NATURAL RADIATION EXPOSURE TO THE PUBLIC IN THE URANIUM AND THORIUM BEARING REGIONS OF CAMEROON: FROM MEASUREMENTS, DOSE ASSESSMENT TO A NATIONAL RADON PLAN

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Abstract

The present paper summarizes the findings of studies carried out since 2014 in the uranium- and thorium-bearing regions of Poli and Lolodorf, respectively, located in northern and southern Cameroon. It also underlines future prospects for strengthening the radiological protection of members of the public exposed to environmental natural radiation in Cameroon. In situ gamma spectrometry and car-borne surveys were performed in the above regions to determine activity concentrations of natural radionuclides in soil and air kerma rates to assess the effective external dose received by members of the public. High natural radiation areas were located and selected for indoor radon, thoron and thoron progeny measurements. Raduet detectors and thoron progeny monitors were deployed in 300 dwellings to measure radon, thoron and thoron progeny indoors in order to assess the inhalation dose received by members of the public. External effective dose ranges of 0.15–0.63 mSv/year with the average value of 0.4 mSv/year in the uranium-bearing region of Poli and 0.1–2.2 mSv/year with the average value of 0.33 mSv/year in the uranium- and thorium-bearing region of Lolodorf. The inhalation dose due to radon and thoron ranges, respectively, between 0.87–2.7 mSv/year and 0.08–1.0 mSv/year with average values of 1.55 mSv/year and 0.4 mSv/year for Poli, and between 0.6–3.7 mSv/year and 0.03–3.0 mSv/year with the average values of 1.84 mSv/year and 0.67 mSv/year for Lolodorf.

Contribution of thoron to the total inhalation dose ranges around 3–34%, with an average value of 20.3% in the uranium region of Poli and 1–79% with the average value of 27% in the uranium- and thorium-bearing region of Lolodorf. Thus, thoron cannot be neglected in dose assessment in order to avoid biased results in radio-epidemiological studies.

1 INTRODUCTION

Numerous environmental radiation surveys have been carried out in Cameroon over the past decade [1–10]. Most of these studies deal with natural radioactivity measurements and corresponding dose assessment in mining and ore-bearing regions of Cameroon. These started by collecting soil, foodstuff and water samples and by deploying Electret ionization chambers (commercially E-PERM) and passive integrated radon–thoron discriminative detectors (commercially RADUET) in dwellings before determining activity concentrations of naturally occurring radionuclides. This determination is followed by assessing inhalation, ingestion and external radiation dose helpful in performing radiation risk assessment. The present work uses a car-borne survey method to measure air absorbed dose rates and in situ gamma spectrometry to determine activity concentrations of natural radionuclides in soil in all the uranium- and thorium-bearing regions of Poli and Lolodorf. The radiological mapping of these regions was established to locate the high natural radiation areas. This information was used to deploy RADUET and thoron progeny monitors in 400 houses for radon (^{222}Rn), thoron (^{220}Rn) and thoron progeny measurements indoors. Measurements of absorbed dose rates in air, ^{238}U, ^{232}Th, and ^{40}K activity concentrations in soil, radon, thoron and its progeny indoors were followed by external and inhalation dose assessment helpful in assessing radiation risk to members of the public in the above regions.

The above results highlight the importance of putting in place a national radon plan in Cameroon in agreement with IAEA Safety Standards Series No. GSR Part 3: Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [11]. An IAEA Technical Cooperation project (CMR9009) on Establishing a National Radon Plan for Controlling Public Exposure Due to Radon Indoors was initiated and is ongoing for the IAEA Technical Cooperation cycle 2018–2019.

2 MATERIAL AND METHODS

1.1. Car-borne survey

The detailed method of undertaking a car-borne survey has been described in many publications [12–14], but only an outline is described here. A car-borne survey which used a 76 mm × 76 mm (3 in × 3 in) NaI(Tl) scintillation spectrometer (EMF-211, EMF Japan Co., Japan) was carried out in the uranium- and thorium-bearing regions of Poli and Lolodorf from November 2015 to August 2016. This spectrometer was positioned inside the car and the car speed was kept at around 30–40 km/h. Measurements of the counts inside the car were carried out every 30 s along the route. In order to generate a dose rate distribution map, the latitude and longitude coordinates were recorded using a global positioning system at each measurement point at the same time as the gamma ray count rates. Since count rate is measured inside the car, it is necessary to estimate the shielding factor of the car body with respect to terrestrial gamma rays in order to represent the unshielded external dose rate. The shielding factor was estimated by making measurements inside and outside the car at 150 points. Those measurements were recorded consecutively at 30 s intervals during a total recording period of 2 min. Measurements of gamma ray pulse height distributions were also carried out 1 m above the ground surface outside the car for 15 min at 24 points along the survey route. The gamma ray pulse height distributions were unfolded using a 22 × 22 response matrix for the estimation of absorbed dose rate in air. These dose rates were used to evaluate the dose rate conversion factor ($nGy \cdot h^{-1} \cdot cpm^{-1}$).

1.2. Radon–thoron discriminative measurements indoors

To determine the concentrations of radon and thoron, RADUET detectors developed at the National Institute of Radiological Sciences (NIRS) in Japan were used in this study [15]. CR-39 was used to detect alpha particles emitted from radon and thoron as well as their progenies. To determine conversion factors of radon and thoron concentrations, these detectors were placed into the radon and thoron chambers at NIRS, respectively [16, 17]. After exposure tests, CR-39 plates were taken out of the chamber and chemically etched with a 6.25M NaOH solution at 90°C for over 6 h, and alpha tracks were counted with a track reading system. The evaluation of a track in image J and microscopic methods has been well described by Bator et al. [18]. Using two alpha track densities of low and high air exchange rate chambers (N_L and N_H), radon and thoron concentrations were determined by solving the following equations [15]:

$$N_H = X_{Rn}.CF_{Rn2}.T + X_{Tn}.CF_{Tn2}.T + B \quad (1)$$

$$N_L = X_{Rn}.CF_{Rn1}.T + X_{Tn}.CF_{Tn1}.T + B \quad (2)$$

where X_{Rn} and X_{Tn} are the mean concentrations of radon and thoron during the exposure period in Bq/m^3, CF_{Rn1} and CF_{Tn1} are respectively the radon and thoron conversion factors for the low air exchange rate chamber in tracks of 2.3 $cm^{-2} \cdot kBq^{-1} \cdot m^3 \cdot h^{-1}$ and 0.04 $cm^{-2} \cdot kBq^{-1} \cdot m^3 \cdot h^{-1}$, CF_{Rn2} and CF_{Tn2} are respectively the radon and thoron conversion factors for the high air exchange rate chamber in tracks of 2.1 $cm^{-2} \cdot kBq^{-1} \cdot m^3 \cdot h^{-1}$ and 1.9 $cm^{-2} \cdot kBq^{-1} \cdot m^3 \cdot h^{-1}$, T is the exposure time in hours, and B is the background alpha track density on the CR-39 detector per cm^2. The lower detection limit of the detector was practically estimated on the basis that one concentration depends on the other. The lower detection limits were 3 Bq/m^3 for radon and 4 Bq/m^3 for thoron.

RADUET detectors were placed at a height of 1–2 m and 20 cm from the wall in 100 and 150 dwellings of the uranium- and thorium-bearing regions of Poli and Lolodorf, respectively, for 2–3 months.

Spot outdoor and indoor gamma dose rate measurements were performed using a RadEye dose rate survey meter calibrated using a Gamma-RAD5 NaI(Tl) scintillation spectrometer. Measurements were conducted at a height of 1 m above the ground surface.

1.3. Inhalation dose due to radon and thoron

The inhalation dose is given by the following equation [19]:

$$E_{inh} = \left[\left(X_{Rn} \times e_{inh,Rn} \times F_{Rn} \right) + \left(X_{Tn} \times e_{inh,Tn} \times F_{Tn} \right) \right] \times F_{occ} \times t \qquad (3)$$

X_{Rn} *and* X_{Tn} are the median radon and thoron concentrations, respectively, and $e_{inh,Rn}$ is the inhalation dose conversion factor of 9 nSv/(Bq·h^{-1}·m^{-3}) for radon and $e_{inh,Tn}$ is the dose conversion factor of 40 nSv·Bq·h^{-1}·m^{-3}) for thoron, F_{occ} is the occupancy factor of 0.6 for the studied areas, $F_{Rn,\ Tn}$ is the equilibrium factor considered to be 0.4 for radon and 0.02 for thoron, *t* corresponds to a year expressed in hours. The occupancy factor was derived from an in situ enquiry performed in the studied areas during field work. The equilibrium factor used is the default value given by United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR) [19].

3 RESULTS AND DISCUSSION

In the uranium-bearing region of Poli, activity concentrations of ^{238}U, ^{232}Th, and ^{40}K range, respectively, between 13–52 Bq/kg, 10–67 Bq/kg and 242–777 Bq/kg with respective average values of 32 Bq/kg, 31 Bq/kg and 510 Bq/kg. In the uranium- and thorium-bearing region of Lolodorf, activity concentrations range between 6–158 Bq/kg, 6–450 Bq/kg and 98–841 Bq/kg with 34 Bq/kg, 58 Bq/kg and 200 Bq/kg as respective mean values. The world average values for these radionuclides given by UNSCEAR [19] are, respectively, 33 Bq/kg, 45 Bq/kg and 420 Bq/kg. Air kerma rates range, respectively, between 25–102 nGy/h and 11–357 nGy/h for the uranium- and thorium-bearing regions of Poli and Lolodorf, with mean values of 57 and 54 nGy/h. At the worldwide level, they range around 24–160 nGy/h with an average value of 57 nGy/h. The annual effective dose ranges respectively between 0.20–0.83 mSv/year and 0.1–2.2 mSv/year with a mean value of 0.35 mSv/year and 0.33 mSv/year less than the world average value of 0.5 mSv/year given by UNSCEAR [19].

In the uranium-bearing region of Poli, radon and thoron concentrations indoors range respectively between 46–143 Bq/m^3 and 18–238 Bq/m^3 with average values of 82 Bq/m^{3}and 94 Bq/m^3. The inhalation dose due to radon and thoron ranges, respectively, between 0.87–2.7 mSv/year and 0.08–1.0 mSv/year with the average values of 1.55 mSv/year and 0.4 mSv/year. The total inhalation dose due to radon and thoron ranges around 0.95–3.7 mSv/year with the average value of 1.95 mSv/year.

In the uranium- and thorium-bearing region of Lolodorf, radon and thoron concentrations indoors range respectively between 31–197 Bq/m^3 and 6–700 Bq/m^3 with the average values of 97 Bq/m^3 and 159 Bq/m^3. The inhalation dose due to radon and thoron ranges respectively between 0.6–3.7 mSv/year and 0.03–3.0 mSv/year with the average values of 1.84 mSv/year and 0.67 mSv/year. The total inhalation dose ranges around 0.6–6.7 mSv/year. At the worldwide level, inhalation dose due to radon ranges around 0.2–10 mSv/year with the mean value of 1.26 mSv/year.

The contribution of thoron to the total inhalation dose in the uranium- and thorium-bearing regions of Poli and Lolodorf ranges, respectively, between 3–34% and 1–79%, with average values of 20.3% and 27%.

Thus, thoron cannot be neglected in dose assessment to avoid biased results in radio-epidemiological studies.

4 CONCLUSION

Natural radioactivity in most of the surveyed areas is normal. However, there are high natural radiation areas found in most of the areas studied. Radon and thoron exposure is a reality in Cameroon. The thoron contribution to inhalation dose is higher than 20% and therefore thoron cannot be neglected in dose assessment. Thoron is abundant in the uranium- and thorium-bearing regions of Poli and Lolodorf. However, extensive measurements of radon and thoron at nationwide scale are needed. In case high inhalation doses are confirmed, epidemiological studies could be planned. An IAEA TC project (CMR9009) dealing with Establishing a National Radon Plan for Controlling Public Exposure Due to Radon Indoors is ongoing since the beginning of 2018. This two-year project is funded within the framework of the TC programme between the IAEA and Cameroon.

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