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Thoron: Ignored and underestimated in the big shadow of radon - an example from China

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RESUMEN

Se midieron ^{222}Rn y ^{220}Rn en cuevas excavadas en sedimentos de loess utilizadas como habitaciones en China Central. En una gran parte de ellas los lechos están construidos a la manera tradicional sobre una base de loess. En esos casos, la población está expuesta a una rapidez de dosis anual de aproximadamente 17 mSv, debido esencialmente a la inhalación del ^{222}Rn y sus productos de decaimiento. Se estima que entre 30 y 40 millones de habitantes viven en habitaciones en cuevas, lo cual representa probablemente el mayor grupo de población a nivel mundial con muy alta exposición a la radiación. Este caso sugiere la necesidad de un aumento de investigaciones radiobiológicas o epidemiológicas.

PALABRAS CLAVE: Torón, radón, China, habitaciones en cuevas, rapidez de dosis, loess.

ABSTRACT

^{222}Rn and ^{220}Rn measurements were carried out in cave dwellings in Central China, which are dug in loess sediments. Most are constructed in a traditional style, with a floor made of loess. Inhabitants are exposed to an annual dose rate of approx. 17 mSv, mainly due to the inhalation of ^{220}Rn decay products. Some 30 - 40 millions Chinese are estimate to be living in cave dwellings, probably the largest population group with very high radiation exposure world-wide. This contribution suggests a need to conduct further radiobiological or epidemiological investigations.

KEY WORDS: Thoron, radon, China, cave dwellings, dose rate, loess.

INTRODUCTION

The world-wide average of natural radiation exposure to the public (2.4 mSv a^{-1}) is mainly due to cosmic rays, terrestrial γ rays, radionuclides in the body, and ranked first to inhalation of radon and its decay products (1.3 mSv a^{-1}, UNSCEAR, 1993). Two different radon isotopes are important: ^{222}Rn with a half-life of 3.8 d, and ^{220}Rn having a half-life of 56 s. Usually, the radiation exposure by ^{222}Rn and particular its progenies is much higher than in case of ^{220}Rn (1.2 vs. 0.07 mSv a^{-1}, UNSCEAR, 1993). This study shows that the radiation exposure due to ^{220}Rn and it's decay products can be significantly higher under special conditions.

In the summer of 1997, ^{222}Rn- and ^{220}Rn-concentrations were measured in Yan'an prefecture in Shaanxi Province (China), (Wiegand *et al.,* 2000). Beside α-spectroscopic indoor radon measurements in brick houses and especially in cave dwellings, radon concentrations of soil-gas and γ-dose-rates were determined. On the countryside of the central Chinese loess plateau more than 65 % of the population is living in cave dwellings (Golany, 1992). Those dwellings are dug into Pleistocene loess sediments, which reach a thickness up to 150 m (Tungsheng, 1988). In the region of Yan'an the percentage of the countryside population living in cave dwellings reaches about 90%. A typical cave dwelling (named *yao-dong*) has one room with a single entrance and two windows next to the door. Most of them are characterised by a *kang*, which is the traditional heated bed built with loess material. Up to now, several studies were conducted about radon exposure in Chinese cave dwellings (Shang *et al.,* 1995, Wang *et al.,* 1996, Wang, 1998), but with the exception of the investigation of Shang and Wang (1998), a discrimination of ^{222}Rn and ^{220}Rn was not possible. Already Doi *et al.* (1992) showed that ^{220}Rn and its decay products can contribute significantly to the radiation exposure under special buildings characteristics, i.e. lack of diffusion barriers. While ^{222}Rn enters buildings by diffusive and advective processes, the ^{220}Rn entry rate is entirely depending on diffusion due to its short half-life. Therefore, only the first few mm of building material will contribute to the ^{220}Rn entry rate, which will be hindered significantly, if floors or walls are covered with no more than paint or wallpaper.

RESULTS

41 dwellings were investigated and classified into two groups: cave dwellings and brick houses. For each dwelling

the fraction of walls consisting of undisturbed loess (called loess-wall-fraction) was calculated (Wiegand *et al.,* 2000). While cave dwellings reach loess-wall-fractions up to 92 %, brick houses have only contact to the loess with the floor or with the floor and the back site of dwellings. Loess is practically the only source for indoor ^{222}Rn and ^{220}Rn. It is an eolian sediment with a low content of ^{222}Rn and ^{220}Rn precursors: ^{238}U = 15 Bq/kg, ^{232}Th = 42 Bq/kg (Chinese average: 40 resp. 49 Bq/kg, NEPA, 1990) . Thus, relatively low ^{222}Rn and ^{220}Rn concentrations in soil-gas (12 Bq l^{-1}, resp. 28 Bq l^{-1}, 0.8 m depth) were measured (Wiegand *et al.,* 2000). Despite the weak radon source, both types of dwellings beat the worldwide average of indoor ^{222}Rn (40 Bq m^{-3}) and ^{220}Rn (3 Bq m^{-3}, UNSCEAR, 1993): In the study area the median indoor ^{222}Rn and ^{220}Rn concentrations amount to 42 resp. 77 Bq m^{-3} for brick houses, and 92 resp. 215 Bq m^{-3} for cave dwellings (Wiegand *et al.,* 2000).

As it was expected, indoor ^{222}Rn concentrations show a significant positive correlation with loess-wall-fractions (Wiegand *et al.,* 2000). No correlation was observed for the short living ^{220}Rn, which cannot accumulate anywhere. For the same reasons, the ventilation rate has a distinct negative influence on ^{222}Rn but only a weak one for ^{220}Rn (Wiegand *et al.,* 2000). A very important feature is that the distance from the measuring point to the loess surface has no correlation with ^{222}Rn-concentrations, while the ^{220}Rn-concentrations show a potential shaped decrease with increasing distance from the loess (Figure 1). Within the first 0.5 m from the surface the gradient of ^{220}Rn-concentrations is very steep, further away, the concentration remains stable.

DOSE RATE

When the natural radiation exposure to the public is estimated for the study area, and the different radiation sources are evaluated, the dominance of indoor ^{220}Rn becomes striking. Of minor importance are indoor and outdoor terrestrial γ rays, which average to an annual effective dose rate of about 0.9 mSv (Chinese average: 0.55 mSv, NEPA, 1990). To calculate the annual effective dose *E* resulting from inhalation of radon and its decay products, E had to be calculated separately for radon gas and decay products (EEC), as well for both radon isotopes:

Radon gas: E[mSv a^{-1}]=C[Bq m^{-3}]*t[h a^{-1}] * D_{gas} [(nSv) / (Bq h m^{-3}] * 10^{-6},
EEC: E[mSv a^{-1}]=C [Bq m^{-3}]*F*t [h a^{-1}]*D_{EEC} [(nSv) / (Bq h m^{-3}] * 10^{-6},
with the following parameters (UNSCEAR, 1993):

C: ^{222}Rn resp. ^{220}Rn concentration,
F: indoor equilibrium factor between ^{222}Rn (^{220}Rn) and its decay products; $F_{Rn\text{-}222}$=0.4, $F_{Rn\text{-}220}$=0.1,

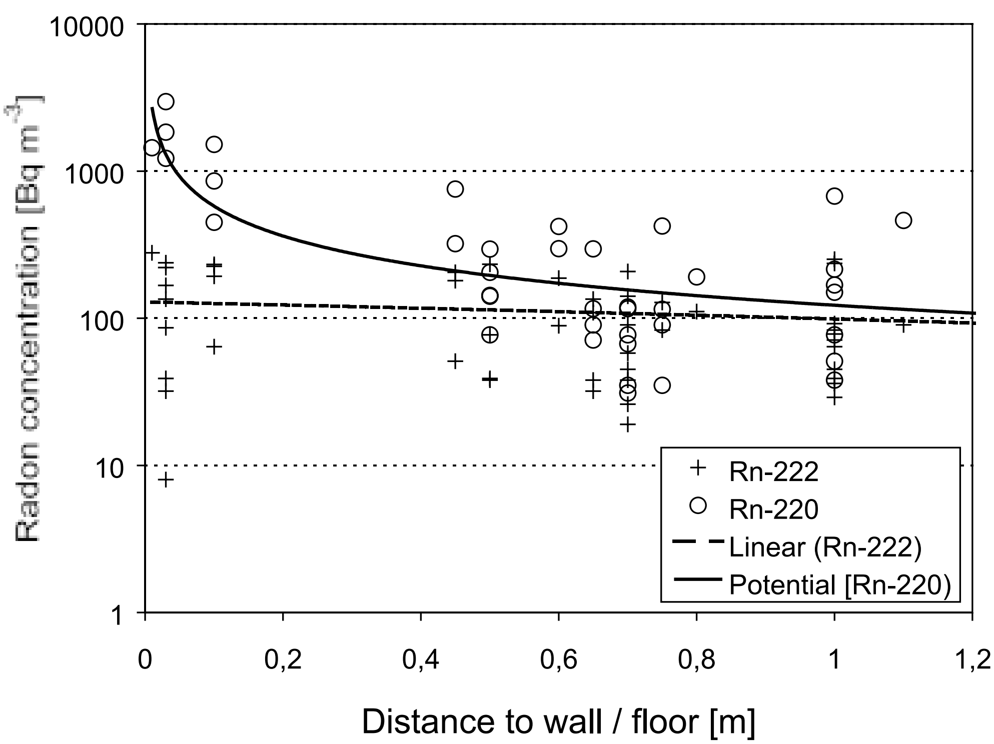

Fig. 1. ^{222}Rn (y=-31x+130, n=49) and ^{220}Rn (y=124x$^{-0.67}$, n=40) distribution within dwellings.

Table 1

Annual effective dose rates in dependence of type of dwelling.

Effective dose rates [mSv a^{-1}]	^{222}Rn gas	^{222}Rn EEC	^{220}Rn gas	^{220}Rn EEC	total
brick house	0.05	1.06	0.06	1.73	2.9
cave dwelling without *kang*	0.11	2.32	0.17	4.82	7.4
cave dwelling with *kang*	0.11	2.32	0.50	14.42	17.4

t: time [h] of exposure per year; *t*=7000 h (indoor occupancy factor of 0.8),

D_{gas}: dose conversion factor for radon gas; ^{222}Rn=0.17, ^{220}Rn=0.11 [nSv per Bq h m^{-3}],

D_{EEC}: indoor dose conversion factor for radon decay products; ^{222}Rn=9, ^{220}Rn=32 [nSv per Bq h m^{-3}].

It has to be pointed out that the calculations consider only data of this study, which was carried out during the hottest season of the year. This implies that the annual average of ^{222}Rn-concentrations will be significantly higher. Regarding the strong gradient of ^{220}Rn-concentrations close to the loess surface, the annual effective dose rate was calculated for brick houses and cave dwellings with and without *kang* (Table 1). While the contribution of ^{222}Rn and ^{220}Rn gas is generally weak, especially the decay products of ^{220}Rn can enhance the dose rate strongly when sleeping on a *kang*. The calculation for cave dwellings with *kang* is separated into day- and night-time. The night-time calculation is based on ^{220}Rn data ≤ 0.1 m distance to the loess surface (median: 1440 Bq m^{-3}), considering a sleeping time of 7 h daily 350 days a year. The day-time calculation is done with the remaining ^{220}Rn data (median: 215 Bq m^{-3}).

Considering the new recommendations of UNSCEAR (2000) the indoor dose conversion factor for ^{220}Rn decay products was scaled up to 40 nSv per Bq h m^{-3}. This would mean for example, that the dose rate due to ^{220}Rn decay products in cave dwellings with *kang* increases from 14.4 mSv a^{-1} to 18.0 mSv a^{-1}.

CONCLUSIONS

The findings of this study reveal the role of ^{220}Rn and its decay products as an important source of radiation exposure under special conditions. The results can be transferred to other regions where people are sleeping close to soil surfaces, especially in the case of Th-rich bedrock. In the field of radiation protection it is unique that such a large population group is exposed to such a high dose rate. If the population is informed, the immense exposure can be reduced easily and effectively, just by using a plastic foil under the mattress or sleeping in a "normal" bed. All the year round, the ^{220}Rn concentrations will be more or less stable. In contrast to that, ^{222}Rn concentrations, which are sensitive to indoor ventilation rate and to indoor air depression caused by heating, will be higher during winter under the prevailing continental climate. To calculate the effective dose rate more precisely, measurements of ^{222}Rn in winter and ^{220}Rn decay products are desirable. Considering that 30-40 millions Chinese live in cave dwellings (Golany, 1992), further epidemiological and radiobiological investigation should focus on this population group. Several endemic diseases of the Chinese loess belt (Tungsheng, 1988) may be a subtle hint to start this task.

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