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Measurement of Natural Radioactivity in Beach Sand of Akkuyu Mersin, Turkey

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Abstract
Distribution of natural radionuclide gamma rays produced by ^{232}Th, ^{226}Ra and ^{40}K, were determined for the sand collected along the cost of Mersin in Akkuyu. Gamma radiation in beach sand samples collected from Akkuyu nuclear power plant region has been measured by NaI(Tl) gamma ray spectrometer. Gamma spectrometer has been calibrated with IAEA reference set which were RGK, RGU and RGTH. The radioactivity concentration of were calculated and expressed in Bqkg^{-1}. The source of cause for the total doses of beach sand was formed due to three primordial radionuclide which were ^{232}Th, ^{226}Ra and ^{40}K. The activity of radionuclide were between 3.96-17.18, 15.82-39.48 and 133.54-287.06Bqkg^{-1} respectively. Radiological hazard, radium equivalent, external hazard and total dose rate were also calculated. Results were discussed with UNCEAR reports.
Keywords: Natural Radioactivity, Sand, Gamma-Ray Spectrometry, Dose Rate, Akkuyu

1. Introduction

Human beings have been exposed to radiation throughout the ages. The main source of such radiation is natural radioactivity and cosmic rays. But cosmic rays are very scarce because of the atmospheric absorption. There are also other radiation sources which are used in medical diagnostics and treatments. Another source is enriched radioactive material which is used for war purposes. The nuclear power plants might emit radiation after a nuclear accident that rarely occurs. Sometimes, radiation leaking from wrecked nuclear power plants and ambient area is overwhelmed by the radionuclide. For instance, there are approximately 440 nuclear power plants in the world (World Nuclear Association 2014) and there were only four major accidents between 1952 and 2013 (Marius and Mario V, 2012). These accidents were Kyshtym in Soviet Union in 1957, Three Mile Island in United States in 1979, Chernobyl in Ukraine in 1986, and Fukushima in Japan in 2011 (Marius and Mario 2012). Furthermore, nuclear reactors have also been used to run over 400 ships and nearly 300 research reactors have been providing radioisotopes for medical diagnostic and cancer therapy, also serving as sources of neutron to researcher and training facility for students over 50 countries (IAEA 2011).

On the other hand, terrestrial natural radiation, especially in beach sand is important for natural radioactivity. For instance, beach sands are used in industrial and construction fields; thus, the radioactivity levels must be at permissible range. The mineral deposits of beach sand are formed by weathering and erosion. The main source of these mineral deposits come from metamorphic and igneous rocks. Some metaphoric and igneous rocks are formed of natural radionuclide that expose radiation to the environment. Natural radioactivity of soils and sands are emanated from concentrations of Uranium(U), Thorium(Th) and Potassium (K).

Numerous studies have been found to obtain about environmental radioactivity at the beach sand, soil, water and air samples. The areas of nuclear power plants have become fairly attractive for radioactivity studies. The radioactivity concentration of three radionuclide in soil and sand, collected from Rathapuram Talu regions have been evaluated (Brahmanandhan, et al. 2007) and Annual effective doses due to ^{238}U, ^{232}Th, and ^{40}K have been found below permissible levels (1mSv) (ICRP-60 1991). Traces of radioactivity in beach sand mineral deposits are performed through the several coasts of Adriatic, Black sea, Canaria Islands and India (Nevenka, e*t al* 2013, Margineanu, e*t al* 2013, Arnedo, *et al.* 2013, Sartandel, *et al*. 2012). The natural radioactivity levels of soil and sediment of Fırtına Valley in Turkey have been determined (Kurnaz, e*t al.* 2007). The radioactivity levels have been found higher than world average; however, insignificant for health hazard (Kurnaz, e*t al.* 2007).

This study is devoted to create a radiation data bank for the upcoming Akkuyu Nuclear Power Plant(ANLP). Determination of natural background radiation in the sand at Akkuyu region has increased the importance of this study due to any radioactivity released in time.

2. Materials and Methods

2.1 Sample Locations and Preparations

Study area has been chosen from coast of Mediterranean next to the Akkuyu Nuclear power plant region at Yeşilovacık Mersin Turkey figure (1). The region between Akkuyu and Yeşilova is occupied mainly with sharp cliff rather than flat beaches. Hence, the samples were collected from beaches Yeşilovacık which is the closest area to Akkuyu Nuclear Power plant.

The side is located in Yeşilovacık, South of Turkey, from 36o11'13" and 36o11'28"N between 33o37'18" E and 33o39'40" E. Fifteen local areas were selected to collect beach sands. At each and every point,

the samples were gathered from the five pits of 40cmx40cmx10cm within area of one to six square meters. The collected samples were mixed uniformly and packed with labels showing their location in a polythene bags about one kg after removing the five cm top layer of vegetation and rood. Sands samples were dried at 110oC in the oven for 24 hours. Dried samples were crashed and sieved trough the 0.5mm sieves to get uniform grain size. The samples were packed into leak proof cylindrical plastic container of which radius and height were 3cm, 5cm respectively. Plastic containers were weighed before and after stuffing the samples in order to get net weight of the each samples. they were ready to measure gamma spectra thought NaI(Tl) gamma detector after kept sealed to get equilibrium ^{238}U and ^{232}Th series and their respective progeny

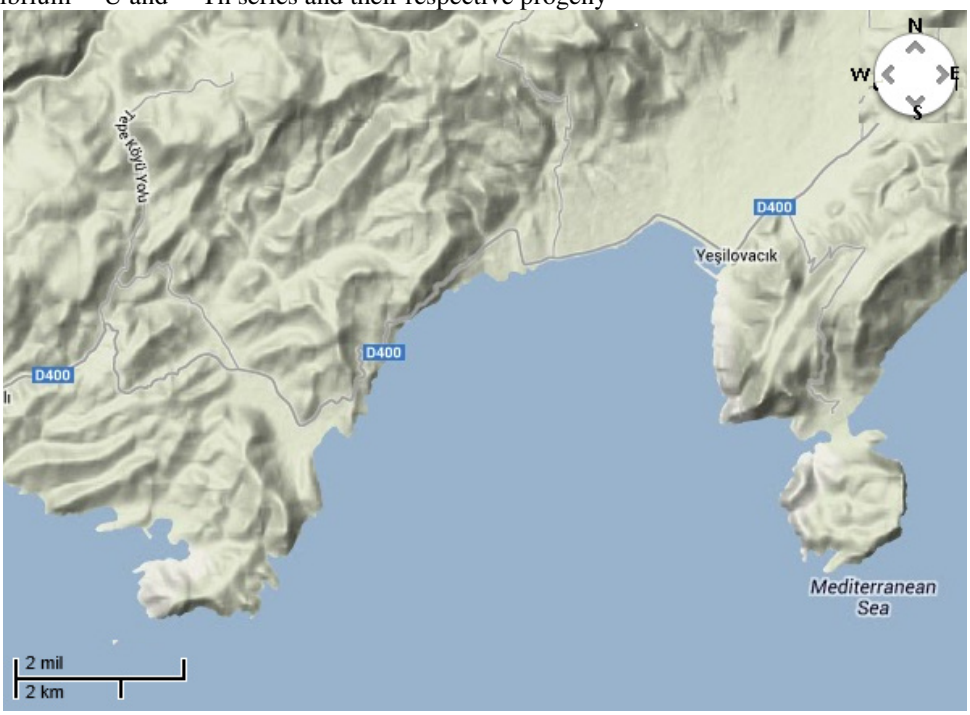

Figure 1. Yeşilovacık Beaches next to the Akkuyu Nuclear Power Plant Region

2.2. Calibration and Measurement by Gamma Ray Spectroscopy

Natural radioactivity measurement of the beach sands were carried out by Mersin University Advanced Technology Research and Application Center, using conventional techniques of gamma spectrometer. Gamma ray spectra were recorded by 905-4 NaI Scintillation Detector, 3- x 3-in. crystal, 3-in. tube coupled with multichannel analyzer. Gamma rays were counted along the spectra during the acquisition time which were between 10h and 24 hours for each samples. An empty plastic container were placed at top of the detector to measure of background gamma emission each week.

Energy calibration of the NaI(Tl) gamma detector was performed by six different nuclides from 100keV up to 1700eV. Also, efficiency calibration was done by using three well-known reference materials obtained from the International Atomic Energy Agency (IAEA) for K, U and Th activity measurements: RGK-1, RGU-1 and RGTH-1 (IAEA, 1987).

2.3 Radioactivity Calculation

Radioactivity calculation was performed using reference standards that had same geometry and density matrix for each radio nuclides. Gamma spectrums from 100keV to 2300keV were measured for each samples. All samples have ^{232}Th, ^{226}Ra and ^{40}K lines and overlap with references spectrum after removing background signals. Equation of the activity;

$$\frac{A_s}{A_r} = \frac{CP_s}{CP_r} \quad (1)$$

A_s and A_r are sample and reference activities respectively. CP_s and CP_r are sample and reference net counting rates respectively.

$$CP_s = \frac{I_s}{t_s} - \frac{I_{nb}}{t_{nb}}$$

and

$$CP_r = \frac{I_r}{t_r} - \frac{I_{nb}}{t_{nb}} \quad (2)$$

I_s, I_r, I_{nb} are integrations of peak area for gamma signals of samples, references and natural backgrounds respectively. t_s, t_r *and* t_{nb} are net integration times for gamma signals of samples, references and natural backgrounds respectively.

The Error Calculation of the Acvitiy;

$$\Delta A_s = A_s \sqrt{(\Delta A_r)^2 + \frac{(\Delta I_s^2 - \Delta I_{nb}^2)}{(CP_s - CP_{nb})^2} + \frac{(\Delta I_r^2 - \Delta I_{nb}^2)}{(CP_r - CP_{nb})^2}} \quad (3)$$

ΔA_s, ΔA_r are the standard deviations of the activities of samples and references respectively. ΔI_s, ΔI_r and ΔI_{nb} are the standard deviations of the total peak areas of samples, references and background signals respectively

3. Results

The concentration of basic components of sand samples from study area were tested by XRF techniques. The results are shown in Table 1. It can be seen clearly that all samples have different oxides and minerals concentrations. SiO_2 and CaO minerals seem to be dominant in all samples. The next abundant oxides and minerals are Al_2O_3, Fe_2O_3 and K_2O which are not radioactive but an exception Potassium (K) which has ^{40}K isotopes natural abundance are about 0.012% radioactive. The main radio nuclides, ^{232}Th and ^{226}Ra, that contributing natural radioactivity should be in ppm levels so they do not appear in XRF measurement.

Table 1. XRF Analysis of Sand Samples.(*Fire Causalities)

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
F (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na_2O (%)	1.79	1.82	2.17	0.66	1.23	1.57	1.21	1.97	1.61	1.81	1.95	1.31	0.50	0.57	1.42
MgO(%)	1.67	1.58	1.67	1.61	1.41	1.61	1.21	1.68	1.66	1.64	1.92	1.76	1.77	1.58	1.74
Al_2O_3(%)	7.36	6.73	9.30	8.00	1.46	8.75	6.55	8.85	6.58	10.34	10.54	2.16	7.43	8.20	5.92
SiO_2(%)	44.99	37.33	43.71	46.48	10.18	46.09	32.80	43.57	42.96	45.86	43.73	15.77	47.83	52.37	26.44
P_2O_5(%)	0.08	0.08	0.09	0.09	0.03	0.09	0.38	0.15	0.12	0.15	0.11	0.04	0.11	0.11	0.09
SO_3(%)	0.34	0.34	0.37	0.15	0.37	0.30	0.22	0.36	0.32	0.28	0.29	0.39	0.10	0.12	0.43
Cl(%)	2.04	2.06	2.56	0.36	1.29	1.73	1.19	2.21	1.90	1.80	2.14	1.34	0.13	0.18	1.43
K_2O(%)	1.81	1.74	2.24	1.94	0.45	1.98	1.56	2.17	1.59	2.36	2.48	0.54	1.64	1.93	1.59
CaO(%)	22.91	27.39	20.51	23.64	47.95	20.09	14.79	22.00	25.93	16.93	17.60	43.54	23.62	18.24	35.12
TiO_2(%)	0.56	0.52	0.66	0.52	0.16	0.59	0.44	0.63	0.53	0.70	0.73	0.21	0.49	0.54	0.59
V_2O_5(%)	0.00	0.02	0.00	0.02	0.00	0.00	0.01	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00
Cr_2O_3(%)	0.02	0.02	0.01	0.02	0.00	0.02	0.01	0.02	0.02	0.02	0.02	0.00	0.02	0.01	0.02
MnO(%)	0.07	0.11	0.08	0.10	0.05	0.07	0.06	0.08	0.08	0.06	0.10	0.06	0.08	0.09	0.08
Fe_2O_3(%)	6.89	5.97	6.71	5.71	1.63	7.88	5.34	6.77	6.68	8.31	8.76	2.31	6.21	6.99	6.53
NiO(%)	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.01	0.01
CuO(%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
ZnO(%)	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00
Rb_2O(%)	0.03	0.03	0.03	0.00	0.00	0.03	0.02	0.03	0.03	0.03	0.01	0.02	0.00	0.00	0.00
SrO(%)	0.06	0.11	0.06	0.04	0.28	0.05	0.04	0.06	0.06	0.05	0.05	0.24	0.03	0.03	0.21
ZrO_2(%)	0.02	0.00	0.00	0.01	0.00	0.02	0.01	0.02	0.01	0.01	0.02	0.00	0.03	0.02	0.02
BaO(%)	0.10	0.10	0.10	0.08	0.07	0.09	0.08	0.09	0.09	0.04	0.05	0.07	0.08	0.10	0.11
WO_3(%)	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.05	0.00
ReO_2(%)	0.00	0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F.C*	9.20	14.00	9.67	10.49	33.40	8.99	33.89	9.29	9.75	9.52	9.43	30.19	9.86	8.80	18.17

The natural radio activities of sand samples were measured by NaI(Tl) gamma scintillation detector and was summarized in table 2. The activity concentration of sand samples due to ^{232}Th, ^{226}Ra and ^{40}K radio nuclides. Major contribution to activity came from ^{40}K and it apparently varied between 133.53±18.06 and 287±18.49Bq/kg. The next radio isotope that contributed to the total activity is ^{226}Ra and it varied between 15.81547±7.69 and 39.4768±9.76Bq/kg. On the other hand, the activities of Thorium ^{232}Th were rather small than ^{226}Ra and ^{40}K radio isotopes and between 3.96±0.34 and 17.18±0.87Bq/kg.

Table 2 Natural Activity of Samples ^{40}K, ^{226}Ra and ^{232}Th (Bq/kg)

Samples	^{40}K(Bq/kg)	^{226}Ra(Bq/kg)	^{232}Th(Bq/kg)
SMPL01	169.7181 ± 16.48217	27.39492 ± 9.907023	6.244612 ± 0.428998
SMPL02	180.8405 ± 16.17148	21.10252 ± 6.077695	3.960267 ± 0.342626
SMPL03	261.9818 ± 18.1609	39.4768 ± 9.756771	8.90989 ± 0.586747
SMPL04	287.0591 ± 18.49797	35.71324 ± 7.501773	8.012973 ± 0.573602
SMPL05	160.9963 ± 16.77277	18.29386 ± 7.077611	4.428975 ± 0.58615
SMPL06	273.1437 ± 19.30617	27.15934 ± 7.602337	11.81092 ± 0.77779
SMPL07	258.6664 ± 18.08396	26.70552 ± 7.307317	12.11755 ± 0.773497
SMPL08	210.1489 ± 18.71696	24.38238 ± 7.340617	11.04084 ± 0.867561
SMPL09	172.186 ± 17.59227	35.18781 ± 7.157374	11.62494 ± 0.86205
SMPL10	270.7546 ± 18.85635	28.51828 ± 7.228256	17.10319 ± 0.849606
SMPL11	257.2227 ± 18.81388	27.96268 ± 7.287231	17.18012 ± 0.866058
SMPL12	133.5364 ± 18.06674	15.81547 ± 7.692052	8.029469 ± 0.965567
SMPL13	202.8907 ± 18.99991	19.72516 ± 7.779507	13.67012 ± 1.009639
SMPL14	230.068 ± 20.53914	20.02011 ± 8.354731	13.86025 ± 0.930296
SMPL15	226.8735 ± 19.09178	27.1337 ± 7.620917	16.64514 ± 0.89653

Absorb dose were estimated from 1 m above the ground by using conversion factor (UNSCEAR, 2000). described as nGyh^{-1} .

$$D(nGyh^{-1}) = 0.0417A_K + 0.461A_{Ra} + 0.604A_{Th} \quad (4)$$

The parameters used in absorb dose equation (4), A_K, A_{Ra} and A_{Th} are activities in Bqkg^{-1} of ^{232}Th, ^{226}Ra *and* ^{40}K radio nuclides respectively. The effective dose 1 meter above from ground also can be calculate from absorbed doses to by applying conversion factor 0.7mSv/Gy(UNSCEAR 1993). The results of effective doses indicated in Figure 2. The value of annual effective dose rate less than ten times average of worldwide exposure 2.4mSv y^{-1} (UNSCEAR, 2000).

In many places beach sand is also used in industry and building materials. The radioactivity due building materials cause radiologic effects on humans. The natural radioactive of building materials are usually defined by ^{232}Th, ^{226}Ra and ^{40}K radio nuclides. Specific activity can be determined as Radium equivalent activity (Beretka and Mathew 1985). They suggest that radium equivalent activity of samples based on estimation that 370Bq kg^{-1} ^{226}Ra, 259Bq kg^{-1} ^{232}Th and 4810Bq kg^{-1} ^{40}K produce same gamma dose rate (Krisiuk, et al. 1971). Radium equivalent activity were calculated as follows,

$$Ra_{eq} = A_{Ra} + 1.43\,A_{Th} + 0.077\,A_K \quad (5)$$

where A_{Th} , A_{Ra} , and A_K are specific activities of ^{232}Th, ^{226}Ra and ^{40}K in Bqkg^{-1} respectively. Radium equivalent activity doses must be less than 370Bqkg^{-1} in building materials for radiation safety. The hazard indexes classified in two types as internal and external. Although, internal hazard index is formed by Radon and its daughters beside the Radium equivalent activity, external hazard index is contributed by radium equivalent as equation (6) and assessment of index must be less than unity for safety usages as an building materials (Beretka and Mathew 1985).

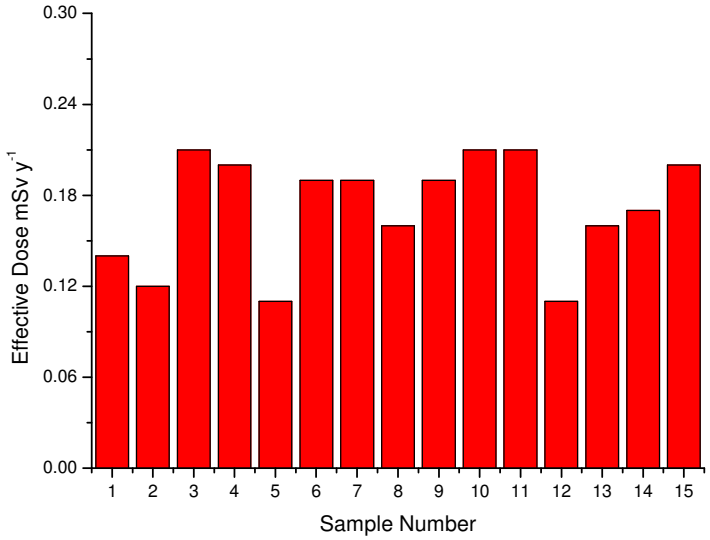

Figure 2 Effective doses of sand samples from near Akkuyu Mersin

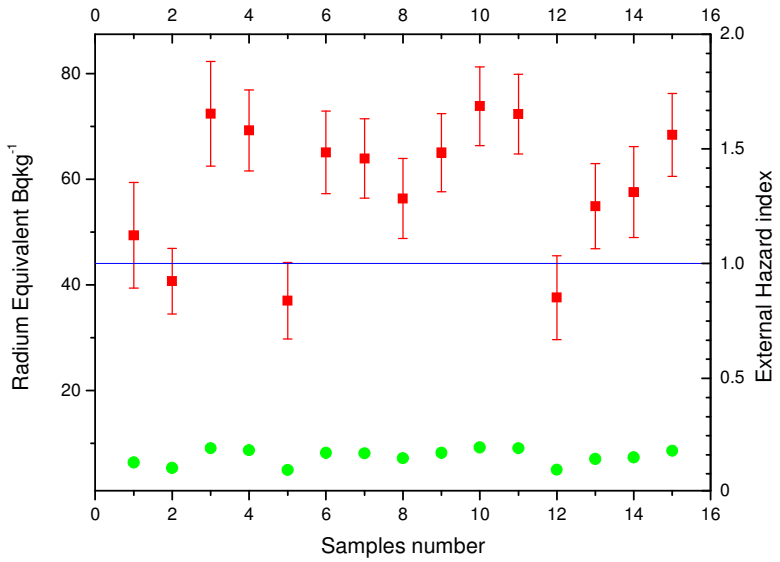

Figure 3. Radium Equivalent and Hazard Index of sand samples from near Akkuyu Mersin

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

Radium equivalent activity and external hazard index are shown in figure (3). It varied between about 37 and 74 Bqkg^{-1}. it is less about 5 to 10 times from permissible level 370Bqkg^{-1} and it is clearly seen that external hazard index is below the unity.

4. Conclusion

Natural radioactivity of beach sand from the coast of near upcoming Akkuyu nuclear power plant was analyzed for radioactivity, absorb dose and radiation hazard due to ^{232}Th, ^{226}Ra and ^{40}K . There were no other radionuclides after analysis of XRF and NaI(Tl) Gamma spectroscopy except ^{232}Th, ^{226}Ra and ^{40}K. In all samples radioactivity of the ^{40}K was higher than ^{232}Th *and* ^{226}Ra radionuclides. This behavior could be explained by scarcity of Uranium series and their daughters. The activity concentration of naturally occurring radionuclide in

sand samples were lower than permissible level of 370Bqkg^{-1}.
Annual absorb doses were less than ten times average of worldwide exposure. So the beaches in Akkuyu region are safety for tourists and local habitants. Hazard index of sand samples as building materials were found less than unity and it is safe for using in industrial area and constructing materials.

Acknowledgments
The research has been carried out within the project no. Mersin University, BAP-FBE FB (SB) 2012 Study of "Radioactivity level of beach sand in Akkuyu Mersin", Measurement of specific activity of ^{238}U, ^{232}Th and ^{40}K in sand samples using NaI(Tl) gamma-ray spectrometer that donated to Mersin University by Turkish Atomic Energy Authority (TAEK).

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