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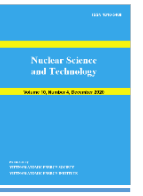

Deposition velocities of some natural radionuclides from the atmosphere at Ninh Thuan and Dong Nai of Vietnam

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Abstract: The deposition velocities of Be-7, K-40, Th-232, U-238 and Pb-210 radionuclides from the atmosphere at Ninh Thuan and Dong Nai monitoring stations of Vietnam were investigated. The deposition velocity was calculated based on it's specific radioactivity in aerosols and deposition density in fallout samples. The data of the deposition velocities of radionuclides from the atmosphere are needed as input data for the models to simulate atmospheric radioactive dispersion and assess the public dose around nuclear facilities. The radioactivity of Be-7, K-40, Th-232, U-238 and Pb-210 nuclides in aerosols and fallout samples were analyzed by using a low level background gamma spectrometer equipped with HPGe detector of high resolution. The results show that the deposition velocities of Be-7, K-40, Th-232, U-238 and Pb-210 nuclides from the air are in ranges of 0.04÷1.71; 1.84÷27.46; 1.46÷23.63; 0.80÷26.13 and 0.06÷1.53 (cm/s), with average values of 0.55; 13.81; 8.22; 8.12 and 0.58 (cm/s), respectively. The deposition velocities of the radionuclides in the survey areas are comparable with those found in tropical and subtropical regions and these results could be served as the database of the World radioactive transport parameters.

Keywords: *Deposition velocity, natural radioactivity, deposition density, aerosol, fallout.*

I. INTRODUCTION

Research and monitoring of environmental radioactivity is a field of science which began and developed along with the use of nuclear energy in various fields of human activity. The initial works on environmental radioactivity research were carried out during the 20s and 30s of the twentieth century. These works were mainly related to the survey for the distribution of natural radionuclides and assessment of the impacts of ionizing radiation on living organisms in regions with high levels of U, Ra, Th and their progenies. Studies of environmental radioactivity were especially important and necessary after the nuclear weapons tests were conducted that caused a lot of artificial radionuclides to disperse globally.

Monitoring of the environmental radioactivity is necessary in Vietnam because it would create a database of the radiation background to assess radiation dose to the population during the industrialization process of the country. Besides, radiation monitoring is essential in Vietnam by now as it needs to timely detect possible nuclear incident that could be happened at nuclear power plants currently operating in southern China and Taiwan that would affect Vietnam due to the both

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Northeast and Southeast monsoons. In recent years, radioactivity in the atmosphere has been constantly monitoring by radiological monitoring stations around the world. In Vietnam, radiological monitoring stations were also set up in numerous provinces to monitor for the radiation background in the air. These stations are under the control of the Institute of Nuclear Science and Technology (Hanoi) and the Nuclear Research Institute (Dalat) [1].

From the atmosphere, radionuclides fall to the ground and the ocean. They are essentially stored and accumulated long term in these environments until complete decay. From the soil, radioactive substances cause external radiation and penetrate living organisms through the food chain causing internal radiation. Therefore, observing the radionuclides due to the deposition is very important to establish a relationship between the source and the effective radiation dose on humans [1].

The objective of this research is to obtain the transport parameters of some radionuclides in the air to create the input data for a model to simulate the atmospheric dispersion of the radioactive materials and to assess the public dose around nuclear facilities.

II. CONTENT

A. Object and method

In this research, aerosols and fallout samples were collected monthly at the Center for Hydro-Meteorological Forecasting in Ninh Thuan province (11°34'51"N, 108°58'25"E) and Dong Nai province (10°50'42"N, 107°14'09"E).

Samples of aerosols were collected on 604LB Cellulose filters by using a high-volume air sampler HV3000 with a flow rate of 100 m^3/h. The sampling point was 1.5 m above the ground. The total sampling volume was about 40000 m^3 per sample; the collection time is one month. Before collecting, filter was dried at 60°C in a vacuum drying oven to constant weight (drying time was >24 hours); then it was removed and placed in a desiccator for about 3-4 hours; balance to determine the weight of blank filter. After the filter with aerosol was collected and dried under the same conditions as that for blank filters, the sample was weighed to determine the amount of the dust attained on the filter [2]. The aerosol deposition density was also monitored at the same location by using stainless steel trays with an area of 1.0 m^2 each [3]. The trays were installed at a height of 1.5 m above the ground.

The analytical methods applied to quantify activities of the radionuclides in the samples were those which were in accordance to the procedures established by the Laboratory of the Center for Environment Research and Monitoring, Nuclear Research Institute (Da Lat). The Laboratory has been evaluated and accredited to be conformable to the ISO/IEC 17025:2017 with the national code of VILAS 525 [2,3].

In this study, the measurements for activities of the radionuclides in aerosols and fallout samples were performed for 24 hours to obtain sufficient uncertainty. The samples were measured on a low background gamma spectrometer equipped with a HPGe detector model GX3019 (CANBERRA) having a relative efficiency of 30%, and an energy resolution of 1.90 keV at the 1333 keV and a peak-to-Compton ratio of 56:1. Computer software MAESTRO-32 was used to process obtained spectrums.

Quality control programme for the measurements was conducted by using the

IAEA-CU-2006-03 standard reference materials (SRM) sample. The counting time for each measurement was around 90,000s in order to obtain good counting statistics.

The activity of Be-7 was quantified based on the photopeak of 477.59 keV (10.358%), for Pb-210 it was based on the peak of 46.5 keV (4.058%). The activity of K-40 was quantified based on it's photopeak of 1460.83 keV (10.671%). The activities of Th-232 and U-238 were quantified based on photo peaks of their progenies Ac-228 at 911.205 keV (26.607%), 338.32 keV (11.254%) and Th-234 at 63.0 keV (3.81%), respectively.

The deposition velocity of radionuclides from the atmosphere was calculated by the formula [4]:

$$V(m/s) = \frac{A_{fallout}}{A_{aerosol}} \quad (1)$$

Where $A_{fallout}$ is the deposition density in a fallout sample, $Bq/m^2/s$;

$A_{aerosol}$ is the specific radioactivity of concerned radionuclide in the aerosol sample, Bq/m^3;

V is the deposition velocity of radionuclide from the atmosphere, m/s.

B. Result

1. Natural radioactivity from the atmosphere

Average values and ranges of radioactivity of Be-7, K-40, Th-232, U-238 and Pb-210 radionuclides detected in the aerosols at Ninh Thuan and Dong Nai monitoring stations are presented in Tables I and II.

Table I. Average values and ranges of radioactivity of Be-7, K-40, Th-232, U-238 and Pb-210 nuclides detected in aerosols at Ninh Thuan (from January 2017 to December 2018) and Dong Nai monitoring stations (from November 2018 to July 2019).

Radionuclide		**Ninh Thuan monitoring station**	**Dong Nai monitoring station**
		µBq/m³	**µBq/m³**
Be-7	Average (n)	1666 (24)	4384 (9)
	Range	607 ÷ 3831	2335 ÷ 7000
K-40	Average (n)	32.7 (24)	73.7 (9)
	Range	11.4 ÷ 57.2	10.8 ÷ 151.7
Th-232	Average (n)	2.89 (24)	5.76 (9)
	Range	1.05 ÷ 5.21	0.60 ÷ 9.72
U-238	Average (n)	3.01 (24)	5.04 (9)
	Range	0.68 ÷ 5.86	1.20 ÷ 9.78
Pb-210	Average (n)	358 (24)	703 (9)
	Range	172 ÷ 780	418 ÷ 925

Note: n is number of measurement

Table II. Average values and ranges of deposition density of Be-7, K-40, Th-232, U-238 and Pb-210 nuclides detected in fallout samples at Ninh Thuan (from January 2017 to December 2018) and Dong Nai monitoring stations (from November 2018 to July 2019).

Radionuclide		***Ninh Thuan monitoring station***	***Dong Nai monitoring station***
		Bq/m²/month	***Bq/m²/month***
Be-7	Average (n)	17.79 (24)	34.38 (9)
	Range	2.55 ÷ 36.98	1.23 ÷ 100.20
K-40	Average (n)	10.47 (24)	3.87 (9)
	Range	2.82 ÷ 18.63	0.49 ÷ 7.71
Th-232	Average (n)	0.51 (24)	0.16 (9)
	Range	0.14 ÷ 1.19	0.05 ÷ 0.23
U-238	Average (n)	0.49 (24)	0.25 (9)
	Range	0.08 ÷ 1.19	0.06 ÷ 0.60
Pb-210	Average (n)	4.62 (24)	6.47 (9)
	Range	1.16 ÷ 12.42	0.61 ÷ 16.51

Note: n is number of measurement

2. Deposition velocity of radionuclide from the atmosphere

From the data of specific radioactivity and deposition densities of radionuclides obtained at Ninh Thuan and Dong Nai monitoring stations (Table I and II), the deposition velocities of the radionuclides were calculated (Eq.1) and the results were presented in Tables III and IV. The temporal variation of the deposition velocities of radionuclides were shown in Figures 1, 2, 3 and 4.

Table III. Deposition velocities of Be-7, K-40, Th-232, U-238 and Pb-210 radionuclides from the atmosphere at Ninh Thuan monitoring station (from January 2017 to December 2018).

Time	**Be-7**	**K-40**	**Th-232**	**U-238**	**Pb-210**
	cm/s	**cm/s**	**cm/s**	**cm/s**	**cm/s**
01/17	0.41 ± 0.05	14.23 ± 3.12	15.93 ±11.63	26.13 ± 8.99	0.81 ± 0.14
02/17	0.17 ± 0.01	14.9 ± 3.31	23.63 ±11.13	25.55 ± 6.85	0.35 ± 0.07
03/17	0.07 ± 0.03	13.2 ± 4.52	4.63 ± 2.94	3.04 ± 1.49	0.18 ± 0.08
04/17	0.20 ± 0.09	10.22 ± 3.45	5.73 ± 5.04	7.16 ± 4.97	0.26 ± 0.08
05/17	1.71 ± 0.22	24.14 ± 5.47	5.07 ± 2.10	4.38 ± 1.68	1.01 ± 0.20
06/17	0.26 ± 0.07	11.63 ± 3.11	3.16 ± 1.60	4.51 ± 2.16	0.39 ± 0.14
07/17	0.53 ± 0.14	12.94 ± 3.16	4.13 ± 2.05	2.95 ± 1.05	0.48 ± 0.12
08/17	1.22 ± 0.17	1.84 ± 0.39	1.46 ± 0.53	1.94 ± 0.41	0.71 ± 0.08
09/17	1.18 ± 0.30	16.53 ± 5.11	3.63 ± 1.70	14.91 ± 5.21	0.87 ± 0.19
10/17	1.00 ± 0.14	26.51 ± 3.22	11.43 ± 3.46	23.65 ± 7.80	0.52 ± 0.06

Time	Be-7	K-40	Th-232	U-238	Pb-210
	cm/s	cm/s	cm/s	cm/s	cm/s
11/17	1.20 ± 0.11	27.46 ± 6.11	12.62 ± 3.90	4.73 ± 1.16	1.53 ± 0.18
12/17	0.43 ± 0.05	10.74 ± 2.66	8.81 ± 2.82	7.83 ± 3.08	0.71 ± 0.11
01/18	0.13 ± 0.03	12.54 ± 2.78	18.17 ± 7.95	5.11 ± 1.67	0.92 ± 0.14
02/18	0.04 ± 0.02	13.89 ± 2.85	1.95 ± 0.83	1.91 ± 0.65	0.06 ± 0.01
03/18	0.05 ± 0.01	8.21 ± 1.74	1.90 ± 0.94	0.80 ± 0.24	0.16 ± 0.03
04/18	0.18 ± 0.05	18.35 ± 4.46	9.10 ± 2.88	16.89 ± 6.25	0.60 ± 0.10
05/18	0.46 ± 0.11	9.21 ± 2.03	18.72 ± 6.06	9.66 ± 2.43	0.44 ± 0.10
06/18	0.35 ± 0.06	8.46 ± 1.65	4.10 ± 1.48	5.73 ± 1.25	0.36 ± 0.06
07/18	0.95 ± 0.12	17.07 ± 3.77	5.67 ± 2.12	4.57 ± 1.00	1.01 ± 0.17
08/18	0.34 ± 0.08	5.57 ± 1.39	4.39 ± 1.47	2.96 ± 0.65	0.27 ± 0.06
09/18	0.79 ± 0.07	6.37 ± 1.19	6.89 ± 2.33	3.45 ± 0.91	0.40 ± 0.08
10/18	0.26 ± 0.04	13.64 ± 4.76	14.91 ± 7.28	3.75 ± 1.36	0.20 ± 0.09
11/18	0.76 ± 0.16	21.37 ± 6.35	2.07 ± 0.96	4.07 ± 1.39	0.82 ± 0.18
12/18	0.57 ± 0.09	12.44 ± 2.79	9.16 ± 3.54	9.28 ± 2.54	0.85 ± 0.22
Min - Max	0.04 ÷ 1.71	1.84 ÷ 27.46	1.46 ÷ 23.63	0.80 ÷ 26.13	0.06 ÷ 1.53
Mean ± SD	0.55 ± 0.45	13.81 ± 6.36	8.22 ± 6.18	8.12 ± 7.60	0.58 ± 0.35
Geomean	0.37	12.17	6.19	5.63	0.47

Table IV. Deposition velocities of Be-7, K-40, Th-232, U-238 and Pb-210 radionuclides from the atmosphere at Dong Nai station (from November 2018 to July 2019).

Time	Be-7	K-40	Th-232	U-238	Pb-210
	cm/s	cm/s	cm/s	cm/s	cm/s
11/18	0.10 ± 0.02	7.55 ± 2.40	13.84 ± 3.75	9.07 ± 1.53	0.16 ± 0.04
12/18	0.35 ± 0.08	1.48 ± 0.35	0.84 ± 0.25	5.81 ± 0.95	0.34 ± 0.06
01/19	0.04 ± 0.01	4.24 ± 1.34	0.28 ± 0.14	0.83 ± 0.18	0.03 ± 0.01
02/19	0.02 ± 0.01	2.47 ± 0.96	1.04 ± 0.33	5.37 ± 1.83	0.22 ± 0.08
03/19	0.08 ± 0.01	3.17 ± 1.10	2.33 ± 0.99	0.77 ± 0.18	0.13 ± 0.06
04/19	0.02 ± 0.01	0.83 ± 0.32	0.74 ± 0.27	0.56 ± 0.47	0.11 ± 0.04
05/19	0.62 ± 0.06	0.27 ± 0.08	0.78 ± 0.23	1.89 ± 0.46	0.55 ± 0.16
06/19	1.41 ± 0.29	3.50 ± 1.13	1.40 ± 0.53	1.30 ± 0.29	1.04 ± 0.26
07/19	0.65 ± 0.06	0.28 ± 0.07	0.52 ± 0.16	1.48 ± 0.26	0.74 ± 0.18
Min - Max	0.02 ÷ 1.41	0.27 ÷ 7.55	0.28 ÷ 13.84	0.56 ÷ 9.07	0.03 ÷ 1.04
Mean ± SD	0.37 ± 0.47	2.64 ± 2.33	2.42 ± 4.32	3.01 ± 3.01	0.37 ± 0.34
Geomean	0.14	1.63	1.14	1.93	0.23

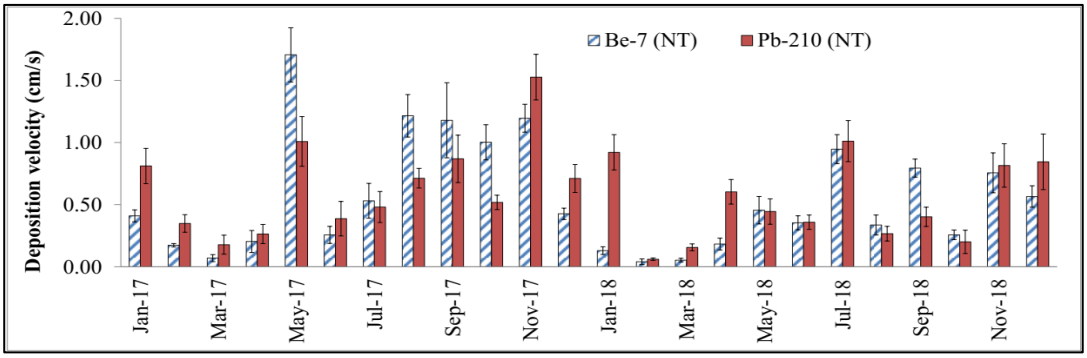

Fig. 1. Deposition velocities of Be-7 and Pb-210 at Ninh Thuan.

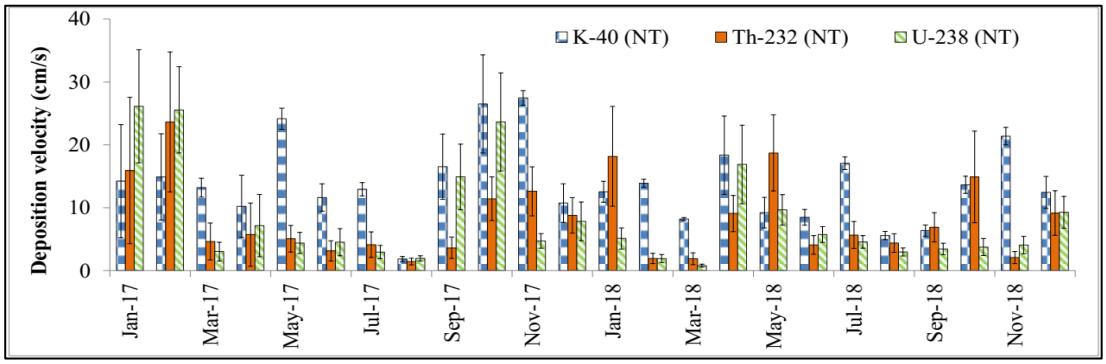

Fig. 2. Deposition velocities of K-40, Th-232 and U-238 at Ninh Thuan.

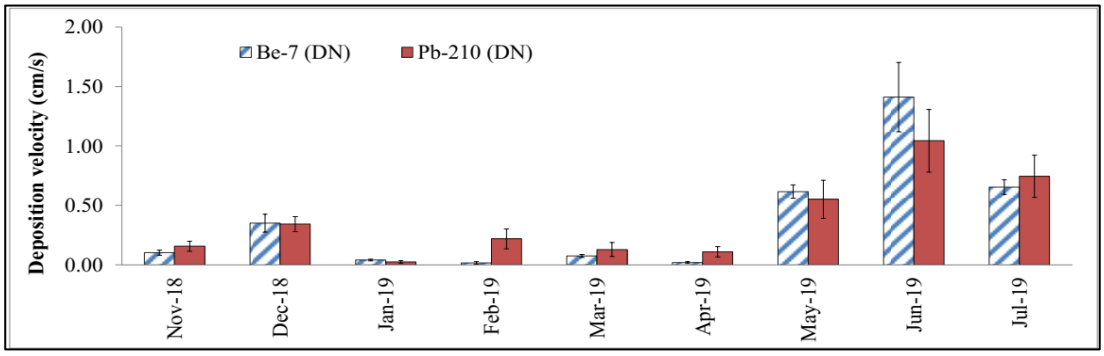

Fig. 3. Deposition velocities of Be-7 and Pb-210 at Dong Nai.

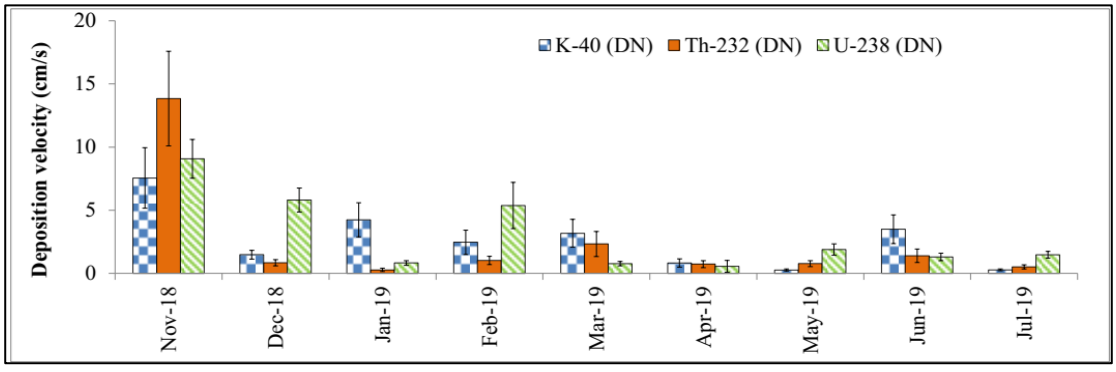

Fig. 4. Deposition velocities of K-40, Th-232 and U-238 at Dong Nai.

Frequency distribution of the deposition velocity for Be-7 and Pb-210 from the atmosphere at Ninh Thuan and Dong Nai were shown in Figure 5 and 6.

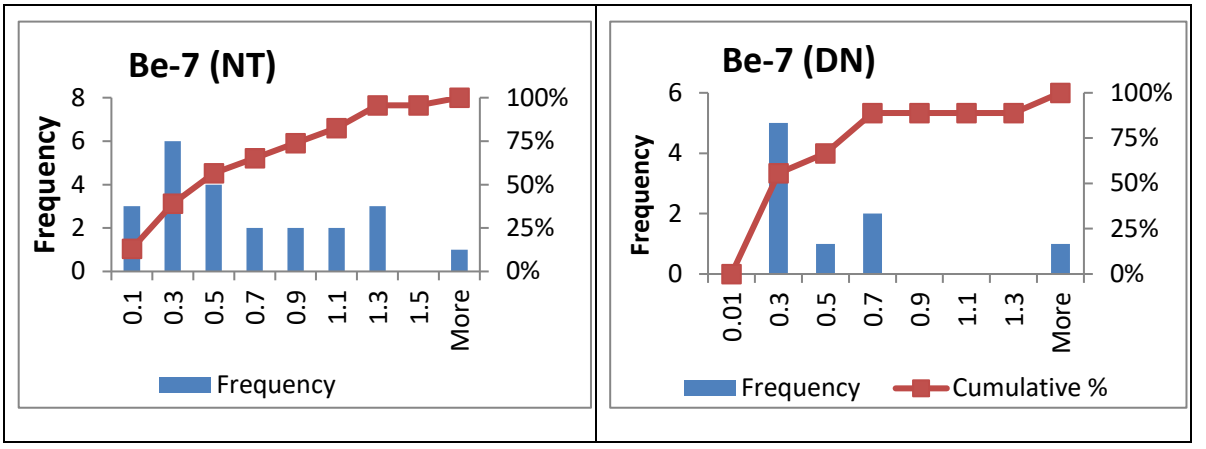

Fig. 5. Frequency distribution of the deposition velocity for Be-7 in the air at Ninh Thuan and Dong Nai.

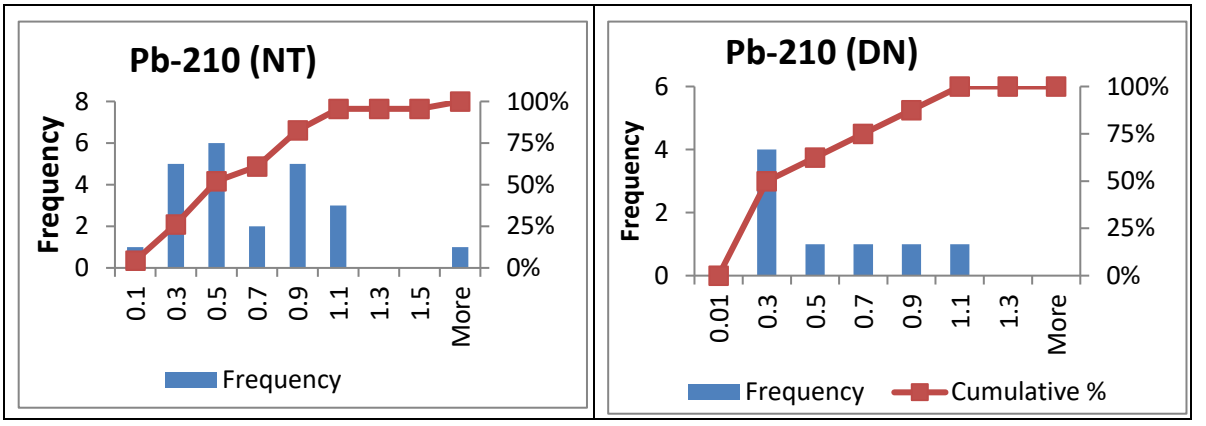

Fig. 6. Frequency distribution of the deposition velocity for Pb-210 in the air at Ninh Thuan and Dong Nai.

C. Discussion

Experimental data show that the deposition velocities of radionuclides Be-7, K-40, Th-232, U-238 and Pb-210 in the air at Ninh Thuan are 0.04 ÷ 1.71; 1.48 ÷ 27.46; 1.46 ÷ 23.63; 0.80 ÷ 26.13 and 0.06 ÷ 1.53cm/s with the average values of 0.55; 13.81; 8.22; 8.12 and 0.58 cm/s, and at Dong Nai are 0.02 ÷ 1.41; 0.27 ÷ 7.55; 0.28 ÷ 13.84; 0.56 ÷ 9.07 and 0.03 ÷ 1.04 with the average values of 0.37; 2.64; 2.42; 3.01 and 0.37 cm/s, respectively.

Deposition velocities of Be-7 and Pb-210 tend to be similar to each other: it was higher in the rainy season (from May to October), but it was lower in the dry season (from November to April of the following year). The deposition velocities of the radionuclides from the atmosphere in the rainy season were about two times higher than that in the dry season (Figs. 1 and 3).

As seen from Table III and IV the deposition velocities of Be-7 and Pb-210 were from 15 to 25 times lower than that of K-40, Th-232, and U-238. Be-7 is formed from the

nuclear interactions between galactic cosmic rays and solar protons with atmospheric nitrogen and oxygen nuclei. Pb-210 is one of the progenies of ^{222}Rn which formed from the U-238 radioactive series. Because ^{222}Rn is an inert gas so it could be able to emanate from the ground into the atmosphere where it decays to form Pb-210. In the atmosphere, Be-7 and Pb-210 are attached to fine aerosols which are easily soluble in water, and therefore the rain has the same effect in washing out both of these radionuclides from the atmosphere. Because Be-7 and Pb-210 are all associated with fine aerosols, while K-40, Th-232 and U-238 in the atmosphere were originated from the dust and they mainly associated with large aerosols. This made the deposition velocities of Be-7 and Pb-210 to be from 15 to 25 times lower than those of K-40, Th-232 and U-238 as mentioned earlier.

Usually K-40, Th-232 and U-238 deposit from the atmosphere with their highest velocities during the months of low rainfall. In contrast, during the months of high rainfall they deposit with the lowest velocities the ratios between the highest and lowest deposition velocities of K-40, Th-232 and U-238 range from 5.09 to 49.18. The deposition velocities of these radionuclides are also high at the beginning of the rainy season indicating that the aerosol cleaning process in the atmosphere is more efficient during the first rain.

The deposition velocities determined for Be-7, K-40, Th-232, U-238 and Pb-210 from the atmosphere at Ninh Thuan location in this study are similar to those that observed in [4]. Also it was revealed that the deposition velocities of the natural radionuclides from the atmosphere found in this study are comparable with those found in other tropical and subtropical regions [4-6] as shown in Table V.

Table V. A comparison of the deposition velocities of radionuclides from the atmosphere in different tropical and subtropical regions.

Location	Deposition velocity, cm/s		Reference
	Be-7	Pb-210	
Toki, Japan (35^{o}19’N, 137^{o}10’E)	1.48		[5]
Atlantic and Mediterranean coasts, Spain (37^{o}16’N, 6^{o}55’W)	0.50	0.51	[4]
Southeastern Michigan, USA (42^{o}25’N, 83^{o}1’W)	1.57	1.05	[6]
Ninh Thuan, Vietnam (11^{o}34'51"N, 108^{o}58'25"E)	0.37	0.47	This study
Dong Nai, Vietnam (10^{o}50'42"N, 107^{o}14'09"E).	0.14	0.23	

III. CONCLUSIONS

In this research, the radioactivity monitoring for Be-7, K-40, Th-232, U-238 and Pb-210 nuclides in the atmosphere has been carried out from Jan 2017 to Dec 2018 at Ninh Thuan and from Nov 2018 to Mar 2019 at Dong Nai locations. The results show that the deposition velocities of Be-7 and Pb-210 in rainy season is much greater than in dry season. Meanwhile, the highest deposition velocities of K-40, Th-232 and U-238 occur in months with hard rain and the lowest values were in the rainy months. These values are also high at the

beginning of rainy season, which indicates that aerosols cleaning process in the atmosphere is more efficient during the first rains.

The deposition velocities of the natural radionuclides from the atmosphere in the survey areas are in ranges for other tropical and subtropical regions and these results could be contributed to the database of world radioactive transport parameters.

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