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DISTRIBUTION OF NATURAL RADIONUCLIDES ON COASTS OF BUSHEHR, PERSIAN GULF, IRAN*

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Abstract – A reconnaissance study has been made on the distribution of ^{238}U, ^{232}Th, ^{40}K, ^{137}Cs and geochemical features in soil and sediment samples at various locations on the coast of Bushehr in the Persian Gulf. In this study a gamma-ray spectrometer based on a High Purity Germanium detector and a PC based MCA and X-ray fluorescence (XRF) method were used. Estimation of the measured radionuclide content have been made for the absorbed dose rate of gamma radiation. The Activity concentration (A), the equivalent radium (R_{eq}), and the external hazard index (H_{ex}) which resulted from the natural radionuclides in soil and sediment are also calculated. The base-line data of radionuclides and heavy metals in view of the commissioning of nuclear and non-nuclear industries for the coast of Bushehr, which does not yet exist, was obtained.

Activity concentration levels due to radionuclides were measured in 50 soil and sediment samples collected from this region. The measurement was performed with respect to their gamma radioactivity for a counting time of 24 hour intervals. From the accumulated spectra, activity concentration were determined for ^{40}K (range from 108 to 520 Bq Kg^{-1}), ^{137}Cs (from 6 to 40 Bq Kg^{-1}), ^{238}U (from 12 to 75 Bq Kg^{-1}) and ^{232}Th (from 8 to 33 Bq Kg^{-1}) with the lowest limit detection (LLD) of, respectively, 68, 3.2, 4.3 and 4.3 Bq Kg^{-1}. The dose rate from ambient air at the soil ranges was between 14 to 44 nGy h^{-1} with an average of 30.56 ± 7.86 nGy h^{-1}.

Keywords – Natural radionuclide, Gamma spectroscopy, Uranium, Thorium, Cesium, Potassium, HPGe, Soil, Bushehr, Persian Gulf

1. INTRODUCTION

Radionuclides have been an essential constituent of the earth since its creation. The earth is still being heated through the decay of long-lived natural radionuclides, e.g. uranium, thorium and potassium which occur in nature as a complex of oxides, hydrated oxides, carbonates, phosphates, sulphates, vanadates and silicates [1]. Using natural or artificial radionuclides require an understanding of their environmental behavior. Such knowledge is needed for their effective application as in-situ tracers and for the estimation of human health risks. Gamma radiation emitted from naturally occurring radioisotopes, called terrestrial background radiation, represents the main external source of irradiation of the human body. Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions and level of the soils of each region in the world [2].

The advent of nuclear science has resulted in the proliferation of nuclear applications and in the

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increase of environmental radioactivity levels. Furthermore, oil industries, mining activities, and intensified navigation activities are non-nuclear pollution sources that could have serious impacts on the marine environment and coastal ecosystems.

The first study on the region of the Persian Gulf was performed by Preusser, et al [3]. They used $^{230}Th/^{234}U$ and the ESR method for age determination beyond the limits of radiocarbon dating. Also, the study on the region of the Northwestern coasts of the Persian Gulf was performed by Abdi, et al [4]. They measured the distribution of radionuclides. In this research a base-line map of the area was prepared. This map will be used as reference information to assess any changes in the background level due to geological processes, the nuclear reactor of Bushehr and artificial impacts on the environment.

Gamma-ray spectrometry has been used in various studies like soil and sediment radioactivity control and environmental impact evaluation. In order to measure the activity of a sample it is necessary to know the system detection efficiency. This is obtained by employing standard sources which have physical dimensions, chemical composition and density similar to those of the samples. With regard to the geometry, the deviation can be reduced to almost zero if the standard Marinelli beakers are used for standard sources and the samples [5].

2. MATERIALS AND METHODS

a) Study of the region

The Persian Gulf, located in the south of Iran, is a shallow semi-enclosed and narrow basin connected to the Indian Ocean by the narrow Hormuze Strait in the east. The study area is in the northern part of the Persian Gulf (Fig. 1). The surface circulation is from the Hormuz Strait northwest along the Iranian coast. This region has about 350 km of coastline. The topography of the area is of low to moderate relief, generally composed of plateaus. Important rivers discharged are Rood Shoor, Dalke, and Mand. This area has a hot and dry climate with temperatures between 20 and 45 ^{o}C [6]. The studied area is important from environmental, economical, and recreational points of view. Commercial and subsistence fisheries provide a living for a large sector of the coastal population in Bushehr province. Also the underconstruction nuclear power plant of Iran is placed in this region.

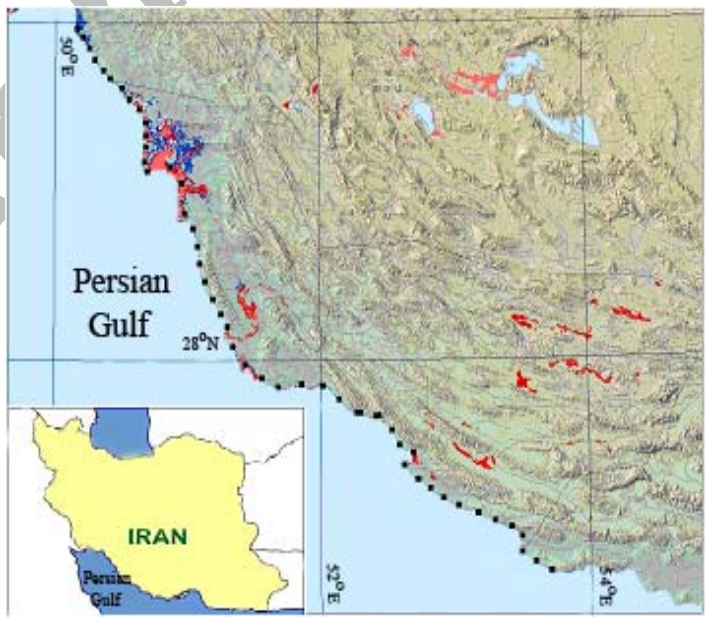

Fig. 1. Map of the Persian Gulf area indicating the location of relevant sites mentioned in the text

b) Sampling and samples preparation

The samples were collected from the beach face along the entire area of study, which extended from Nayband (Latitude 27^0, 21', 35.3" N) to Deylam (Latitude 30^0, 03', 57.5" N). The area was divided into 25 sites. From each site, 10 samples were taken with a distance of about 10-15 m and 10 a cm subsurface. Fifty soil and sediment samples were collected from January to March 2004. The beach sediments in the study area are predominantly sand.

Surficial samples (3 kg) were scooped using a template of a 15×15 cm^2 area and a 5 cm depth and collected in polythene bags according to the method described by Ivanovich and Harmon, [7]. Samples with a particle size greater than 2 cm were discarded. For radiometric analysis, the samples were first dried in air for 6 days, pulverized, homogenized, and sieved through a 170 mesh sieve. The samples were then dried at 110 ^oC [8]. Plastic containers were used for packing the samples. The container material was chemically resistant for the elements and compounds of soil and sediment.

c) Analytical techniques

The dried samples were transferred to polyethylene Marinelli beakers of 600 cm^3 capacity and sealed. They were left for at least 5 weeks to reach secular equilibrium between radium and thorium, and their progenies. ^{238}U series, ^{232}Th series, ^{40}K and ^{137}Cs specific activities were measured using gamma-ray spectrometry employing a coaxial hyper- germanium (HPGe) detector with a beryllium window (GMX-10180 ORTEC model) and a multichannel analyzer of 8192 channels. Spectrum analysis was done by using Maestro computer software. The resolution was 1.8 keV for the 1332.5 keV gamma-ray transition of ^{60}Co. A shield containing lead bricks of 5 cm thickness, iron plates of 2 mm thickness, copper plates of 2 mm thickness, and polyethylene plates of 3 cm thickness were used to reduce background. The gamma spectrometers were calibrated using ^{60}Co, ^{226}Ra point sources, reference material RG-Set, IAEA-Soil-6 and mixed gamma (Table 1) in the same geometry as the samples [5].

Table 1. Quality control measurements using the reference soil material mixed gamma that has been treated as an " unknown" sample [5]

Radionuclide	Recommended Value Bq kg^{-1}	Standard deviation Bq kg^{-1}
^{133}Ba	15.22	± 0.172
^{241}Am	13.86	± 0.142
^{152}Eu	71.66	± 0.601
^{24}Na	25.11	± 0.201

The gamma-ray transition of 1460.7 keV was used to determine ^{40}K and 661.6 keV for ^{137}Cs. The gamma-ray lines of 186.1 keV (^{226}Ra), 295.1, 235.0 keV (^{214}Pb) and 609.3, 768.4, 934.0, 1120.3, 1729.9, 1764.7, 2204 keV (^{214}Bi) were used to determine ^{238}U. The gamma-ray lines of 463.1, 911.1, 968.9 keV (^{228}Ac), 727.3, 1620.7 keV (^{212}Bi) and 860.1, 2614.7 keV (^{208}Tl) were used to determine the ^{232} Th series. In order to determine the background distribution in the environment around the detector, a blank sample was counted in the same manner and geometry. The counting time of 86400 sec was set for activity and background. The background spectra were used to correct the net peak areas of the gamma-rays of the measured isotopes.

The samples were also studied by X-ray fluorescence spectrometry (model S4PIONEER BRUKER) to obtain their elemental and matrix compositions. The loss on ignition (LOI) of the samples was also measured by the gravimetry method.

3. RESULTS AND DISCUSSION

Table 2 gives values of the international recommended limit. Activity concentration of ^{238}U series, ^{232}Th series, ^{40}K and ^{137}Cs ($Bq.kg^{-1}$ dry weight) in the soil and sediment samples are shown in Table 3. Table 4 gives the chemical composition of the sample as oxides content. From Table 2 and 3 it is concluded that the average concentration of ^{238}U, except for some of the samples, is higher than the International limit. The measured activities differed widely, as their presence in marine environments depends on their physical, chemical and geo-chemical properties and the pertinent environment [9]. This indicates that the radioactive minerals are distributed erratically. The same observation was made on the sample studies in Portugal and Malaysia (Table 5) [5, 7, 10]. The mean activity concentration of ^{232}Th is lower than the reported limit [10], whereas that of ^{40}K is lower than the International limit. This could be attributed to the presence of Muscovite in the sample. This is confirmed by chemical analysis of the samples which shows high K_2O content. The samples studied in Turkey, Bangladesh and Malaysia showed the same behavior [10]. The mean activity concentration of ^{238}U is higher than the reported limit. As to artificial radioactivity, the ^{137}Cs isotope was clearly observed in some of the samples. The highest recorded value of ^{137}Cs was 45 $BqKg^{-1}$. This artificial radioactivity may have different origins. Nuclear weapons, bomb tests and accidents are the most probable origin. The presence of ^{137}Cs in the studied samples can be considered as being due to any single one or any combination of these sources [11]. To be more precise, it can be readily deduced that the ^{137}Cs concentration is attributed to global fallout.

Table 2. International UNSCEAR data [10]

Radionuclide	International UNSCEAR
^{238}U	35 Bq kg^{-1}
^{232}Th	35 Bq kg^{-1}
^{40}K	370 Bq kg^{-1}
Dose rate	55 nGy/h

Table 3. The average values of activity concentration ^{238}U, ^{232}Th, ^{40}K, ^{137}Cs

Ser	Code	N(Deg.Min.S	E(Deg.Min.S)	^{137}Cs (Bq/kg)	^{40}K (Bq/kg)	^{232}Th (Bq/kg)	^{238}U (Bq/kg)
1	B-1-S	29, 04,15	50, 53, 57	< LLD	366 ± 23	16 ± 0.7	54 ± 2
2	B-1-R	29, 04,17	50, 53, 53	< LLD	360 ± 22	18 ± 0.8	51 ± 2
3	B-2-S	29, 19, 07	51, 05, 41	< LLD	360 ± 22	27 ± 1.3	48 ± 1.8
4	B-2-R	29, 19, 10	51, 05, 39	0	330 ± 20	27 ± 1.3	34 ± 1.3
5	B-3-S	29, 27, 52	50, 38, 18	< LLD	375 ± 23	19 ± 0.9	38 ± 1.4
6	B-3-R	29, 27, 55	50, 38, 14	< LLD	450 ± 28	33 ± 1.5	46 ± 1.7
7	B-4-S	29, 33, 47	50, 30, 32	0	365 ± 23	24 ± 1.1	75 ± 2.8
8	B-4-R	29, 33, 55	50, 29, 32	0	270 ± 17	18 ± 0.8	24 ± 0.9
9	B-5-S	29, 32, 31	50, 48, 12	7 ± 0.3	280 ± 17	25 ± 1.2	69 ± 2.6
10	B-5-R	29, 32, 31	50, 48, 12	0	180 ± 11	15 ± 0.7	65 ± 2.5
11	B-6-S	28, 54, 42	50, 48, 56	< LLD	240 ± 15	15 ± 0.7	45 ± 1.7
12	B-6-R	28, 54, 42	50, 48, 55	< LLD	375 ± 23	19 ± 0.9	38 ± 1.4
13	B-7-S	28, 49, 34	50, 54, 11	6 ± 0.3	315 ± 19	21 ± 1	34 ± 1.3
14	B-7-R	28, 49, 22	50, 54, 10	0	170 ± 10	9 ± 0.4	15 ± 0.6
15	B-8-S	28, 45, 3.4	51,02, 57	< LLD	188 ± 12	14 ± 0.6	52 ± 2
16	B-8-R	28, 45, 1.5	51, 02, 60	0	200 ± 12	12 ± 0.6	21 ± 0.8
17	B-9-S	28, 40, 51	51, 04, 20	0	228 ± 14	17 ± 0.8	55 ± 2
18	B-9-R	28, 40, 53	51, 04, 21	0			
19	B-10-S	28, 34, 12	51, 04, 55	10 ± 0.5			
20	B-10-R	28, 34, 19	51, 04, 53	0			

Table 3. (Continued)

Ser	Code	N(Deg.Min.S	E(Deg.Min.S)	^{137}Cs (Bq/kg)	^{40}K (Bq/kg)	^{232}Th (Bq/kg)	^{238}U (Bq/kg)
21	B-11-S	28, 30, 41	51, 05, 39	< LLD	219 ± 13	17 ± 0.8	44 ± 1.7
22	B-11-R	28, 30, 43	51, 05, 33	0	520 ± 32	28 ± 1.3	65 ± 2.5
23	B-12-S	28, 21, 40	51, 10, 37	< LLD	237 ± 15	12 ± 0.6	24 ± 0.9
24	B-12-R	28, 21, 36	51, 10, 29	0	477 ± 29	30 ± 1.4	41 ± 1.6
25	B-13-S	28, 17, 17	51, 14, 3	6 ± 0.3	224 ± 14	15 ± 0.7	39 ± 1.5
26	B-13-R	28, 17, 14	51, 14, 02	0	219 ± 13	16 ± 0.7	35 ± 1.3
27	B-14-S	28, 09, 60	51, 18, 27	< LLD	108 ± 7	10 ± 0.5	40 ± 1.5
28	B-14-R	28, 09, 33	51, 17, 01	< LLD	265 ± 16	14 ± 0.6	43 ± 1.6
29	B-15-S	27, 57, 03	51, 32, 01	< LLD	267 ± 16	15 ± 0.7	22 ± 0.8
30	B-15-R	27, 58, 55	51, 32, 27	< LLD	310 ± 19	17 ± 0.8	34 ± 1.3
31	B-16-S	27, 50, 37	51, 39, 29	0	307 ± 19	17 ± 0.8	31 ± 1.2
32	B-16-R	27, 50, 35	51, 39, 28	< LLD	483 ± 30	30 ± 1.4	45 ± 1.7
33	B-17-S	27, 50, 36	51, 48, 17	40 ± 2.1	290 ± 18	18 ± 0.8	36 ± 1.4
34	B-17-R	27, 50, 32	51, 48, 19	0	309 ± 19	17 ± 0.8	59 ± 2.2
35	B-18-S	27, 51, 14	51, 57, 26	5 ± 0.3	297 ± 18	19 ± 0.9	37 ± 1.4
36	B-18-R	27, 50, 01	51, 56, 11	< LLD	419 ± 26	22 ± 1	55 ± 2
37	B-19-S	27, 50, 15	52, 03, 00	5 ± 0.3	233 ± 14	11 ± 0.5	27 ± 1
38	B-19-R	27, 50, 18	52, 02, 55	0	337 ± 21	19 ± 0.9	57 ± 2
39	B-20-S	27, 40, 3.5	52, 19, 44	8 ± 0.5	307 ± 19	17 ± 0.8	31 ± 1.2
40	B-20-R	27, 40, 3.5	52, 19, 44	0	193 ± 12	13 ± 0.6	50 ± 2
41	B-21-S	27, 37, 37	52, 28, 04	0	150 ± 9	11 ± 0.5	40 ± 1.5
42	B-21-R	27, 37, 37	52, 28, 04	< LLD	270 ± 17	17 ± 0.8	52 ± 2
43	B-22-S	27, 33, 31	52, 33, 50	0	140 ± 9	8 ± 0.4	35 ± 1.3
44	B-22-R	27, 21, 35	52, 36,16	0	400 ± 25	22 ± 1	55 ± 2
45	B-23-S	27, 21, 35	52, 47, 52	0	337 ± 21	19 ± 0.9	50 ± 2
46	B-23-R	27, 21, 10	52, 48, 33	0	160 ± 10	15 ± 0.7	36 ± 1.4
47	B-24-S	27, 16, 18	52, 56, 05	45 ± 2.2	110 ± 7	10 ± 0.5	12 ± 0.5
48	B-24-R	27, 16, 33	52, 55, 27	< LLD	108 ± 7	< LLD	22 ± 0.8
49	B-25-S	27, 05, 42	53, 05, 28	< LLD	108 ± 7	11 ± 0.5	17 ± 0.7
50	B-25-R	27, 06, 09	53, 05, 58	0	460 ± 28	30 ± 1.4	66 ± 2.5
					350 ± 22	18 ± 0.8	35 ± 1.3
					430 ± 26	25 ± 1.2	42 ± 1.5
					150 ± 10	< LLD	37 ± 1.4

Table 4. Elements content (%) of different samples

Ser	SiO_2	Al_2O_3	Fe_2O_3	MgO	P_2O_5	K_2O	TiO_2	Na_2O	CaO	LOI(%)
	14.6	3.52	1.52	4.57	0.485	0.8	0.175	1.77	34.84	34.5
2	20.77	5.45	1.97	5.32	0.391	0.942	0.303	1.48	31.17	30.9
3	19.5	5.02	2.505	3.83	0.10	0.935	0.335	0.439	43.76	22.9
4	20.99	5.2	2.207	3.82	0.10	0.812	0.41	0.712	35.2	29.9
5	21.2	5.3	1.99	4.21	0.09	0.99	0.39	1.09	29.3	26.89
6	24.18	7.07	2.76	5.23	0.11	1.21	0.4	1.25	28.14	28.5
7	23.3	5.71	2.4	4.07	0.11	0.89	0.44	0.96	34.2	27.1
8	7.82	1.53	1.51	1.01	0.04	0.311	0.217	1.66	50.32	34.10
9	15.23	3.4	2.66	3.9	0.44	0.78	0.198	1.56	33.49	34.66
10	5.08	1.35	0.612	1.14	0.03	0.231	0.082	0.343	33.78	35.6
11	10.9	3.03	1.34	2.53	0.1	0.46	0.17	0.294	43.54	36.7
12	20.33	5.54	1.997	4.29	0.12	0.928	0.315	1.29	32.67	31.25
13	16.35	4.80	1.84	3.46	0.12	0.7	0.261	0.989	38.05	33.84
14	3.83	1.01	0.688	2.34	0.081	0.188	0.066	1.97	45.56	42.7
15	8.20	1.82	1.15	2.89	0.052	0.304	0.172	1.26	44.26	38.50
16	7.74	1.49	1.23	1.3	0.041	0.285	0.161	2.29	46.39	37.8
17	10.8	2.62	1.62	2.14	0.06	0.43	0.22	0.42	48.31	32.7
18	8.51	1.56	2.14	1.24	0.04	0.32	0.43	2.22	50.23	31.4
19	25.42	7.75	3.3	5.3	0.15	1.24	0.407	0.396	27.86	27.2
20	12.5	2.19	1.78	1.61	0.046	0.401	0.234	2.19	45.25	32.60
21	25.53	7.17	3.240	6.21	0.11	1.24	0.458	0.986	24.81	22.46
22	9.21	2.43	2.00	3.23	0.065	0.414	0.151	0.892	43.71	36.80
23	5.89	1.56	0.78	1.11	0.055	0.24	0.097	0.365	31.65	34.26
24	1.38	0.497	0.87	1.57	0.086	0.114	0	1.56	55.91	36.8
25	11.1	2.97	1.62	4.92	0.138	0.486	0.17	0.332	40.56	35.9
26	13.9	2.45	2.18	2.30	0.067	0.418	0.331	2.48	42.56	31.90
27	14.51	3.92	1.74	5.02	0.070	0.655	0.203	2.38	34.81	33.60
28	20.8	4.82	2.154	4.75	0.078	0.699	0.39	0.759	35.43	29.2
29	28.56	8	3.503	6.67	0.12	1.28	0.519	1.05	25.49	23.7
30	24.23	7.17	2.66	5.19	0.16	1.25	0.38	1.22	28	28.56
31	17.54	3.73	1.85	3.24	0.066	0.637	0.241	0.422	38.27	29.60
32	22.72	4.62	2.475	3.81	0.092	0.658	0.672	2.39	34.43	26.72
33	22.13	5.24	2.010	10.52	0.100	0.968	0.323	1.17	24.62	26.80
34	13	2.12	1.57	2.1	0.066	0.367	0.388	3.23	43.47	32.1
35	19.68	4.21	1.63	10.43	0.1	0.696	0.295	1.09	28.56	29.8
36	10.2	2.5	1.2	2.54	0.046	0.45	0.15	1.24	31.6	30.7
37	6.70	1.80	0.938	2.60	0.113	0.306	0.078	0.19	46.32	40.4041.10
38	5.04	1.04	0.653	1.87	0.098	0.223	0.055	2.10	46.44	30.8
39	10.1	2.6	1.16	5.5	0.29	0.48	0.144	1.3	33.3	42.9
40	2.44	0.7	0.57	2.6	0.051	0.154	0.04	1.16	48.5	31.33
41	20.7	4.9	2.16	5.11	0.08	0.71	0.41	0.84	32.12	43.56
42	6.99	1.99	0.99	3.11	0.22	0.21	0.089	0.21	45.12	40.20
43	4.90	1.54	0.648	2.25	0.022	0.199	0.073	0.318	47.06	44.75
44	0.539	0.176	0.154	1.96	0.067	0.055	0.066	2.29	47.97	48.98
45	1.44	0.088	0.142	2.01	0.087	0.044	0.046	1.89	46.87	29.88
46	21.55	5.01	1.99	4.76	0.078	1.08	0.52	0.56	31.23	32.92
47	19.59	6.91	2.590	3.30	0.147	0.934	0.345	0.054	32.77	32.12
48	15.32	7.56	3.12	4.56	0.66	1.23	0.123	0.065	33.2	30.05
49	20.89	5.53	2.590	4.97	0.099	0.927	0.342	2.20	29.87	42.12
50	5.90	0.846	0.979	1.78	0.066	0.175	0.094	1.02	45.91	

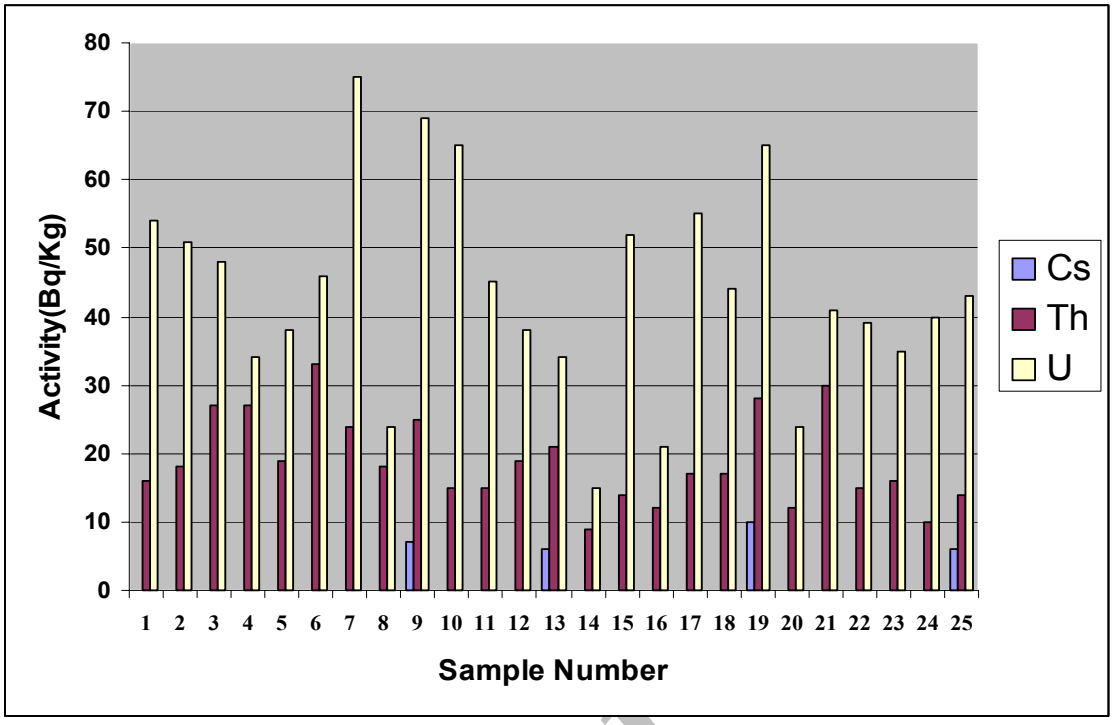

Fig. 2. ^{238}U, ^{232}Th, and ^{137}Cs percentage contribution for 1- 25 regions studied

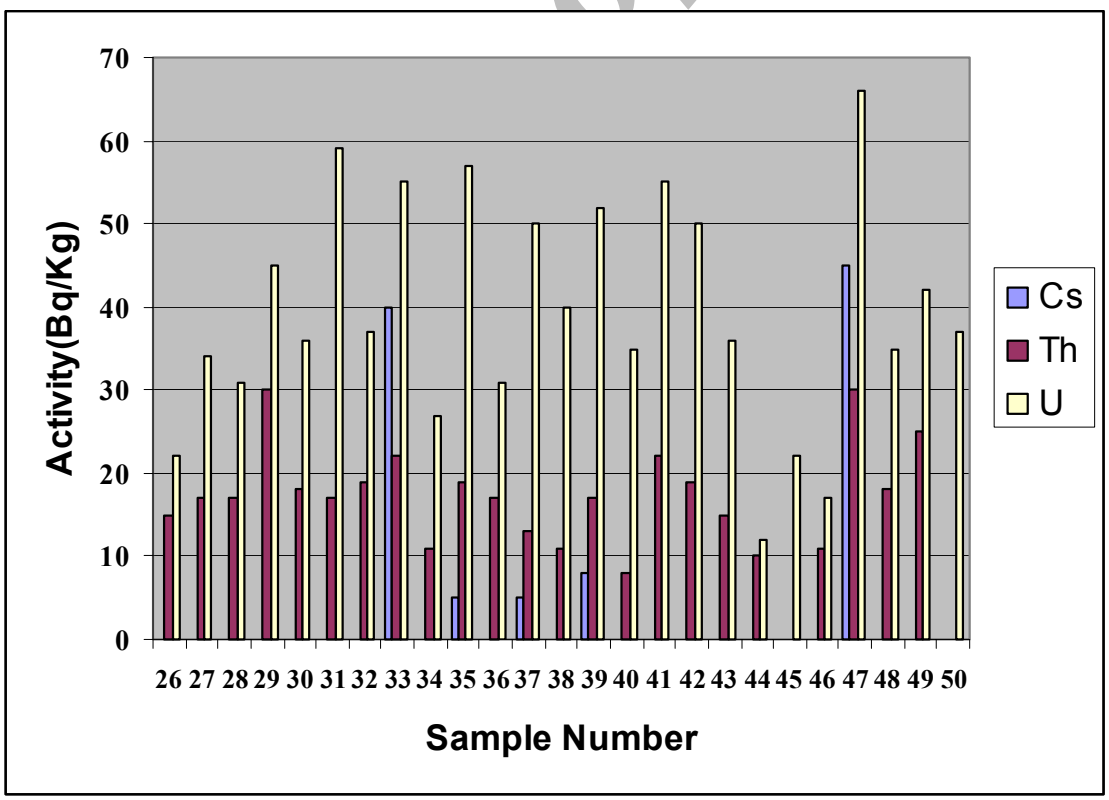

Fig. 3. ^{238}U, ^{232}Th, and ^{137}Cs percentage contribution for 26 - 50 regions studied

Table 5. Summary of activity concentrations and dose rates of natural radioisotopes in soil samples in some of the world regions

Region / Country	^{40}K (Bq/kg)		^{232}Th (Bq/kg)		^{238}U (Bq/kg)		^{226}Ra (Bq/kg)		Dose rate (nGy/h)	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Bangladesh[10]	130-610	350	-	-	-	-	21-43	34	-	-
China[10]	9-1800	440	1-360	41	2-690	33	2-440	32	2-340	62
Hong Kong[10]	80-1100	530	16-	95	25-	84	20-	59	51-120	87
India[10]	38-760	400	200	64	130	29	110	29	20-1100	56
Japan[10]	15-990	310	14-	28	7-81	29	7-81	33	21-77	53
Kazakstan[10]	100-	300	160	60	2-59	37	6-98	35	10-250	63
Korea[10]	1200	670	2-88	-	12-	-	12-	-	18-200	79
Malaysia[10]	17-1500	310	10-	82	120	66	120	67	55-130	92
Thailand[10]	170-430	230	220	51	-	114	-	48	2-100	77
United States[10]	7-712	370	-	35	49-86	35	38-94	40	14-118	47
Syrian Arab	100-700	270	63-	20	3-370	23	11-78	20	52-67	29
Republic[10]	87-780	342	110	37	4-140	21	8-160	-	-	-
Turkey[7]	125-570	562	7-120	49	10-64	26	13-32	26	18-93	65
Pakistan[5]	525-602	320	4-130	18	7-200	37	-	17	8-93	22
Egypt[10]	29-650	490	10-32	45	25-28	110	25-28	54	-	-
Croatia[10]	140-710	140	4-90	-	6-120	-	5-64	17	9-52	18
Cyprus[10]	0-670	360	45-53	20	83-	25	21-77	25	30-109	56
Greece[10]	12-1570	840	2-96	51	180	49	0-120	44	4-230	84
Portugal[10]	220-	520	12-65	30	-	19	1-240	27	12-102	65
Russian[10]	1230	470	-	33	1-240	-	8-65	32	40-120	76
Spain[10]	100-	285	1-190	17	26-82	42	1-76	35	14-44	30
Bushehr *	1400		22-		0-67		6-250			
	25-1650		100		-		10-54			
	108-520		2-79		15-69					
			2-210							
			8-33							

*****North coast of Persian Gulf, Iran (present study).

Activity concentrations of the detected radioisotopes in different locations are shown in Figs. 2 and 3. The distribution of ^{226}Ra, ^{232}Th and ^{40}K in soil is not uniform. Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity (Ra_{eq}) in Bq kg^{-1} to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. The Ra_{eq} was calculated by the equation given by:

$$Ra_{eq}=C_{Ra}+1.43C_{Th}+0.07C_K \text{ (Bq kg}^{-1}\text{)} \quad (1)$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. The gamma radiation doses for the population living in a rural area is due to the soil content of radionuclides, which can be estimated by employing a half-infinite source of an homogenous distribution and by considering only the contribution D from the natural radionuclides in the soil and sediment. The convenient formula is given as [12, 13]:

$$D=0.427C_{Ra}+0.662C_{Th}+0.00043C_K \quad (2)$$

H_{ex} is given by the following equation:

$$H_{ex}=C_{Ra}/370+C_{Th}/259+C_K/4810 \quad (3)$$

Ra_{eq}, D, and H_{ex} of the samples are given in Table 6. The mean values of dose rates in the region are lower

than the International limit.

Table 6. The dose rate (nGy/h) and equivalent radium (Bq/kg) and external hazard indices H_{ex} of the soil and sediment samples of the Persian Gulf

Ser	Ra_{eq} (Bq/kg)	Dose rate (nGy/h)	H_{ex}
1	85	27	0.23
2	86	27	0.23
3	109	38	0.30
4	92	31	0.25
5	88	28	0.24
6	124	42	0.34
7	100	34	0.27
8	81	28	0.22
9	106	38	0.28
10	76	28	0.21
11	75	26	0.20
12	92	29	0.25
13	91	31	0.25
14	54	19	0.14
15	70	25	0.19
16	62	21	0.16
17	79	28	0.21
18	79	28	0.21
19	124	39	0.34
20	62	20	0.17
21	113	36	0.31
22	74	26	0.20
23	71	25	0.19
24	61	24	0.16
25	80	27	0.21
26	74	25	0.20
27	85	28	0.23
28	82	27	0.22
29	117	38	0.32
30	78	26	0.21
31	84	28	0.23
32	80	27	0.22
33	103	33	0.28
34	65	21	0.17
35	96	32	0.26
36	79	26	0.21
37	68	24	0.18
38	58	21	0.15
39	82	28	0.22
40	56	20	0.15
41	103	33	0.28
42	102	35	0.28
43	69	26	0.18
44	52	20	0.14
45	43	21	0.14
46	39	14	0.10
47	130	44	0.35
48	81	25	0.22
49	99	31	0.27
50	65	18	0.18

In Table 5 a summary of recent results on natural gamma radioactivity levels derived from similar investigations conducted in some of the world regions and around the Persian Gulf is presented [13]. The

corresponding activity concentration levels and dose rates obtained from this study are near to the most reported values from other worldwide and neighboring areas. Since natural radioactivity is mainly composed of these three radioisotopes, the coast of Bushehr can be considered as one of the world areas that exhibits medium levels of natural radioactivity.

Geochemical features

The chemical composition of the collected samples is shown in Table 4. The samples can be differentiated according to their SiO_2, Al_2O_3, Fe_2O_3, TiO_2, and P_2O_5 content. The difference could be attributed to the hydrothermal alteration and metasomatism processes. i.e; the area was subjected to surface and subsurface processes of alteration. The subsurface processes are represented by hydrothermal alteration caused by the mobility of some major oxides, which lead to enrichment in SiO_2, Fe_2O_3, P_2O_5 and the depletion of Al_2O_3. The surface processes include the effect of meteoric water, responsible for leaching some elements such as uranium from high to low physiographic features [12].

Knowing the chemical composition of the samples is helpful for preparing standard sources with a matrix similar to that of the samples. The similarity is extremely necessary for HPGe calibration and detecting gamma self-absorption. It is well known that the presence of calcite and Phosphate can affect radioisotope abundance in soil. Chemical analysis of the samples ascertained that such deposits do not exist in the studied areas.

4. CONCLUSIONS

The data obtained in the present work cover a wide area in the south of Iran, which can be considered as the base-line of the region. The lowest concentration of uranium (12 Bq Kg^{-1}) was observed in Asaloyeh sediment, and the highest (75 Bq Kg^{-1}) in Genaveh soil. Similarly, the lowest (10 Bq Kg^{-1}) and highest (33 Bq Kg^{-1}) levels of ^{232}Th were found in Asaloyeh sediment and Genaveh soil. This indicates that the radioactive minerals are distributed erratically.

The lowest (108 Bq Kg^{-1}) and highest (520 Bq Kg^{-1}) levels of ^{40}K were found in Asaloyeh sediment and Rostame soil, respectively. Similarly, the highest (45 Bq Kg^{-1}) levels of ^{137}Cs were found in Berkehdoka. The total absorbed radionuclides from ambient air ranges from 14 to 44 nGy h^{-1} with an average of 30.86 nGy h^{-1}. The highest dose rates were found in Berkehdoka and Reeg, which were lower than the international recommended limit.

REFERENCES

1. Akhtar, N., Tufail, M., Ashraf, M. & Mohsin Iqbal, M. (2005). Measurement of environmental radioactivity for estimation of radiation exposure from saline soil of Lahor, Pakistan. *Radit. Measur. 39*(1), 11-14.
2. Mamaney, M. H. & Khater, E. M. (2004). Environmental characterization and radio-ecological impacts of non-nuclear industries on the Red Sea coast. *J. Environ. Radioactivity*, *73*, 151-168.
3. Preusser, F., Radtke, U., Fontugne, M., Haghipour, A., Hilgers, A. & Kasper, H. U. (2003). ESR dating of raised coral reefs from Kish Island, Persian Gulf. *Quaternary Science Reviews*, *22*, 1317-1322.
4. Abdi, M. R., Faghihian, H., Mostajaboddavati, M., Hassanzadeh, A. & Kamali, M. (2006). Distridution of Natural Radionuclides and hot points in coasts of Hormozgan, Persian Gulf, Iran. *Journal of Radioanalytical and Nuclear Chemistry, 270*(2), 319-324.
5. Mostajaboddavati, M., Hasanzadeh, A., Faghihian, H., Abdi, M. R. & Kamali, M. (2006). Efficiency Calibration and Measurement of Self-Absorption Correction for Environmental Gamma Spectroscopy of Soil Samples using Marinelli beaker. *Journal of Radioanalytical and Nuclear Chemistry*, *268*(3), 539-544.
6. Shenn, Y. (1992). A numerical investigation of circulation in the Persian Gulf. *Journal of Geophysical Research*,

97(C7), 219-236.

7. Ivanovich, M. & Harmon, R. S. (1992). Uranium series Disequilibrium: applications to Earth, Marin and Environmental Sciences. Oxford: Clarendon press.
8. Lee, S. C., Kein, C. K., Lee, D. M. & Kang, H. D. (2001). Natural radionuclides content and radon exhalation rates in building material used in south Karea. *Radiation Protection and Dosimetry, 94*(3), 269-274.
9. Khatir, S. A., Ahamed Mustafa, M. O., El-Khaangi, F. A., Nigumi, Y. O. & Holm, E. (1998). Radioactivity levels in Red Sea coastal environment of Sudan. *Marine Pollution Bulletin, 36*(1), 19-26.
10. United Nation Scientific committee on the Effects of Atomic Radiation (UNSCEAR). (1988). Sources, effects and risk of ionizing radiation. New York, NY: United Nations.
11. Baggoura, B., Nouredine, A. & Benkrid, M. (1998). Level of natural and artificial radioactivity in Algeria. *Appl.Radiat.Isot*., *49*(7), 867-873.
12. Sroor, A., Afifi, S. Y., Abdel-Haleem, A. S., Salman, A. B. & Abdel-Sammad, M. (2002). Environmental pollutant isotope measurements and natural radioactivity assessment for North Tushki area, South Western desert, Egypt. *Appl. Radi. Isoto., 57*, 427-436.
13. Karahan, G. & Bayulken, A. (2000). Assessment of gamma dose rates around Istanbul. *J. Environ. Radioactivity, 47*, 213-221.