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Assessment of lifetime cancer risk from natural radioactivity levels in Kadikoy and Uskudar District of Istanbul

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Abstract

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are measured in soil samples from various locations in the Kadikoy and Uskudar district of Istanbul (Turkey). The ^{226}Ra activity concentrations range from 19.97 Bqkg^{-1} to 50.80 Bqkg^{-1} and average ^{226}Ra concentration value 31.40 Bqkg^{-1} was calculated. The ^{232}Th activity concentrations range from 21.38 Bqkg^{-1} to 52.61 Bqkg^{-1} and average ^{232}Th concentration value 34.44 Bqkg^{-1} was calculated. The ^{40}K activity concentrations range from 464.06 Bqkg^{-1} to 711.27 Bqkg^{-1} and average ^{40}K concentration value 619.59 Bqkg^{-1} was calculated. In addition, radium equivalent (Ra_{eq}), absorbed gamma dose rate (D), annual effective dose equivalent, (AEDE), excess lifetime cancer risk (ELCR) were calculated in this study. All of the calculations have been compared with both national and international standards and similar studies. As a result of this comparison, levels of natural radioactivity and radiological effects were slightly higher than the World average and Turkey.

Keywords Soil · Natural radioactivity · Istanbul

Introduction

Environmental natural gamma radiation comes mainly from high energy cosmic ray and terrestrial sources (Merdanoğlu and Altınsoy 2006). The natural radioactivity in terrestrial sources comes from the ^{238}U, ^{232}Th, and ^{40}K (UNSCEAR 2000; Akkurt et al. 2015). The amount of natural radiation in a region depends on geographic structure, geological formations, and characteristics of the soil. Because of this, natural radionuclide amounts are found at different concentrations in different regions (Malain et al. 2012 and Veiga et al. 2006).

Human beings are exposed to radiation from natural radionuclides, artificial sources, and cosmic rays. So knowledge of the concentration and distribution of natural radionuclides in the environment plays an important role in determining public exposure levels (Korkulu and Özkan 2013). Therefore, surveys of natural radioactivity in soils have been investigated in various studies (Aközcan 2014; Hannan et al. 2013; Ozturk et al. 2013; Aközcan et al. 2014; Kuluöztürk and Dogru 2015; Uyanik et al. 2015; Çetin et al. 2016; Zaim et al. 2016; Bouhila and Benrachi 2017; Arnedo et al. 2017; Bolat et al. 2017; Seçkiner et al. 2017; Aközcan et al. 2018; Ribeiro et al. 2018).

In this study the concentrations of natural radionuclides in soils were determined using gamma ray spectrometry by HPGe (hyper pure germanium) detector. The aim of this study is to determine the natural radiation level and to survey the radiological hazards in the Anatolian district of Istanbul. For this reason, radium equivalent activity (Raeq), absorbed gamma dose rate (D), Annual Effective Dose Equivalent (AEDE) and excess lifetime cancer risk (ELCR) were calculated.

Materials and methods

Study area

Istanbul province has a population of approximately 15.000.000 in Turkey. It is the most important city in Turkey both in terms of economy and tourism. Therefore, the concentrations of natural radioactivity must be measured continuously. There is no information about radioactivity level in the Istanbul surface soils samples so far. Kadikoy (450.000

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Table 1 Coordinates of the sampling points and the natural radioactivity concentrations

Samplig point	Geograpic location		^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
	N	E			
B1	40° 57′ 42″	29° 05′ 32″	32.35 ± 0.73	47.39 ± 0.89	711.27 ± 5.81
B2	40° 57′ 46″	29° 05′ 16″	36.58 ± 0.65	40.20 ± 0.74	522.75 ± 5.96
B3	40° 58′ 36″	29° 04′ 51″	50.80 ± 2.91	52.61 ± 1.39	655.55 ± 6.78
B4	40° 59′ 14″	29° 03′ 38″	29.50 ± 1.09	37.66 ± 0.34	692.21 ± 5.49
B5	40° 59′ 05″	29° 02′ 46″	22.32 ± 2.76	23.62 ± 0.84	524.94 ± 6.58
B6	41° 00′ 23″	29° 01′ 59″	19.97 ± 0.59	21.38 ± 0.67	464.06 ± 5.37
B7	41° 00′ 54″	29° 01′ 39″	34.15 ± 3.95	30.62 ± 1.25	628.83 ± 9.89
B8	41° 01′ 14″	29° 01′ 43″	23.57 ± 1.42	30.36 ± 0.83	651.47 ± 8.07
B9	41° 02′ 20″	29° 02′ 00″	32.47 ± 1.67	28.46 ± 0.38	639.28 ± 6.72
B10	41° 03′ 54″	29° 03′ 24″	32.30 ± 1.92	32.07 ± 1.16	705.52 ± 7.94
Mean			31.40 ± 8.76	34.44 ± 10.01	619.59 ± 85.87

population) and Uskudar (530.000 population), are district on the Marmara Sea coast in Istanbul Province. Studied area stands from 40° 57′ 26″ to 40° 57′ 26″ north latitudes and from 29° 01′ 28″ to 29° 06′ 06″ east longitudes. The coordinates of the sampling points were determined by the Global Positioning System (GPS). The region where the study is done is both a historically rich region and one of the most active regions in Istanbul in terms of tourism. At the same time, the region has considerable opportunities in terms of employment opportunities. Some of the residents of different districts are working in these areas of study and the daytime population is much more than the above mentioned amounts. Considering that the number of people affected by natural radiation is considerably high due to the high population density, these regions have been selected in the study.

Sample collection and preparation

A total of 10 (5 samples in Kadikoy and 5 samples in Uskudar), soil samples of two different district were collected. The soil sampled from each site was obtained from four sub-samples collected using a 1 m^2 area method with a depth of 5 cm. After collection, the four sub-samples obtained were thoroughly mixed in order to homogenize and a sample profile of approximately 500 g was prepared (Korkulu and Özkan 2013).

All the soil samples were dried in oven at 105 °C for 48 h. After soil samples dried were sieved through a 1-mm mesh-sized sieve. So the soil samples obtained were free from pebbles, stones, and other macro-impurities. The homogenized soil sample was placed in a 250 ml polyethylene cylindrical container. These containers were tightly sealed with a thick band around the circumference in order to prevent the escape of ^{220}Rn and ^{222}Rn from the soil samples. Then containers kept aside for four weeks to ensure radioactive equilibrium of ^{226}Ra and ^{232}Th with their offspring (Schotzig and Debertin 1983).

Gamma rays analysis

The gamma activities were measured by using HPGe (high-purity germanium) gamma detector (Ortec, USA) with and GammaVision- 32 as the software programme. The type of HPGe detector is p-type and the relative efficiency of the

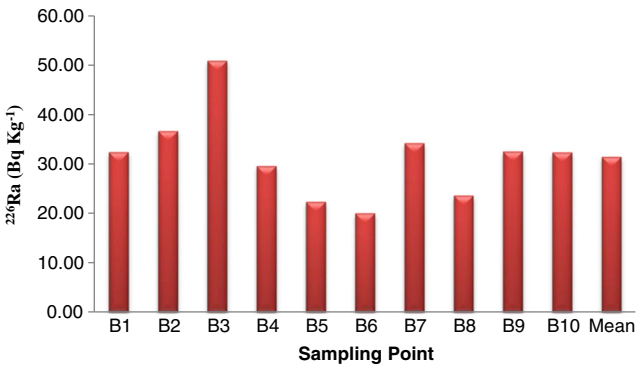

Fig. 1 ^{226}Ra activity concentration

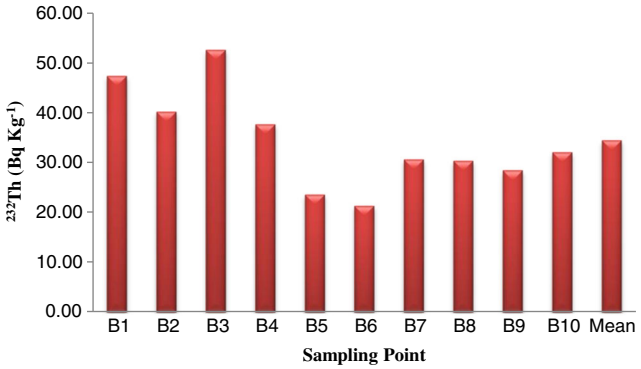

Fig. 2 ^{232}Th activity concentration

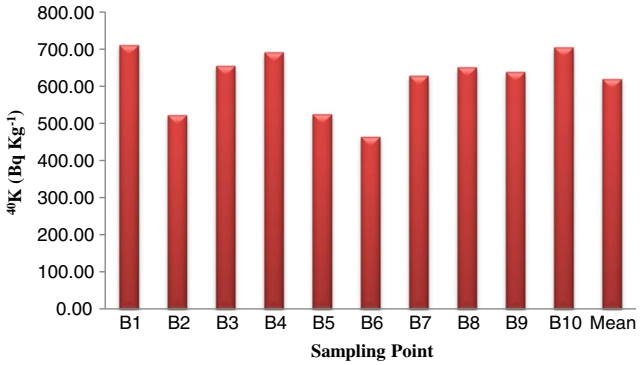

Fig. 3 ^{40}K activity concentration

detector is 70%. The efficiency and energy calibrations were used a standard mixed source containing known levels of gamma activity including ^{51}Cr, ^{57}Co, ^{60}Co, ^{85}Sr, ^{241}Am, ^{88}Y, ^{109}Cd, ^{123m}Te, ^{113}Sn, ^{137}Cs, peaks for energy range between 80 and 2500 keV. Density of the calibration source is 1gcm^{-3} in a 250 ml polyethylene cylindrical container. The background and samples were counted for 160,000 s. The ^{226}Ra activity determination was based on ^{214}Pb (351,9 keV) and ^{214}Bi (609,3 keV). The activity concentrations of ^{232}Th was determined by the ^{228}Ac (911.1 keV) and ^{208}TI (583.1 keV). The activity of ^{40}K was determined through its 1640 keV gamma rays. Samples were counted for three times and average concentration is calculated. The activity of ^{226}Ra, ^{232}Th and ^{40}K in the measured soil samples are calculated (1) equation.

$$A\left(Bq\,kg^{-1}\right) = (\mathrm{CPS})/(\varepsilon \times I\gamma \times M) \quad (1)$$

Where,

A represents the specific activity,
CPS the net gamma counting rate,
ε the detector efficiency of a specific gamma ray,
I_γ the gamma ray emission probability,
M the mass of the sample (kg).

Dosimetry assessment

In this study, absorbed gamma dose rate (D), radium equivalent activity (Ra_{eq}), annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) have been calculated in order to assessment dosimetry.

The contribution to the radiation dose from calculated radionuclides in the soil samples is non-uniform. Radium equivalent activity is defined as a single parameter that compares the activity of varying concentrations of ^{226}Ra, ^{232}Th and ^{40}K (Beretka and Mathew 1985, Sivakumar et al. 2014). In order to calculate radium equivalent activity was used from (2) equation.

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2)$$

The gamma dose rates absorbed in air at 1 m above the ground surface for the uniformly distribution of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) are calculated according to Eq. (3) (UNSCEAR 2000):

$$D\left(\mathrm{nGyh^{-1}}\right) = 0.604C_{Th} + 0.462C_{Ra} + 0.0417C_K \quad (3)$$

Where D (in nGyh^{-1}) represents the gamma dose rate and C_{Th}, C_{Ra}, and C_K are the specific activities of ^{232}Th, ^{226}Ra, and ^{40}K (in Bq/kg), respectively.

In order to determine annual effective doses equivalent (AEDE), the effective dose conversion coefficient taken by adults (0.7 SvGy^{-1}), the absorptive dose rate in the air, and the outdoor occupancy factor (0.2) in the environment were used (UNSCEAR 2000).

In order to calculate annual effective doses equivalent was used from (4) equation

$$\mathrm{AEDE}\left(\mathrm{mSvy^{-1}}\right) = D\left(\mathrm{nGyh^{-1}}\right) {}^{*}8760h {}^{*}0.2 {}^{*}0.7\left(\mathrm{SvGy^{-1}}\right) {}^{*}10^{-6} \quad (4)$$

Table 2 Radium equivalent activity (Ra_{eq}), gamma dose rate (D), annual effective dose equivalent (AEDE), excess lifetime cancer risk (ELCR) from sampling point

Samplig Point	Ra_{eq} (Bqkg^{-1})	D (nGyh^{-1})	AEDE (mSvy^{-1})	ELCR (10^{-4})
B1	154.90	73.23	0.090	3.14
B2	134.32	62.98	0.077	2.70
B3	176.51	82.58	0.101	3.54
B4	136.66	65.24	0.080	2.80
B5	96.52	46.47	0.057	1.99
B6	86.27	41.49	0.051	1.78
B7	126.36	60.50	0.074	2.60
B8	117.14	56.39	0.069	2.42
B9	122.40	58.85	0.072	2.53
B10	132.49	63.71	0.078	2.73
Mean	128.36 ± 26.02	61.14 ± 11.84	0.075 ± 0.014	2.62 ± 0.51

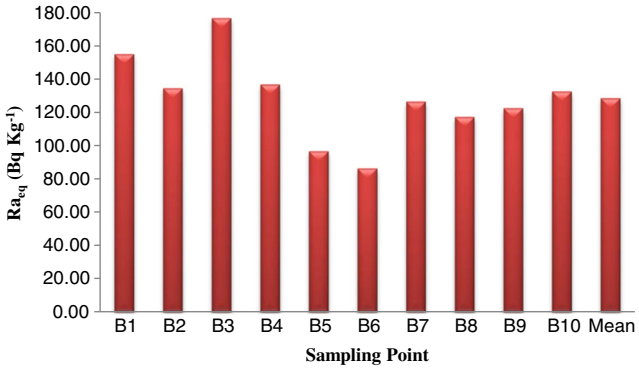

Fig. 4 Ra_{eq} activity concentration

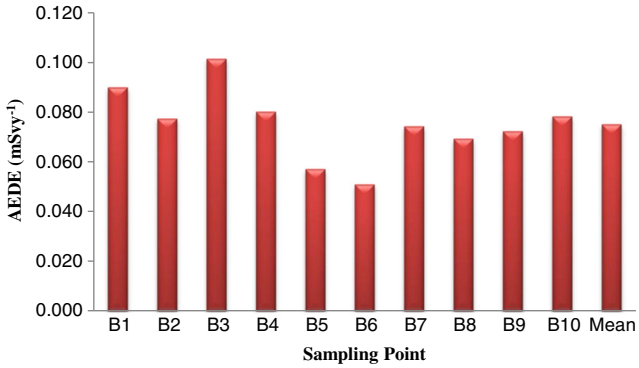

Fig. 6 Annual effective doses equivalent (AEDE)

Excess lifetime cancer risk (ELCR) is defined as the likelihood that a person will be exposed to cancer if exposed to a certain dose of radiation throughout their lifetime. The risk of life-long cancer (Eq. 5) was calculated by multiplying (parameter 3) the parameters of annual effective dose (AEDE ($mSvy^{-1}$)), average duration of life (DL = 70 years) and risk factor ($RF = 5.10^{-2}\ Sv^{-1}$) obtained. The risk factor is defined by the ICRP as the risk of lethal cancer in stochastic effects (ICRP 1990).

$$ELCR = AEDE*DL*RF \quad (5)$$

Results and discussion

Coordinates of the sampling points and the natural radioactivity (^{226}Ra, ^{232}Th, ^{40}K) concentrations measured using the HPGe detector is shown in Table 1. In this table, the samples from B1 to B5 belong to the Kadikoy, from B6 to B10 belong to the Uskudar.

Minimum ^{226}Ra concentration value $19.97 \pm 0.59\ Bqkg^{-1}$ in B6 sampling point, maximum ^{226}Ra concentration value $50.80 \pm 2.91\ Bqkg^{-1}$ in B3 sampling point and average ^{226}Ra concentration value $31.40 \pm 8.76\ Bqkg^{-1}$ was calculated (Fig. 1). In the UNSCEAR 2000 report, the world's natural radioactivity environments are 35 $Bqkg^{-1}$ for ^{226}Ra. The average concentration of ^{226}Ra in this study is lower than the world average.

Minimum ^{232}Th concentration value $21.38 \pm 0.67\ Bqkg^{-1}$ in B6 sampling point, maximum ^{232}Th concentration value $52.61 \pm 1.39\ Bqkg^{-1}$ in B3 sampling point and average ^{232}Th concentration value $34.44 \pm 10.01\ Bqkg^{-1}$ was calculated (Fig. 2). In the UNSCEAR 2000 report, the world's natural radioactivity environments are 30 $Bqkg^{-1}$ for ^{232}Th. The average concentration of ^{232}Th in this study is higher than the world average.

Minimum ^{40}K concentration value $464.06 \pm 5.37\ Bqkg^{-1}$ in B6 sampling point, maximum ^{40}K concentration value $711.27 \pm 5.81\ Bqkg^{-1}$ in B1 sampling point and average ^{40}K concentration value $619.59 \pm 85.87\ Bqkg^{-1}$ was calculated (Fig. 3). In the UNSCEAR 2000 report, the world's natural radioactivity environments are 400 $Bqkg^{-1}$ for ^{40}K. The average concentration of ^{40}K in this study is higher than the world average.

Radium equivalent activity (Ra_{eq}), absorbed gamma dose rate (D), annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) calculated in the study are shown in Table 2.

Minimum Ra_{eq} concentration value 86.27 $Bqkg^{-1}$ in B6 sampling point, maximum Ra_{eq} concentration value 176.51 $Bqkg^{-1}$ in B3 sampling point and average Ra_{eq} concentration value 128.36 $Bqkg^{-1}$ was calculated (Fig. 4). In the UNSCEAR 2000 report, the world's natural radioactivity environments are 108.70 $Bqkg^{-1}$ for Ra_{eq}. The average concentration of Ra_{eq} in this study is higher than the world average.

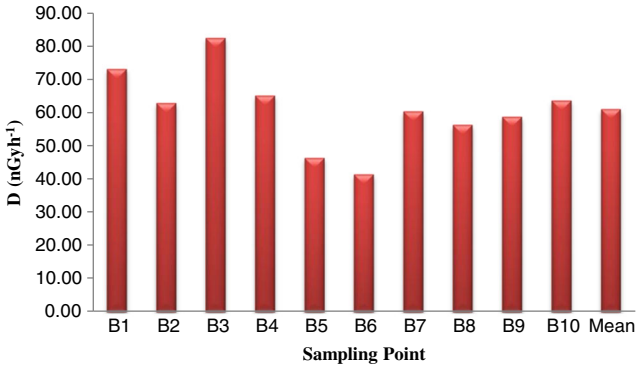

Fig. 5 Gamma dose rates (D) concentration

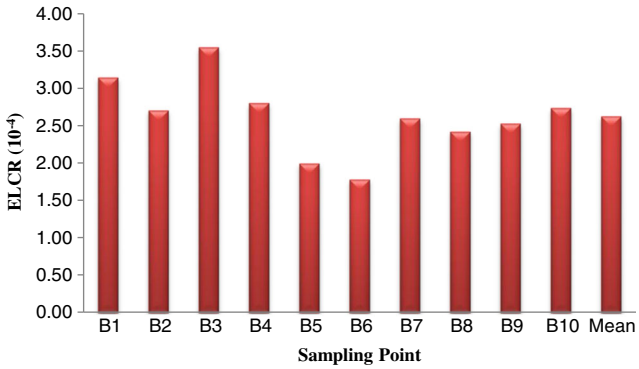

Fig. 7 Excess lifetime cancer risk (ELCR)

Table 3 Comparison of activity concentration Istanbul with some other countries of the world

Location	^{226}Ra (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	Ra_{eq} (Bqkg^{-1})	D (nGyh^{-1})	AEDE (mSvy^{-1})	ELCR (10^{-4})	References
Kırklareli (Turkey)	32	23	1318	180	85	0.104	3.65	Aközcan et al. 2014
Mersin (Turkey)	27	34	370	104	48	0.059	2.08	Karataslı et al. 2016
Yalova (Turkey)	22	26	419	91	43	0.053	1.86	Kapdan et al. 2011
Palestine	41	19	113	77	35	0.043	1.51	Abu Samreh et al. 2014
Pakistan	31	44	575	138	65	0.080	2.78	Rafique et al. 2014
Nigeria	25	77	710	190	88	0.108	3.76	Oyeyemi et al. 2017
Egypt	14	12	1233	126	65	0.080	2.80	Ahmed and El-Arabi 2005
Algeria	47	33	329	134	61	0.075	2.64	Boukhenfouf and Boucenna 2011
India	64	93	124	207	91	0.111	3.90	Singh et al. 2005
USA	40	35	370	119	55	0.068	2.36	UNSCEAR 2000
Bulgaria	45	30	400	119	56	0.068	2.39	UNSCEAR 2000
Turkey (average)	34	35	450	119	56	0.068	2.39	TAEA 2010
World (average)	35	30	400	109	51	0.063	2.19	UNSCEAR 2000
This study	31	34	620	128	61	0.075	2.62	

Minimum gamma dose rates (D) concentration value 41.49 nGyh^{-1} in B6 sampling point, maximum gamma dose rates (D) value 82.58 nGyh^{-1} in B3 sampling point and average gamma dose rates (D) concentration value 61.14 nGyh^{-1} was calculated (Fig. 5). In the UNSCEAR 2000 report, the world's natural radioactivity environments are 50.97 nGyh^{-1} for gamma dose rates (D). The average concentration of gamma dose rates (D) in this study is higher than the world average.

Minimum annual effective doses equivalent (AEDE) value 0.051 mSvy^{-1} in B6 sampling point, maximum AEDE value 0.101 mSvy^{-1} in B3 sampling point and average AEDE value 0.075 mSvy^{-1} was calculated (Fig. 6). In the UNSCEAR 2000 report, the world's natural radioactivity environments are 0.063 mSvy^{-1} for AEDE. The average concentration of AEDE in this study is higher than the world average.

Minimum excess lifetime cancer risk (ELCR) value 0.000178 in B6 sampling point, maximum ELCR value 0.000354 in B3 sampling point and average ELCR value 0.000262 was calculated (Fig. 7). In the UNSCEAR 2000 report, the world's natural radioactivity environments are 0.000219 for ELCR. The average concentration of ELCR in this study is higher than the World average.

The studies on the determination of natural radioactivity levels in different regions of the world are shown in Table 3. Compared to 11 studies conducted in the world, the concentrations of ^{226}Ra in this study were found to be higher than 4 studies, lower than 6 studies, and equal to 1 study; ^{232}Th in this study were found to be higher than 5 studies, lower than 6 studies; ^{40}K in this study were found to be higher than 8 studies, lower than 2 studies, and equal to 1 study; Ra_{eq} in this study were found to be higher than 6 studies, lower than 5 studies; gamma dose rates (D) in this study were found to be higher than 3 studies, lower than 8 studies; annual effective doses equivalent (AEDE) in this study were found to be higher than 6 studies, lower than 5 studies; excess lifetime cancer risk in this study were found to be higher than 5 studies, lower than 6 studies (Table 3).

Conclusions

In this study, 10 sampling points were collected in the Kadikoy and Uskudar district of Istanbul and the concentrations of terrestrial natural radioactivity were determined. Equivalent radium activity, absorbed gamma radiation dose rate, annual effective dose value, lifetime cancer risk were calculated using natural radioactivity concentrations.

Calculated on the results of the measurements of radium, thorium, potassium, equivalent radium activity, absorbed gamma radiation dose rate, the annual effective dose value, the lifetime cancer risk parameters were found higher than world (average) and Turkey (average). Some of the radiochemical parameters found in this study are higher than the other studies done in the world, while others are lower.

The main objective of this study is the fact that the risk of cancer ($2.62 * 10^{-4}$) is slightly higher than the average of the world ($2.19 * 10^{-4}$) and Turkey average ($2.39 * 10^{-4}$), although it is lower than the study done in Kirklareli (Turkey), Nigeria, Pakistan Egypt Algeria and India.

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