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Assessment of Natural Radioactivity Levels and Radiation Hazards of Building Materials of Lao PDR

X.Sonexay[1,3], L.H.Khiem[2,3], L.D.Nam[3]

[1]*Faculty of Science, The National University of Laos, Lao PDR, Sokpaluang, Sisatanak District, Vientiane 3166 Lao PDR;*
[2]*Institute of Physics, Vietnam Academy of Science and Technology, 10 Dao Tan, Ba Dinh, Ha Noi, Vietnam;*
[3]*Graduate University of Science and Technology, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, Cau Giay, Ha Noi, Vietnam*
Corresponding Author: X.Sonexay

ABSTRACT: The results of the first investigation of the activity concentrations in some main building materials including cement produced by Lao cement companies, soil and sand samples collected at various locations of Lao PDR are presented in this work. The activity concentrations of the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K of the collected samples were determined by a low background high resolution gamma spectrometer. For ^{226}Ra, the activity concentration range from 24.83±1.18 to 54.39±5.90 with the average value of 37.76±3.16 Bq.kg^{-1} for the cement samples, from 11.43±0.5 to 30.98±2.19 with the average value of 22.81±1.22 Bq.kg^{-1} for the soil samples and from 12.46±0.52 to 22.90±0.29 with the average value of 17.08±1.12 Bq.kg^{-1} for the sand samples. For ^{232}Th, the activity concentration are in between 6.63±1.59 to 21.17±0.48 with the average of 13.77±1.04 Bq.kg^{-1} for the cement samples, between 7.24±0.04 and 44.56±2.59 with the average of 27.22±0.86 Bq.kg^{-1} for the soil and between 17.61±1.17 to 31.72±0.50 with the average of 23.14±0.72 Bq.kg^{-1} for the sand samples. For ^{40}K, the activity concentration are between 43.28±7.68 and 168.70±3.34 with the average of 116.07±7.34 Bq.kg^{-1} for the cement samples, between 40.96±6.98 and 581.71±16.98 with the average of 235.49±7.51 Bq.kg^{-1} for the soil samples, and between 414.58±19.25 to 492.99±19.56 with the average of 463.31±12.28Bq.kg^{-1} for the sand samples. The absorbed gamma dose rate in air at 1m above the ground surface, the radium equivalent activity, the external and internal hazard indices and the gamma-index were calculated. The obtained results indicate that the radiation hazard from natural ^{226}Ra, ^{232}Th and ^{40}K radionuclides in all investigated building materials are safe in use for dwelling constructions.

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I. INTRODUCTION

The natural radionuclides are present everywhere with different concentrations. They were created together with the creation of the Earth. Among the natural radionuclides, ^{238}U, ^{232}Th and ^{40}K are most significant. The isotopes ^{238}U and ^{232}Th are radioactive and they undergo radioactive decay into many other radioactive isotopes until they are stable. As radium and its daughter products produce 98.5% of the radiological effects of the uranium series, the contribution from the ^{238}U is used to be replaced with the ^{226}Ra decay product.

The natural radionuclides emit gamma radiation which continuously affect to human health. Therefore, investigation of their concentrations in the living environments of human beings is an important task in order to be able to estimate the radiation hazard from these natural radionuclides to human. Humans spend almost of time of their life in the buildings including their houses which are made from different building materials. These materials are made from the Earth's crust in which the natural radionuclides exit. Therefore, the building materials contain trace amounts of the radionuclides which are the major source of radiation exposure to humans. The activity concentrations of the building materials are different from region to region so that measuring the activity concentrations of radionuclides in building materials is important for the assessment of population exposures. Due to the importance of this issue, the survey of the activity concentration of natural

radionuclides in the different building materials has been attracted the interest of many researchers in the world[1-6]. However, in Lao PDR this issue so far has not been carried out. Our work aims to determine the activity concentration of naturally occurring radioactive material in the building materials collected in Lao PDR. This is the first investigation of the natural radioactivity of Lao building materials. Such kind of investigation will be carried out continuously in the future in different provinces in order to provide the data on natural radioactivity of soil in different areas of Lao PDR. These data are important information for the local people to use these materials in the construction of dwellings. Furthermore, the obtained data may be used to develop the national standards of natural radioactivity for the use and management of building materials in the country.

In this work, we will present the first results of measuring the activity concentrations of the natural radionuclides of some building materials including cement, soil and sand by using high-resolution gamma-ray spectroscopy. The investigated cement samples were chosen randomly from 4 famous local cement production companies in Lao PDR. The soil samples were taken at 10 locations in Thoulakhon district of Vientiane Capital and the sand samples were collected at 6 different locations of the riverside along Vientiane passage of the Mekong river. These samples were analyzed to determine the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides. These data were used for evaluating the potential radiological hazards associated to that materials by determining the absorbed dose rate in air D, the radium equivalent activity Ra_{eq}, the external H_{ex} and internal H_{in} hazard indices and the gamma-index I_{γ}.

II. EXPERIMENTAL DETAILS

2.1 Sample collection

In this work, we have collected different samples of the building materials in Lao PDR including cement, sand and soil. A total of 80 cement samples of two types (Portland and mixed) were collected from 4 local famous cement production companies namely VangVieng Cement plant.II, BMC Cement Factory Golden Elephant-Laos, Lao Cement Industry (Golden Elephant) and Lao Cement Industry TLD. The investigated soil samples were collected at different locations in Thoulakhom district of Vientiane Capital as shown in Fig.1. The locations for collecting the samples are presented in the map on the left side. A total number of the locations for soil collection is 10 and they are indicated by the circles with the dots inside which are marked as P1, P2,... P10. A soil auger has been used for collecting the soil samples at a depth of about 0.6 meter from the surface layer at the designed locations. At each location, about 5 kg wet weight per sample was collected. The sand samples in our study were obtained from the locations along Vientiane passage of the Mekong river as shown in the map of Figure 2.1 on the right side. A total number of the sampling sites is 6 and they are indicated by the circles with the dots marked as SP1, SP2,...SP6 inside the map.

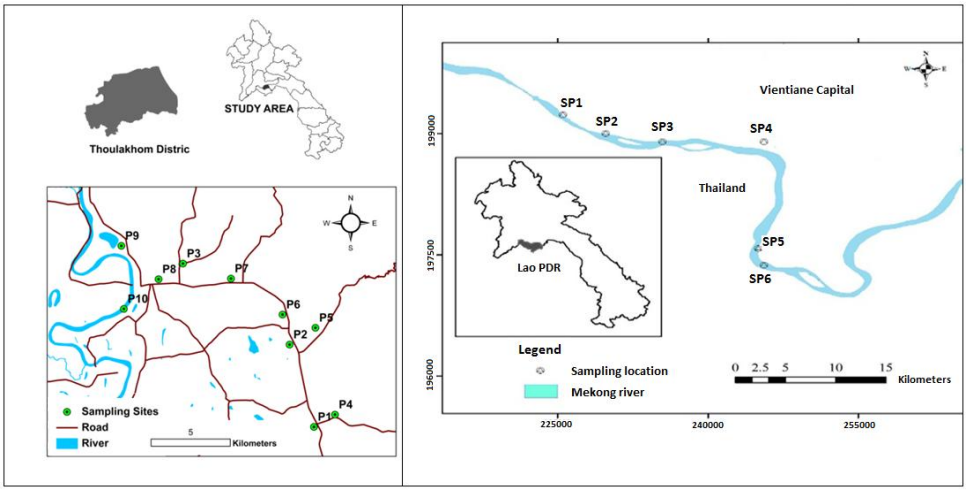

Fig. 2.1 The locations for collecting the soil and sand samples in Vientiane capital. The map on the left side showing the Thoulakhom district. In this figure, the soil sampling locations were indicated as P1, P2, …, P10. The map on the right side shows the sand sampling locations along the Mekong river which were indicated as SP1, SP2, …, SP6.

2.2 Preparation of the samples for the activity concentration measurement

All samples were sent to the laboratory of the Center for Nuclear Physics of the Institute of Physics of Vietnam Academy of Science and Technology for measurement of the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K radionuclides. The samples were placed in an oven for drying at 100^{o}C for 24 hours in order to remove the moisture. After removing moisture, the samples were crushed and sieved by using a sieve to pass a mesh of 0.2

mm. The homogenized samples were contained in the PVC cylindrical beakers with the diameter of 10 cm, which were then hermetically sealed with the aid of tape to prevent the escape of airborne ^{222}Rn and ^{220}Rn from the samples. The samples were weighted and stored for more than 30 days for reaching secular equilibrium between ^{226}Ra and its short-lived daughters.

2.3 Measurement of the activity concentration of the samples

A gamma-ray spectrometer has been used for measuring the activity concentration of the soil samples. The gamma-ray spectrometer is connected with a coxial cylinder HPGe detector model GEM20P4-70 made by Ortec company. The relative detection efficiency of the detector is about 20% relative to a 3" x 3" NaI(Tl) scintillation detector. The energy resolution of the detector at 1.332 MeV is 1.8 keV. The electronic system of the spectrometer contains a detector high voltage power supply and signal processing modules. The latter include a main spectroscopy amplifier model 572A made by Ortec company and a computer based PCA-MR 8192 ACCUSPEC multi-channel analyzer. For data acquisition, storage, display and on-line analysis of the acquired gamma-spectra, an advanced multi-channel analyzer emulation software MAESTRO-32 has been used. For spectral off-line analysis, the software, GENIE-2K software has been used.

In order to reduce the number of background gamma radiation present at the laboratory site, the HPGe detector is placed in a low-level Canberra Model 747 lead shield having a lead thickness of 10 cm. It will prevent high background counts due to external sources, thus reducing counting times and improving the lower limit of detection. The 1 mm tin and 1.6 mm copper graded liner prevents interference by lead x rays. Energy calibration of the detector was carried out by using two different sources ^{60}Co and ^{226}Ra, which emit γ-rays of energy ranged between 186.21 keV and 2447.86 keV.

The activity concentration of ^{40}K was determined directly by its own γ-ray at 1460.8 keV (10.7%), while the specific activities of ^{226}Ra and ^{232}Th were calculated based on the weighted mean values of their respective decay products in equilibrium. The specific radioactivity of ^{226}Ra was determined using the 295.22 keV (18.5%), 351.93 keV (35.6%) γ-rays from ^{214}Pb and 609.31 keV (45.49%), 768.36 keV (4.89%), 1120.14 keV (15.0%), 1764.43 keV (15.28%) from ^{214}Bi. The activity concentration of ^{232}Th was determined using the 583.187 keV (85.0%), the 2614.511 keV (99.79%) from ^{208}Tl and 911.12 keV (25.8%) from ^{228}Ac. The value written inside the parentheses following gamma-ray energy indicates the absolute emission probability of the γ-decay. In order to obtain a good statistics, gamma spectra of the soil samples should be measured in long enough time. In our case, each sample was measured for about 72000 seconds. Measurements with an empty sample container under the same measuring condition of the sample containers filled with the sample materials were also carried out to determine the ambient background in the laboratory site.

The activity concentrations of the investigated samples were determined by relative method using the standard samples made from the IAEA-RGU-1, IAEA-RGTh-1 and IAEA-RGK-1 reference materials. These materials were obtained from the International Atomic Energy Agency (IAEA), for which the activity concentrations of the interested radionuclides are known. The densities of the reference and investigated samples are similar. Furthermore, the geometry of the containers of the investigated samples was identical to that of the reference materials (IAEA-RGU-1, IAEA-RGTh-1 and IAEA-RGK-1). By applying the relative method for the activity concentration determination, many corrections can be avoided.

III. RESULTS AND DISCUSSIONS

3.1 Calculation of the activity concentration

The following equation has been used for calculating the activity concentration of ^{40}K, ^{226}Ra and ^{232}Th radionuclides in the samples:

$$A_s = \frac{C_s}{C_{ref}} \times \frac{M_s}{M_{ref}} \times \frac{G_s}{G_{ref}} \times \frac{1-e^{-0.683\, t_S/T_{1/2,i}}}{1-e^{-0.693\, t_{ref}/T_{1/2,i}}} \times A_{ref} \qquad (1)$$

where:

A_s and A_{ref} are the activity concentrations of the cement and reference samples in Bq.kg^{-1};

C_s and C_{ref} are the count rates obtained under the corresponding peak of cement sample and reference samples in counts.s^{-1};

M_s and M_{ref} are masses of the cement and reference samples in kg;

G_s and G_{ref} are the self-absorption correction factors of the cement and reference samples;

t_s and t_{ref} are the measuring live times for the cement and reference samples (s);

$T_{1/2,i}$ is the half-life of the radionuclide.

The self-absorption correction factors for analyzing and reference samples were determined experimentally by transmission method as suggested in detail in reference reported by Cutshall et.al.[7]. Two point gamma-ray emitter sources of ^{226}Ra and ^{60}Co were used to perform transmission measurements in order to obtain the self-absorption correction factors for the analyzing and reference samples. The following gamma-rays were used for in these measurements: 241.9 keV, 295.2 keV, 351.9 keV, 609.3 keV, 1274.5 keV and 2204.5

keV emitted by ^{226}Ra; 1173.2 keV and 1332.5 keV emitted by ^{60}Co. We exactly followed the procedure written in the reference and the self-absorption correction factors were obtained at the gamma-ray energies listed above. The self-absorption correction curves for the analyzing and reference samples were obtained. The self-absorption correction factors at a specific gamma-ray energy of the analyzing and reference samples can be easily obtained by interpolation method.

The mean activity concentrations together with standard deviations in Bq.kg^{-1} of the natural radionuclides of ^{226}Ra, ^{232}Th and ^{40}K measured of all investigated samples of the building materials of Lao PDR were listed in Table 1. It is noted that each sample was divided by 5 sub-samples for measurement and the mean value of the activity concentration of the sample was determined by averaging the activity concentration values of these 5 sub-samples. The corresponding world population-weighted average values in soil are listed in the last row for comparison.

3.2 Activity concentration of the soil samples

It can be seen in this table, the activity concentrations of the natural radionuclides range from 11.43±0.5 to 30.98±2.19 for ^{226}Ra, from 7.59±0.49 to 44.53±1.21 for ^{232}Th and from 40.96±6.98 to 581.71±16.98 for ^{40}K. The mean activity concentrations are 22.81 Bq.kg^{-1} for ^{226}Ra, 27.23 Bq.kg^{-1} for ^{232}Th and 235.5 Bq.kg^{-1} for ^{40}K. These average values are lower than the corresponding world population-weighted average values in soil reported in UNSCEAR-2000 report[8] which are listed in the last row of the table, namely 32 Bq.kg^{-1} for ^{226}Ra, 45 Bq.kg^{-1} for ^{232}Th and 420 Bq.kg^{-1} for ^{40}K. However, the activity concentrations of ^{40}K of Ban Nam Ang (581.71±16.98 Bq.kg^{-1}) and Ban Keun (468.69±10.85 Bq.kg^{-1}) are a bit higher than the world population-weighted average value (420 Bq.kg^{-1}).

3.3 Activity concentration of the cement samples

According to the values listed in Table 3.1, we are able to draw the following remarks for the cement samples. The ^{226}Ra activity concentrations in the investigated cements were found to vary from 24.83±1.18 to 54.39± 5.90 with the mean of 37.76±3.16 Bq.kg^{-1}. Among 8 investigated cement samples, 6 values of the activity concentration of ^{226}Ra are higher than the world population-weighted average of 32 Bq.kg^{-1} for ^{226}Ra activity concentration in soil. For the case of ^{232}Th, the activity concentrations in the investigated cements were found to vary from 6.63±1.59 to 21.17±0.48 with the mean of 13.77±1.04 Bq.kg^{-1}. Furthermore, the ^{40}K activity concentrations in the investigated cements were in the range from 43.28±7.68 to 168.70±3.34 with the mean of 116.07±7.34 Bq.kg^{-1}. All values of the activity concentrations of ^{232}Th and ^{40}K of all investigated cement samples are less than the world population-weighted average of 45 Bq.kg^{-1} for ^{232}Th and 420 Bq.kg^{-1} for ^{40}K in soil. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K of Lao cements vary from one type to another. These variations may depend on the geochemical characteristics of the regions where the raw materials for cement production were taken.

3.4 Activity concentration of the sand samples

From the Table 3.1, the activity concentrations of the sand samples are in the range from 12.46±0.52 to 22.90±0.29 with the mean of 17.08±1.12 Bq.kg^{-1} for ^{226}Ra. The activity concentrations of ^{232}Th range from 17.61±1.17 to 31.72±0.50 with the mean value of 23.14±0.72 Bq.kg^{-1}. All values of the activity concentration of the sand samples are lower the world population-weighted average in soil of 32 Bq.kg^{-1} for ^{226}Ra and 45 Bq.kg^{-1} for ^{232}Th. The activity concentrations of ^{40}K of the sand samples however are higher than the world population-weighted average in soil of 420 Bq.kg^{-1} and they range from 414.58±19.25 to 492.99±19.56 with the mean value of 463.31±12.28 Bq.kg^{-1}.

3.5 Estimation of radiation hazard indicators

Natural occurring radionuclides in the building materials used for dwelling construction produce an external radiation field. Human beings are exposed to this radiation field continuously. Therefore, estimation of radiation hazard due to the use of the building materials for construction is an important task. By using the obtained activity concentrations of ^{226}Ra and ^{232}Th and ^{40}K radionuclides of the investigated building material samples, the radiological hazard indices of all samples were calculated including absorbed dose rates (D), radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}) and representative level index (I_{γ}). Table 3.2 presents the average values of these quantities of all investigated Lao building material samples.

Table 3.1 Mean activity concentrations of the investigated samples of the Lao building materials.

Sample	Location	^{226}Ra (Bq.kg^{-1})	^{232}Th (Bq.kg^{-1})	^{40}K (Bq.kg^{-1})
Cement				
1V, Portland	VangVieng Cement plant.II	39.88±2.19	10.10±0.93	156.92±10.94
2V, Mixed		38.83±4.91	9.67±1.57	126.99±22.07
1VT, Portland	BMC Cement factory Golden Elephant-Laos	33.57±2.14	17.37±0.92	131.93±4.60
2VT, Mixed		30.32±1.16	21.17±0.48	168.70±3.34
1SV, Portland	Lao Cement Industry (Golden Elephant)	54.39±5.90	7.91±0.97	45.22±1.41
2SV, Mixed		51.74±4.64	6.63±1.59	43.28±7.68
1K, Portland	Lao Cement Industry.co.,LTD	28.55±3.13	20.73±0.61	141.83±3.94
2K, Mixed		24.83±1.18	16.61±1.26	113.71±4.71
Average		37.76±3.16	13.77±1.04	116.07±7.34
Sand				
SP1	Mekong river in Vientiane	22.90±0.29	31.72±0.50	484.70±6.55
SP2	Mekong river in Vientiane	16.84±0.99	25.23±0.40	484.95±11.07
SP3	Mekong river in Vientiane	18.14±1.53	22.42±0.70	465.68±7.54
SP4	Mekong river in Vientiane	18.36±2.56	23.77±0.96	492.99±19.56
SP5	Mekong river in Vientiane	13.80±0.74	17.61±1.17	414.58±19.25
SP6	Mekong river in Vientiane	12.46±0.52	18.06±0.58	436.96±9.72
Average		17.08±1.12	23.14±0.72	463.31±12.28
Soil				
1P	Ban Dong	11.43±0.5	7.59±0.49	40.96±6.98
2P	Ban PhaThao	25.77±1.92	29.50±0.43	137.15±2.47
3P	Ban Nam Ang	29.51±1.67	44.56±2.59	581.71±16.98
4P	Ban Nanokkhoum	20.55±1.17	14.58±0.44	81.91±11.12
5P	Ban Phonmouang	15.38±0.78	15.00±1.22	68.73±4.49
6P	Ban NaKang	12.89±1.37	7.24±0.04	99.79±4.29
7P	Ban Naxanglek	28.69±0.74	37.99±0.39	88.32±1.60
8P	Ban Keun	30.98±2.19	44.53±1.21	468.69±10.85
9P	Ban Hatnoi	27.94±0.72	39.73±1.33	415.29±8.19
10P	Ban Boungphao	24.94±1.12	31.53±0.48	372.35±8.13
Average		22.81±1.22	27.22±0.86	235.49±7.51
World population-weighted average in soil[8]		33	45	420

The absorbed dose rate D in air at 1m above the ground surface can be calculated by using the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and the conversion factors 0.042 nGy.h^{-1} for ^{40}K, 0.462 nGy.h^{-1} for ^{226}Ra and 0.604 nGy.h^{-1} for ^{232}Th taken from UNSCEAR-2000 report[8].

$$D(nGy.h^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_{K} \quad (2)$$

where D is the absorbed dose rate in nGy.h^{-1} and A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq.kg^{-1} of the measured samples.

It can be seen from Table 3.2 that the calculated absorbed dose rates in the cement samples are ranged between 26.28±0.96 and 33.88±0.63 with the mean value of 30.64±1.66 nGy.h^{-1}. For the soil samples, the absorbed dose rates are in between 11.59±0.48 and 64.98±1.88 with the mean of 36.87±0.89 nGy.h^{-1}. For the sand samples, the absorbed dose rates are in between 34.42±1.13 and 50.10±0.43 with the mean of 41.32±0.88 nGy.h^{-1}. Therefore, the average values of the absorbed dose rates of the investigated samples are lower than the world average population-weighted value of absorbed dose rate in air outdoors from terrestrial gamma radiation[8] of 60 nGy.h^{-1}.

Radium equivalent activity is an index that has been introduced to compare the activity concentration of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K radionuclides and to represent their activity concentrations by a single quantity, which takes into account the radiation hazards associated with them. It is calculated as the weighted sum of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations, based on the assumption that 10 Bq.kg^{-1} of ^{226}Ra, 7 Bq.kg^{-1} of ^{232}Th and 130 Bq.kg^{-1} of ^{40}K produce the same gamma dose rate. The formula to calculate it is as follows[9,10]:

$$Ra_{eq}(Bq.kg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_{K} \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq.kg^{-1}, respectively. According to Table 2, the values Ra_{eq} of the cement samples range from 94.55±7.85 to 190.49±2.90 with the average of 146.84±7.07 Bq.kg^{-1}. For the soil samples, the values of this quantity are in the range between 53.82±5.44 and 541.15±13.69 with the average of 243.06±6.18 Bq.kg^{-1}. For the sand samples, its values are between 358.21±14.93 and 441.48±5.1 Bq.kg^{-1}.

Table 3.2 The average values of absorbed dose rate, radium equivalent activity, external hazard index, internal hazard index and gamma-index of all investigated building material samples.

Sample	Absorbed dose rate ($nGy.h^{-1}$)	Ra_{eq} ($Bq.kg^{-1}$)	H_{ex}	H_{in}	I_γ
Cement					
1V, Portland	31.12±1.25	175.15±8.80	0.179	0.287	0.236
2V, Mixed	29.11±2.63	150.44±17.83	0.169	0.274	0.22
1VT, Portland	31.54±1.15	160.00±4.34	0.185	0.276	0.243
2VT, Mixed	33.88±0.63	190.49±2.90	0.199	0.281	0.263
1SV, Portland	31.81±2.79	100.52±6.16	0.187	0.334	0.236
2SV, Mixed	29.73±2.37	94.55±7.85	0.174	0.314	0.22
1K, Portland	31.67±1.50	167.40±4.45	0.187	0.264	0.246
2K, Mixed	26.28±0.96	136.14±4.22	0.155	0.222	0.204
Average	30.64±1.66	146.84±7.07	0.179	0.281	0.233
Sand					
SP1	50.10±0.43	441.48±5.1	0.285	0.347	0.396
SP2	43.39±0.70	426.33±8.60	0.244	0.289	0.344
SP3	41.49±0.88	408.77±6.09	0.232	0.281	0.328
SP4	43.54±1.55	431.95±15.34	0.244	0.294	0.344
SP5	34.42±1.13	358.21±14.93	0.191	0.229	0.272
SP6	35.00±0.61	374.70±7.56	0.194	0.228	0.277
Average	41.32±0.88	406.91±9.60	0.232	0.278	0.327
Soil					
1P	11.59±0.48	53.82±5.44	0.069	0.100	0.09
2P	35.48±0.93	173.56±2.77	0.212	0.282	0.279
3P	64.98±1.88	541.15±13.69	0.373	0.452	0.515
4P	21.74±0.76	104.47±8.66	0.129	0.184	0.169
5P	19.05±0.84	89.75±3.95	0.114	0.155	0.149
6P	14.52±0.66	100.06±3.58	0.084	0.118	0.112
7P	39.91±0.42	151.02±1.54	0.243	0.320	0.315
8P	60.89±1.33	455.55±8.81	0.353	0.473	0.482
9P	54.35±0.94	404.53±6.63	0.315	0.391	0.43
10P	46.21±0.60	356.74±6.40	0.267	0.334	0.365
Average	36.87±0.89	243.06±6.18	0.216	0.277	0.291
Worldwide recommended values in soil[8]	55	<370	<1	<1	<1

According to UNSCEAR-2000 report[8], the recommended permissible of the radium equivalent activity is 370 $Bq{\cdot}kg^{-1}$ for keeping the external dose below 1.5 $mSv.y^{-1}$. For the cement, all values are lower than this limit but for the sand samples, three values of 3P, 8P and 9P samples taken in Ban Nam Ang, Ban Keun and Ban Hatnoi are higher. Especially, Ra_{eq} of all sand samples are higher than this recommended value. Therefore, further investigation is required to confirm these results.

The external hazard index H_{ex} and internal hazard index H_{in} are used as radiological indicators to estimate the radiological implications of the use of the building materials. The external hazard index due to emitted gamma-rays and the internal hazard index due to ^{222}Rn and its radioactive progeny are calculated by the following formulae[11]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

where, A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in $Bq.kg^{-1}$, respectively.

The gamma index Iγ proposed by the European Commission[12] was calculated for all investigated samples in order to check if the safety requirements for Lao building materials are fulfilled using the following formula:

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (6)$$

The values of these hazard indices must be less than unity in order for the radiation hazard to be negligible. According to Table 2, none of the values of these indices exceeds this limitation.

IV. CONCLUSION

This is the first investigation of natural radioactivity of the building materials in Lao PDR. In this study, the activity concentrations of natural radionuclides of ^{226}Ra, ^{232}Th and ^{40}K in the cements produced by the

famous local cement production companies, the soil and sand samples taken from different locations in Vientiane capital were investigated by the help of the low background and high resolution gamma-ray spectrometer using HPGe detector. The activity concentrations of the natural radionuclides are in the investigated samples are as follows.

The mean activity concentrations of ^{226}Ra ranged from 24.83±1.18 to 54.39±5.90 with the average value of 37.76±3.16 Bq.kg^{-1} in the cement samples, from 11.43±0.5 to 30.98±2.19 with the average value of 22.81±1.22 Bq.kg^{-1} in the soil samples and from 12.46±0.52 to 22.90±0.29 with the average value of 17.08±1.12 Bq.kg^{-1} in the sand samples.

The mean activity concentrations of ^{232}Th are in between 6.63±1.59 to 21.17±0.48 with the average value of 13.77±1.04 Bq.kg^{-1} in the cement samples, between 7.24±0.04 and 44.56±2.59 with the average value of 27.22±0.86 Bq.kg^{-1} in the soil samples and between 17.61±1.17 to 31.72±0.50 with the average value of 23.14±0.72 Bq.kg^{-1} in the sand samples.

The mean activity concentrations of ^{40}K are between 43.28±7.68 to 168.70±3.34 with the average value of 116.07±7.34 Bq.kg^{-1} in the cement samples, between 40.96±6.98 and 581.71±16.98 with the average value of 235.49±7.51 Bq.kg^{-1} in the soil samples and between 414.58±19.25 to 492.99±19.56 with the average value of 463.31±12.28 Bq.kg^{-1} in the sand samples. The average activity concentrations of of ^{226}Ra, ^{232}Th and ^{40}K of Lao cement, soil and sand samples investigated by us are comparable to the world population-weighted averages in soil (32, 45 and 420 Bq.kg^{-1}) written in the UNSCEAR-2000 report[8].

Using the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K of Lao building materials, the absorbed dose rate in air, radium equivalent activity, external hazard index, internal hazard index and representative gamma index of the investigated samples were estimated in order to assess the radiological hazard from Lao building materials. It can be seen from the obtained results of these quantities that most of the values of these quantities were found to be less than the worldwide average values. It means that these building materials are safe to use for dwelling constructions. The more detailed investigation on this subject will be carried out in near future.

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