the rocks above forming a wedge and crystallizing around 600 million years ago (Burger and Coertze, 1973; Theron et al., 1992). When the top layers subsequently weathered, the outcrops were formed. Paarl is a long, narrow town running north–south with the Berg River bisecting the town. The western side of the town rises steeply up the slopes of Paarl Mountain. On the eastern side of the river, where approximately 70% of the Paarl population (approximately 110,000) live, housing areas are built on a series of low hills with small streams running towards the Berg River. The altitude on the west side of the river rises quickly from the Berg River at about 100 m above sea level to a height of 600 m. Since granite contains above-average values of uranium there was concern among Paarl residents about the potentially high values of radon (^{222}Rn) in Paarl houses, especially those on the slopes of Paarl Mountain. This study was initiated as a result of this concern, and is significantly larger in scope than a previous Paarl study (Leuschner et al., 1991). This earlier study was part of a nationwide survey that found some high values in Paarl, but the study was not extended once the initial values were measured. The uranium (or more properly its decay product ^{226}Ra) concentration is generally seen as the major indicator of houses where high radon concentration is expected, but several studies have found that there are many other factors which play a large role as well (Andersen et al., 2007; Smith and Field, 2007). The present study considers an interesting case where there is a large difference in geology within the one town.

^{222}Rn, the radon isotope with the longest half-life namely 3.8 days (usually referred to simply as radon) occurs naturally in the decay chain of the long-lived radionuclide ^{238}U. The relatively long half-life of radon allows the gas to move from the soil into the houses by diffusion and advection. Radon has been recognized as a health hazard for many years, mainly as a result of the dose to lungs that results from attached and unattached fractions of the radon progeny found in the air (Porstendörfer, 2001). Results from one of the most extensive studies on effects of radon are contained in the BEIR VI report (BEIR VI, 1998). Other authoritative radon investigations include those by the International Commission on Radiological Protection (ICRP) in their report number 65 (ICRP, 1993) and the United Nations report on radiation (UNSCEAR, 2000). A more recent study (Darby et al., 2005) reports on a summary of European studies which indicate that the elevated levels in houses are correlated to higher lung cancer rates. In some countries, legislation has been adopted to enforce a reduction in radon levels if the concentration in houses exceeds certain levels. So for example, the intervention level in the USA is 148 Bq m^{-3} (USEPA, 1992). There is currently no action level set in South Africa. Below we report only on radon concentrations found rather than doses inferred from the radon decay products.

2. Materials and methods

The airborne radon concentrations in houses were measured using electret ion chambers (EIC). In particular, electret passive

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environmental radon monitors (E-PERM^{TM}) from Rad-Elec Inc. (USA), with S-chambers having an inner diameter of 8.1 cm and volume of 210 mL were used. The EICs were deployed (usually on a shelf in the television or living room) for periods between 5 and 20 days. After collection, the voltage across the electrets were read using a surface potential electret voltage reader (SPER) (Rad-Elec Inc., USA) and the drop of voltage since deployment was used to calculate the average radon concentration in the house air using the standard formalism (Kotrappa et al., 1990). The standard background correction for the contribution of environmental gamma rays to the depletion of electret voltage was employed. The uncertainties in the measured radon concentrations were determined as proposed by the manufacturer (RAD, 1995) by combining in quadrature contributions stemming from the voltage readings, electret manufacture (5% effect) and background due to gamma rays. The electrets are also sensitive to gamma rays, which necessitates this last correction to the radon concentration. The default correction that corresponds to an exposure of 100 nGy h^{-1} (equivalent to a subtraction of 32 Bq m^{-3} of radon concentration) was used throughout for consistency. Four measurements of the gamma dose were performed by placing electrets in mylar bags on the western side of the river in houses with high radon concentration, which would be expected to have high gamma dose rates as well. These measurements averaged to twice the default value. In view of the high radon values in these houses ($>$200 Bq m^3), the extra correction was ignored for consistency with the other results.

Teachers and pupils at Paarl schools were introduced to the project. Some of these pupils, with their parents' permission, then agreed to allow us to monitor radon levels in their homes. Initial results indicated that the radon concentrations were higher in houses on the west side of the Berg River, in particular, on the Paarl Mountain foothills. Pamphlets were then distributed among residents in this area on which we advertised a free radon measurement service. In total radon levels were measured in 62 and 38 homes on the west and east sides of the Berg River, respectively. Since the houses selected used in this study were not regularly spaced throughout Paarl, we do not claim to have achieved a uniform coverage of the whole town. The latter measurements were in fact concentrated in areas where the initial readings were high. The measurements were made in the period September 2003–March 2004, thus spanning the spring and summer seasons in the Western Cape. Important house features (e.g. floor type) that are pertinent to a survey of this nature were also recorded.

In order to study the potential for radon generation, ex situ and in situ measurements of primordial radionuclides in the Paarl soils were made using gamma-ray spectrometry. A total of 15 soil samples were collected from 15 locations (3 west and 12 east of the Berg River). The samples were collected in the depth range 0–15 cm, placed in labeled plastic bags, sealed and then taken to the laboratory for analysis. The main purpose of the soil samples was to calibrate the in situ measurements and to complement these.

The ex situ gamma-ray spectrometric analyses was carried out at the Environmental Radioactivity Laboratory (ERL) of iThemba LABS. The soils were oven dried at 105 °C and placed into polypropylene marinelli beakers and sealed to achieve secular equilibrium between ^{226}Ra, ^{222}Rn and the short-lived ^{222}Rn progeny. After being sealed for at least 21 days, the samples (1000 cm^3) were each counted in the ERL using a lead-shielded HPGe detector (45% relative efficiency at 1.33 MeV) for measurement times of at least 24,000 s.

To determine the activity concentrations in a particular soil sample measured with the HPGe detector, the associated absolute full-energy peak (FEP) detection efficiency response was determined using the approach described by Croft and Hutchinson (1999).

The in situ gamma-ray survey was conducted using a MEDUSA-type detector (Hendriks et al., 2001; Venema and De Meijer, 2001). Gamma rays are detected by means of a scintillation system comprising, amongst others, a CsI(Na) crystal (15-cm-long, 7 cm in diameter). For this study, the detector was mounted on the front of a 4 × 4 vehicle, 0.6 m off the ground. With this geometry, the MEDUSA detector can be used to measure the average activity concentration in the top ~30 cm of the traversed terrain (assuming it is flat). In order to record spatial coordinates of the detector, a GPS signal receiver (Garmin 76) was located above the MEDUSA scintillator. The region surveyed (in July 2004) had latitude values that ranged between 33°41.90′S and 33°46.13′S, and longitude values that ranged between 18°56.62′E and 18°59.93′E. Two types of data sets were acquired, namely data acquired while stationary (6 locations) and moving (10 data sets), respectively. Care was taken not to include data taken over tar road section in the results presented in this work. A map of MEDUSA detector count rate generated from the survey is shown in Fig. 1, with the dark and light areas indicating lower and higher count rates, respectively. The count rates varied between 60 and 1500 counts s^{-1}.

Activity concentrations of the primordial radionuclides were determined from the measured MEDUSA spectra using the full-spectrum analysis (FSA) procedure (Hendriks et al., 2001). The FSA technique involves the (least-squares) fitting of a gamma-ray spectrum with a linear combination of the so-called standard spectra after proper background subtraction. The FSA-derived activity concentrations were put on an absolute scale by multiplying by the so-called normalization factors. These factors were obtained by making a stationary MEDUSA measurement and thereafter taking a soil sample from beneath the detector for ex situ analysis. The normalization factors used in this study were 0.8

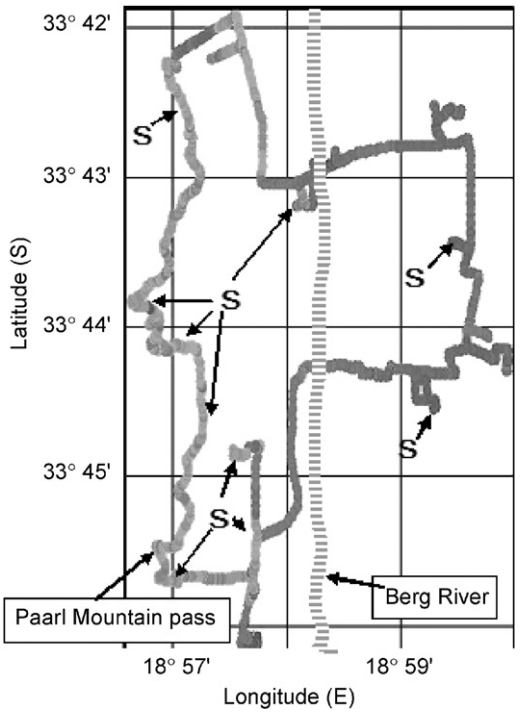

Fig. 1. MEDUSA detector count rate map. The dark and light areas indicate lower and higher count rates, respectively. "S" denotes locations where stationary measurements were made. The location of the Berg River is shown schematically. The map includes tar road sections, but the stationary points were all taken away from roads.