RADIOLOGICAL HAZARD ASSESSMENT OF CEMENT AND SAND USED FOR CONSTRUCTION OF DWELLINGS IN DINGXI, CHINA

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Natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in cement and sand used for construction of dwellings in Dingxi, China were determined using gamma ray spectrometry. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the studied materials range from 13.2 to 64.7, 15.4 to 46.7 and 165.7 to 1283.5 Bq kg^{-1}, respectively, which are in the range of Chinese soil values. The associated radiological hazards to residents living in dwellings made of the studied materials were evaluated using radium equivalent activity, external hazard index, internal hazard index, indoor air absorbed dose rate, annual effective dose and excess lifetime cancer risk. The values of all radiation parameters are lower than the recommended limits except the mean indoor air absorbed dose rate of sand are higher than the world population-weighted average value. The study shows that the cement and sand from Dingxi may be safely used as construction materials and do not pose significant radiation hazards to local residents.

Key words: Natural radioactivity, radiation hazard, building material, gamma ray spectrometry, excess lifetime cancer risk.

1. INTRODUCTION

Natural occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K widely distribute in rock, soil and sediment, as well as building materials [1, 2]. Natural radioactivities of building materials are valuable in assessing population exposures to natural radiation due to most individuals spend 80% of their time indoors [3–5]. The radiological hazards of radionuclides in building materials to residents are external exposure caused by gamma radiation originating from ^{40}K, ^{226}Ra, ^{232}Th and their decay products, as well as internal exposure come from the inhalation of radioactive inert gases radon (^{222}Rn, a daughter product of ^{226}Ra) and thoron (^{220}Rn, a daughter product of ^{224}Ra) exhaled from building materials, and their short-lived decay products [5–7].

Building materials have varying natural radioactivity levels due to the disparity of their sources and chemical compositions [2–4]. For estimating the radiological hazards to residents, it is imperative to measure the activity concentration of natural radionuclides in building materials collected from different places. Cement and sand are the widely used building materials around the world. More concerns have been addressed over the natural radioactivity of main building materials such cement, sand, concrete and brick during past decades, and a large amount of researches have been done in many countries [7–15], including some regions of China [2, 4, 16–18]. However, the detail information about natural radioactivity of cement and sand used in Dingxi of China was not available in the literature. Dingxi is one important city in the southeast of Gansu province in northwest China (Fig. 1). There are about 2.7 million people living in Dingxi city. The aims of this work were to determine the activity concentration of natural ^{226}Ra, ^{232}Th and ^{40}K in cement and sand used for construction of dwellings in Dingxi using gamma ray spectrometry and to assess the potential radiological hazards associated with the usage of these two building materials by computing radium equivalent activity, external and internal hazard indices, indoor absorbed dose rate, annual effective dose and excess lifetime cancer risk. The results are compared with the recommended values and similar studies carried out in other countries.

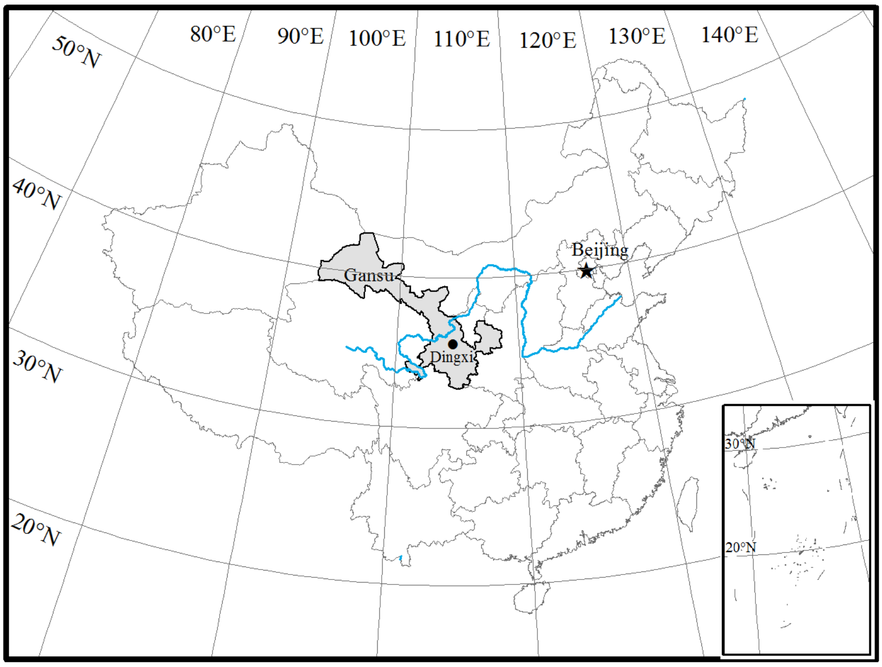

Fig. 1 – The location of Dingxi, China.

2. MATERIALS AND METHODS

2.1. SAMPLE

Cement and sand samples were randomly collected from local construction sites in Dingxi city. Fourteen samples of each type of building materials were collected. The sand samples were ground to a finer power with a particle size < 0.16 mm and all collected samples were dried in a temperature-controlled furnace at 110 ºC for 12–24 h to remove moisture [2]. Then, the dried samples were weighted and stored in cylindrical polyethylene plastic containers. The containers were hermetically sealed to prevent the escape of gaseous ^{222}Rn and ^{220}Rn from the samples and kept laboratory for more than 4 weeks to ensure radioactive equilibrium between ^{226}Ra and ^{232}Th and their decay products [19].

2.2. RADIOACTIVITY MEASUREMENT

^{226}Ra, ^{232}Th and ^{40}K activity concentrations in the samples were determined by a 3×3 inch NaI(Tl) gamma ray spectrometric system with >8% energy resolution (^{137}Cs 661.6 keV) [2]. The detector, placed in a lead shielding room with the thickness of 10.5 cm and height of 38 cm, was coupled to a 1024 microcomputer multi-channel pulse height analyzer and the system was calibrated for the gamma energy range 50 keV to 3.2 MeV. The activity of ^{226}Ra was determined by the photopeaks of ^{214}Bi at 609.3 and 1764.5 keV, and the activity of ^{232}Th was measured through the photopeaks of ^{212}Pb at 238.6 keV and ^{208}Tl at 2614 keV [8]. ^{40}K activity was determined directly by its own gamma ray at 1460.8 keV. All samples were counted for 18,000 s. Each sample was counted twice before an average value was calculated.

3. RESULTS AND DISCUSSION

The minimum (Min), maximum (Max), mean, standard deviation (SD) and coefficient of variation (CV) of the specific activity values of ^{226}Ra, ^{232}Th and ^{40}K in cement and sand are shown in Table 1. The specific activities of ^{226}Ra, ^{232}Th and ^{40}K in sand samples range from 13.2 to 22.2, 15.4 to 46.7 and 260.9 to 1283.5 Bq kg^{-1} with an average of 17.7, 31.2 and 905.8 Bq kg^{-1}, respectively. The CV values show that the specific activity variation of ^{232}Th and ^{40}K in the sand samples are higher than ^{226}Ra.

Table 1

^{226}Ra, ^{232}Th and ^{40}K activity concentration, radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), indoor air absorbed dose rate (D_{in}), annual effective dose (AED_{in}) and the excess lifetime cancer risk ($ELCR_{in}$) for cement and sand from Dingxi

Materials	Activity concentration (Bq kg^{-1})			Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	D_{in} (nGy h^{-1})	AED_{in} (mSv y^{-1})	$ELCR_{in}$ (×10^{-3})
	^{226}Ra	^{232}Th	^{40}K						
Sand									
Min	13.2	15.4	260.9	55.3	0.15	0.19	50.0	0.245	0.92
Max	22.2	46.7	1283.5	179.6	0.48	0.52	167.0	0.819	3.07
Mean	17.7	31.2	905.8	132.1	0.36	0.40	123.1	0.604	2.26
SD	2.7	9.4	300.1	35.6	0.10	0.10	33.7	0.165	0.62
CV(%)	15	30	33	27	27	25	27	27	27
Cement									
Min	16.9	13.8	165.7	54.7	0.15	0.19	49.5	0.243	0.91
Max	64.7	38.5	328.7	142.7	0.39	0.56	125.7	0.617	2.31
Mean	35.1	24.2	250.1	88.9	0.24	0.34	78.9	0.387	1.45
SD	15.2	7.0	45.6	26.0	0.07	0.11	22.5	0.111	0.41
CV(%)	43	29	18	29	29	33	29	29	29

The mean activity concentrations of ^{226}Ra and ^{232}Th in the sand are lower than the worldwide population-weighted average values for soil (32 and 45 Bq kg^{-1} for ^{226}Ra and ^{232}Th, respectively) [20], while the mean ^{40}K activity concentration in the sand is higher than the worldwide population-weighted average value for soil (420 Bq kg^{-1}) [20]. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in cement vary from 16.9 to 64.7, 13.8 to 38.5 and 165.7 to 328.7 Bq kg^{-1} with an average of 35.1, 24.2 and 250.1 Bq kg^{-1}, respectively. The activity concentration variation of ^{226}Ra and ^{232}Th in the cement samples are higher than ^{40}K. The mean ^{226}Ra activity concentration in the cement is higher than, while the mean values of ^{232}Th and ^{40}K activity concentration are lower than, the corresponding worldwide population-weighted average values for soil [20]. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in all cement and sand samples are in the range of Chinese soil values [20]. ^{40}K, accounting for 74–96% total activity concentration, is the largest contributor to the total activity in all investigated samples.

Table 2 presents the comparison of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in cement and sand used in Dingxi with other areas [1, 2, 4, 5, 10, 12, 13, 16–18, 21–23]. It can been found that the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in cement and sand from Dingxi are comparable to other areas. The differences of natural radioactivity in cement and sand among the compared areas would be due to the difference of their sources and chemical compositions.

To assess the radiological hazards of individuals living in dwellings made of the studied materials, radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}), indoor air absorbed dose rate (D_{in}), annual effective dose (AED_{in}) and excess lifetime cancer risk ($ELCR_{in}$) were calculated in the study. The detailed calculation formulas of Ra_{eq}, H_{ex} and H_{in} were cited from Beretka and Mathew [24]. D_{in} and AED_{in} were calculated using the equations provided by EC [25] and UNSCEAR [20], while the calculation method of $ELCR_{in}$ was referenced from Taskin *et al.* [26]. The duration of life in the calculation of $ELCR_{in}$ was Chinese datum (75 years) (http://en.worldstat.info/Asia/China). The calculated results of all parameters are shown in Table 1.

It can been found from Table 1, the Ra_{eq} values for cement and sand range from 54.7 to 142.7 and 55.3 to 179.6 Bq kg^{-1} with an average of 88.9 and 132.1 Bq kg^{-1}, respectively, which are below the recommended limit of 370 Bq kg^{-1} for building materials [20]. Figure 2 shows that ^{226}Ra and ^{232}Th activity concentrations in cement are significantly positive correlation with Ra_{eq}, while in sand the activity concentrations of ^{232}Th and ^{40}K are significantly positive correlation with Ra_{eq}. It indicates that the relative contribution of natural radionuclides to Ra_{eq} for cement is mainly from ^{226}Ra (38%) and ^{232}Th (39%), while for sand is mainly from ^{40}K (52%) and ^{232}Th (34%). The values of H_{ex} and H_{in} for cement and sand are all less than unity. The estimated D_{in} values for cement and sand used in Dingxi are in the range of 49.5 to 125.7 and 50.0 to 167.0 nGy h^{-1} with an average of 78.9 and 123.1 nGy h^{-1}, respectively (Table 1). The mean D_{in} value of sand is higher than and the mean D_{in} value of cement is lower than the world population-weighted average indoor absorbed gamma dose rate of 84 nGy h^{-1} [20]. The corresponding indoor annual effective dose (AED_{in}) due to gamma ray emission of ^{226}Ra, ^{232}Th and ^{40}K from the investigated samples ranges from 0.243 to 0.617 mSv y^{-1} with an average of 0.387 mSv y^{-1} for cement and 0.245 to 0.819 mSv y^{-1} with an average of 0.604 mSv y^{-1} for sand (Table 1). Controls on gamma radiation of building materials should be based on a dose in the range of 0.3–1 mSv y^{-1} [25]. The average of annual effective dose of cement and sand exceed the reference level of 0.3 mSv y^{-1} but do not reach the maximum acceptable value of 1 mSv y^{-1}.

The values of $ELCR_{in}$ for the sand and cement samples range from 0.92×10^{-3} to 3.07×10^{-3} and 0.81×10^{-3} to 2.36×10^{-3} with an average of 2.26×10^{-3} and 1.45×10^{-3}, respectively. According to the above-mentioned recommended limit (1 mSv y^{-1}) of AED_{in}, the maximum $ELCR_{in}$ should not exceed 3.75×10^{-3} for indoor exposure. The values of $ELCR_{in}$ for all investigated cement and sand samples are less than this maximum. The relationships between natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) activity concentration and H_{ex}, H_{in}, D_{in}, AED_{in}, as well as $ELCR_{in}$ in sand and cement samples have the similar characteristics as Ra_{eq}.

Table 2

Comparison of activity concentration (Bq kg^{-1}) with other areas

Materials	**City, Country**	**Activity concentration (Bq kg^{-1})**			**Reference**
		^{226}Ra	**^{232}Th**	**^{40}K**	
Sand	Namakkal, India	2.27	21.72	352.8	[13]
	Cuba	17	16	208	[22]
	Malaysia	60[a]	13	750	[23]
	Greece	18	17	367	[5]
	Algeria	12	7	74	[21]
	Turkey	44	24	461	[8]
	Punjab, Pakistan	24[a]	39	462	[12]
	Egypt	15.84	15.43	219.19	[10]
	Aden, Yemen	20.78	27.68	1118.36	[1]
	Weinan, China	32.5	47.7	249.6	[16]
	Xianyang, China	19.7	30.3	852.0	[2]
	Urumqi, China	22.4	25.1	789.3	[4]
	Baotou, China	16	26	736	[18]
	Xining, China	21.5	32.7	764.1	[17]
	Dingxi, China	**17.7**	**31.2**	**905.8**	**Present study**
Cement	Namakkal, India	37.99	34.87	188.13	[13]
	Cuba	23	11	467	[22]
	Malaysia	51[a]	23	832	[23]
	Algeria	41	27	422	[21]
	Qena, Egypt	134	88	416	[7]
	Punjab, Pakistan	37[a]	28	200	[12]
	Aden, Yemen	40.39	24.57	428.48	[1]
	Turkey	41	26	267	[8]
	Egypt	35.6	43.17	82.08	[10]
	Greece	20	13	247	[5]
	Weinan, China	118.7	36.1	444.5	[16]
	Xianyang, China	51.7	32.0	207.7	[2]
	Urumqi, China	29.1	15.8	333.2	[4]
	Baotou, China	52	103	310	[18]
	Xining, China	76.3	46.2	293.9	[17]
	Dingxi, China	**35.1**	**24.18**	**250.1**	**Present study**

[a] ^{238}U

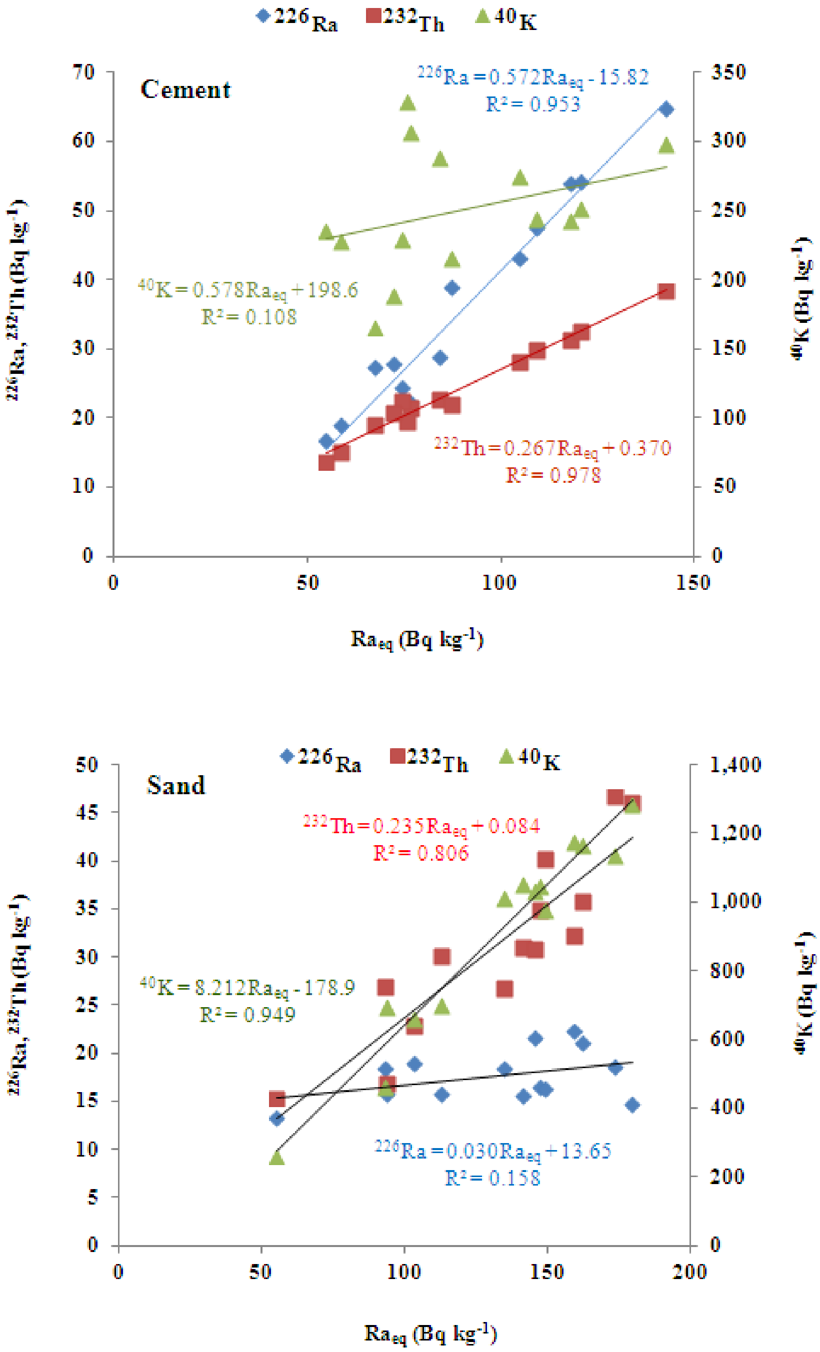

Fig. 2 – Relationship between ^{226}Ra, ^{232}Th, ^{40}K concentration and Ra_{eq} in sand and cement.

4. CONCLUSION

The activity concentrations of ^{226}Ra, ^{40}K and ^{232}Th in cement and sand used in Dingxi of China are in the range of Chinese soil values. Their radium equivalent activity values are below the internationally accepted value of 370 Bq kg^{-1}. The external hazard index and internal hazard index values of the cement and sand are less than unity. The mean indoor air absorbed dose rate of the cement is lower than and the mean indoor air absorbed dose rate of the sand is higher than the world population-weighted average indoor absorbed gamma dose rate. The corresponding annual effective dose values of the cement and sand are less than the recommended limit of 1 mSv y^{-1} and the excess lifetime cancer risk of the investigated cement and sand do not exceed the maximum value for indoor exposure. Therefore, the investigated cement and sand of Dingxi can be safely used in the construction of dwellings and do not pose a significantly radiological hazard to local residents.

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