

Environmental Natural Gamma Radiation Level and Activity of Uranium-238, Thorium-232 at Different Places Measured Using NaI (Tl) Scintillation Detector

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Abstract: *Natural and cosmogenic radioactive nuclides are present all over the world. Radiation emitted from these nuclides forms the natural background. Exposure to ionizing radiation from natural sources is a continuous and unavoidable feature of life on the earth. The environmental effective gamma radiation dose from terrestrial and cosmic radiation at height one foot above the earth's surface in open atmosphere has been measured at twenty six different places in Sindhudurga district of Maharashtra state (INDIA) (15°22'-16°24'N; 73°12'-74°12'E) by using 2X2 NaI (Tl) scintillation detector. The effective gamma radiation dose at different locations varies between 0.286 mSv/y to 0.804 mSv/y, with an average of 0.524 mSv/y. The activity of U^{238} and Th^{232} has been measured using gamma ray spectroscopy. The U^{238} activity varies from 0.466 KBq/m² to 1.133 KBq/m² with mean value of 0.751 KBq/m². The Th^{232} activity varies from 0.552 KBq/m² to 1.267 KBq/m² with mean 0.8466 KBq/m². The U^{238} to Th^{232} activity ratio varies from 0.494 to 1.2 with mean 0.886.*

Keywords: gamma ray spectroscopy, NaI (Tl) scintillation detector, natural background.

1. Introduction

Exposure to ionizing radiation from natural sources is a continuous and unavoidable feature of life on the earth. The major sources responsible for this exposure are due to the presence of naturally occurring radioactive nuclei in the earth's crust such as U-238, U-235, Th-232 and their decay chain up to one of the stable isotope of Pb. K-40 and Rb-87 are intense primordial radionuclide and so many light and moderate radionuclide of natural and cosmogenic origin are present in soil, water, materials and atmosphere. The distribution of naturally occurring radionuclides depends on the distribution of rocks from which they originates and the processes which concentrate them. [2,7,8]

In most places on the earth, the natural radioactivity varies within narrow limits, with world annual effective average dose from terrestrial gamma rays and cosmic rays 0.9 mSv/y. In some places there observes wide deviation from normal levels because of presence of high levels of radioactive minerals. The natural radioactive decay chains of U-238, Th-232, and U-235 nuclei emit α , β particles and γ rays. Alpha, beta particles penetrates little thickness and they are absorbed immediately. The major equilibrium concentration of nuclear radiation in the earth's atmosphere contains gamma ray flux. The estimation of natural background radiation level at place to place on the earth becomes the part of national and international survey [11]. Gamma radiation spectroscopy is widely used for the detection and measurement of radioactivity. [1, 2, 7]

We have recorded background gamma radiation spectrum using single channel NaI (Tl) detector at 26 different places in Sindhudurga district of Maharashtra state (INDIA) and from it obtained effective dose from terrestrial gamma radiation and cosmic rays and U-238 and Th-232 activities at the places of observation. The results obtained are presented in the paper.

2. Experimental Details and Data Collection

Single channel NaI (Tl) gamma radiation detector has been used in present study. It consists of 2X2 NaI crystal doped with Tl, as scintillator detector with inbuilt photomultiplier tube operating at 900 volts dc voltage. The analyzer can be operated on window mode or on threshold mode. It has facility of varying the window from 0 to 1 volt. When operated on the threshold mode it can count all the particles having energy greater than that corresponding to the baseline voltage. When operated on the window mode it can count all the particles having energy between that corresponds baseline voltage and of window width.

The detector have been calibrated for counting efficiency with the standard gamma ray source Cs-137 (661.6 keV) and Co-60 (1173, 1332 keV). At above energies the counting efficiency matches well with that of the efficiency data provided in the manufacturer manual [12]. In the present study the efficiency corresponding to different energies were used from the manufacturer data sheet. The energy calibration with baseline voltage was obtained using standard source of Cs-137 and Co-60.

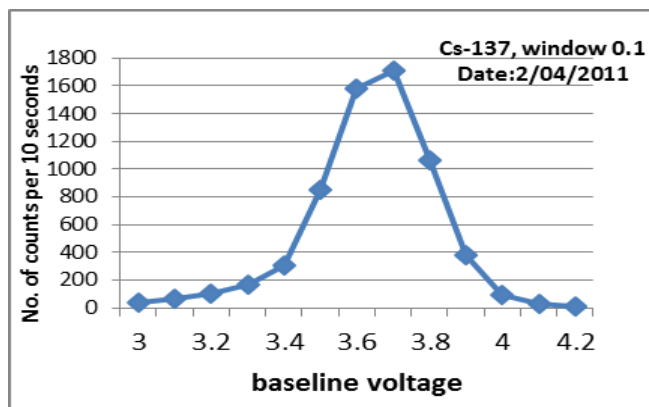


Figure 1(a): Recorded peak of Cs-137

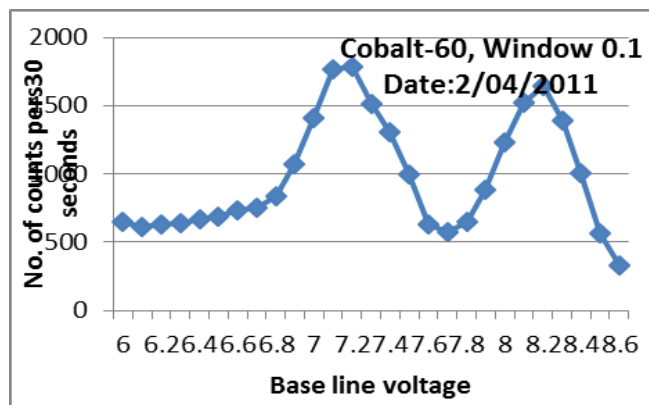


Figure 1(b): Recorded peak of Co-60

Fig.1(a) and (b) shows the recorded peaks of Cs-137 and Co-60 corresponding to the baseline voltage of 3.7, 7.2, 8.2 volts corresponding to the energies of 661.6, 1173 and 1332 keV when single channel analyzer is operated at gain of 3.9. In the entire study the detector has been operated at 900 volts tube voltage and gain of 3.9. From the above three energies peaks average conversion factor is obtained as, a baseline voltage of 0.1 volts equals to energy of 14.943 keV. Using this factor baseline voltages were converted to the energy. The energy resolution (FWHM) of the detector has been calculated and it is found to be 49 keV at 661.6 keV energy, and 41.8 keV at 1173 keV energy. In comparison with the resolution of HPGe gamma detector the resolution of NaI (Tl) detector is poor. Within the limit of poor resolution of the detector the results obtained are good.

2.1 Study Area

Observations were carried out at twenty-six different places of Sindhudurga district of Maharashtra state (India) (15°22'-16°24'N; 73°12'-74°12'E). Places of observation were nearly equally distributed in the entire district.

2.2 Data Collection

The background spectra at each place (Twenty-six places) have been obtained by two ways, one in which the detector has been operated in threshold mode by changing the baseline voltage every time by 0.5 volts and number of counts for 30 second were observed for three times and the mean of this three time counts were taken. The spectrum was obtained from 0.0 volt to 10 volts every time by increasing

the baseline voltage by 0.5 volts. The difference between the successive readings gives total number of observed counts in the baseline interval of 0.5 volts that is energy interval of 74.72 keV.

Table 1: Observed data at place Vijayadurg obtained on 09-02 2011.

Base line voltage (volts)	Observed counts for 30 second			Mean observed counts for 30 seconds	Difference between successive counts
	I	II	III		
0.0	3306	3025	2546	2959	----
0.25	4148	4162	4246	4185	-1226
0.5	3034	2942	3012	2996	1189
1.0	1523	1421	1435	1460	1536
1.5	1013	908	957	959	509
2.0	744	762	753	752	207
2.5	598	610	627	612	140
3.0	487	472	500	486	126
3.5	409	444	389	414	72
4.0	345	359	353	352	62
4.5	316	315	313	315	37
5.0	265	246	259	257	58
5.5	223	220	213	219	48
6.0	190	209	215	205	14
6.5	176	204	185	188	17
7.0	184	185	166	178	10
7.5	150	162	165	159	19
8.0	159	139	155	151	08
8.5	140	131	138	136	15
9.0	120	144	128	131	05
9.5	100	109	111	107	24
10.0	79	81	90	83	24
Above 10 volts					83

We have used this data for the calculation of gamma radiation dose at each place of observation. As an example, Table No. 1 show the data obtained at the place Vijayadurg. The negative difference between 0.0 volt and 0.25 volt is due to nonzero offset baseline voltage of the tube (- 0.6 volts).

In the second part of observations, at each place of observation the detector was operated in window mode. Window was kept at 0.25 volt. Every time changing the baseline voltage by 0.1 volts the number of counts observed above the baseline in a window of 0.25 volts for the duration of 90 second was observed. The baseline voltage was continuously changed from 0.0 to 10 volts by an interval of 0.1 volts and the number of observed counts for 90 seconds was recorded. By this way full spectra have been scanned in 100 channels each of energy 14.943 keV from energy of 0 to 1494.3 keV. Three rounds of observations of similar scanning of spectra by two ways were carried out at twenty-six different places respectively in the month of October, February, and May, of the year 2011. The average of counts per 90 second per channel of the above three months data were used for obtaining the uranium and thorium activity at the place of observation.

2.3 Data Analysis

The data obtained in the first part have been used for the calculation of the average effective external dose from

terrestrial and cosmic radiation at each place of observation. The method followed is, as indicated in Table No.1. The number of observed counts in the interval of each 0.5 volt baseline, that is the last column of table No.1 were taken. The counts were corrected for the counting efficiency of detector at respective energies. From the corrected counts, using planner geometry for the detector, the fluence corresponding to each energy interval has been calculated. The fluence is number of gamma photons incident per unit time per unit area of detector. To calculate the effective dose, the fluence is multiplied by conversion factor taken from ICRP publication. [11] We have scanned the spectra up to 1.5 MeV. Taking the exponential decay of observed gamma photons with energy and natural background gamma ray energy limit at 3 MeV, the observed count above 10 volts

baseline is respectively divided as 50%, 35% and 15% at 1.5, 2.0 and 2.5 MeV and they have been used for the calculation. The sum of effective dose from photons of all the energy intervals, were taken as the total effective dose at the place of observation [5]. The observed effective dose at each place is corrected for the negative offset voltage for the counting system. The calculation carried out for the data taken at the place Natal is presented in Table No.2. To account for large number of low energy photons unable to penetrate detector thickness and photons opposed due to negative offset voltage for the tube observed total dose is corrected by dividing to total dose obtained by a factor 0.4 at each place of observation. The effective average gamma radiation dose from terrestrial and cosmic rays obtained at twenty-six places of observation is presented in Table No.4.

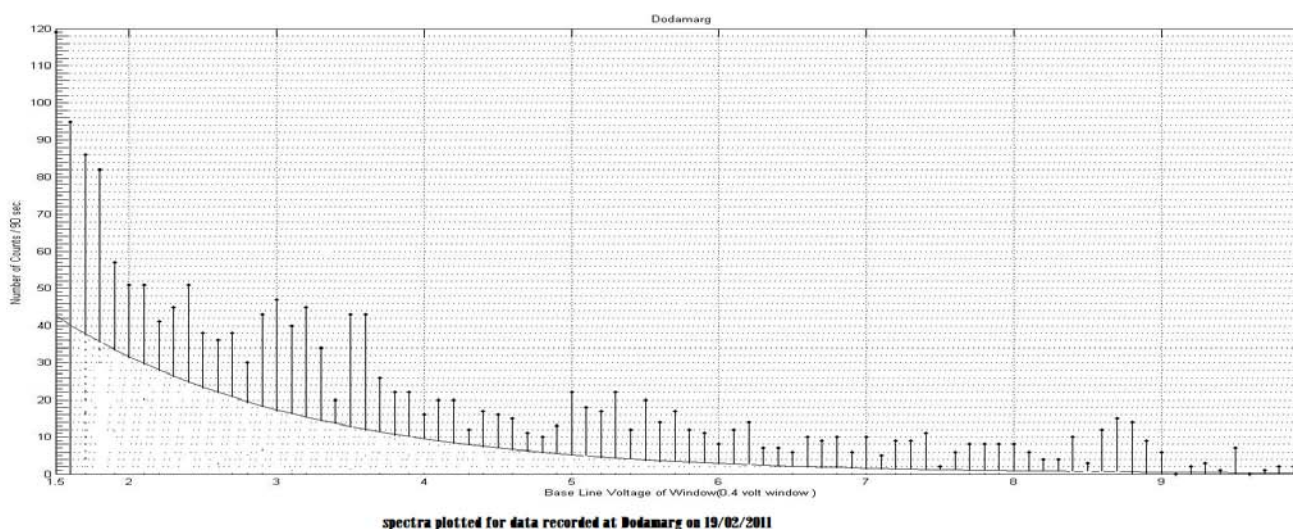


Figure 2: Spectra obtained by plotting average count with baseline voltage at place Dodamarg.

When monochromatic beam of gamma radiation of energy E enters the detector then, not all of them are counted at energy E . Along with the peak at energy E , counts at energy less than Compton edge corresponding to energy E are observed in the detector. In the second part of observations, scanned background spectra for 100 different channels each of energy 14.943 keV from energy 0 to 1494.3 keV contain specific peaks corresponding to radiation from different gamma emitters on the background of Compton scattered photons. We have plotted average number of observed counts for 90 second (average of three times data) with the baseline voltage for each place of observation. An exponential line passing through the lowest points has been drawn on these graphs. The counts below the exponential line are taken as Compton scattered counts and they have been subtracted from the corresponding energy peaks of the lines. The background spectra plotted for the data obtained at the place Dodamarg on 19-02-2011 above the baseline voltage of 1.5volts presented in Fig.2 [13].

The baseline voltage is calibrated to energy. The activity of U-238 is obtained from the observed counts after subtracting Compton counts from the four lines, Pb-214 (295.3 KeV, 18.5 %), Pb-214 (352 KeV, 35.6%), Bi-214 (609.3 KeV, 45.49%) and Bi-214 (1120 KeV, 14.9%). The activity of Th-232 is obtained from the observed counts after subtracting Compton counts from the six lines from its decay series as,

Pb-212(238KeV,43%), Tl-208(510KeV,13.8%), Tl-208(583KeV,30.6%), Bi-212(727 KeV, 6.74%), Ac-228(911KeV, 25.8%) and Ac-228(965Kev, 15.8%).[3] To calculate the activity, the corrected counts for detector efficiency and yield of the corresponding line, per second are divided by the total area of detector and it is converted per meter square. The calculations carried out on the data at the place Dodamarg are presented in Table No.3. Due to the low resolution of the detector, the activity calculated from each line show deviation but within the limit of resolution, obtained activity from each line in decay series matches good. The calculation of uranium and thorium activity for the data at Dodamarg (presented in Fig.2) is presented in the Table No. 3. To calculate the activity, the observed corrected counts per second are divided by detector area and it is converted per square meter.

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Table 2: Calculation of effective dose at the place of Natal.

Baseline voltage (V)	Observed counts	Energy (keV)	Conversion factor (PSv.cm ²)	Efficiency of detector	Corrected counts for efficiency	Fluence (cm ⁻²)	dose in mSv/year
0.5	235	75.6	0.5200	0.9500	247.4	3.4414	0.001870
1.0	166	151.2	0.8900	0.9500	174.7	2.4309	0.002272
1.5	183	226.8	1.3220	0.9338	196.0	2.7264	0.003785
2.0	104	302.4	1.8000	0.8354	124.5	1.7319	0.003274
2.5	54	378	2.2270	0.7360	73.4	1.0207	0.002387
3.0	66	453	2.6850	0.5923	111.4	1.5502	0.004371
3.5	23	529.2	3.0779	0.4779	48.1	0.6695	0.002164
4.0	29	604.8	3.4400	0.4276	67.8	0.9435	0.003408
4.5	17	680.4	3.4688	0.3840	44.3	0.6159	0.002244
5.0	23	756	4.1732	0.3477	66.1	0.9202	0.004033
5.5	11	831.6	4.5071	0.3120	35.3	0.4904	0.002322
6.0	14	907.2	4.7900	0.2747	51.0	0.7090	0.003567
6.5	12	982.7	5.1262	0.2446	49.1	0.6825	0.003674
7.0	10	1158.4	5.3700	0.2309	43.3	0.6025	0.003398
7.5	14	1133.9	5.6420	0.2145	65.3	0.9080	0.005380
8.0	0	1209.6	5.8800	0.2018	0.0	0.0000	0.000000
8.5	19	1285.1	6.1860	0.1963	96.8	1.3465	0.008748
9.0	13	1360.7	6.4240	0.1796	72.4	1.0070	0.006793
9.5	5	1436.3	6.6960	0.1637	30.5	0.4249	0.002988
10.5	0	1511.9	6.9340	0.1557	0.0	0.0000	0.000000
10.5	20	2000.0	7.0360	0.1188	168.4	2.3421	0.017305
	15	2500.0	8.6000	0.0988	151.8	2.1121	0.019075
	7	3000.0	11.1000	0.0850	82.4	1.1457	0.013355

Table 3: Activity calculation of observed data

Nuclei in Uranium Series

Sr.No	Nuclei in the decay series	Energy keV	% Yield	Efficiency of detector at corresponding energy	Position of line on the graph (at baseline voltage)	Observed counts for 90 Sec.	Corrected Counts for Efficiency and Yield	Mean corrected counts per 90 Sec.	Calculated Activity KBq / m ²
1.	Pb ²¹⁴	295.3	18.50	0.8360	1.2	45.0	290	257.5	0.941
2.	Pb ²¹⁴	352.0	35.60	0.7560	1.5	76.0	282		
3.	Bi ²¹⁴	609.3	45.49	0.4270	3.2	31.0	159		
4.	Bi ²¹⁴	1120.0	14.90	0.2245	6.6	10.0	299		

Nuclei in Thorium Series

1.	Pb212	238.0	43.00	0.9333	0.9	120.0	272	230.0	0.841
2.	Tl208	510.0	13.80	0.4879	2.5	15.0	222		
3.	Tl208	583.0	30.60	0.4370	2.8	29.0	216		
4.	Bi212	727.0	6.27	0.3770	4.0	6.2	244		
5.	Ac228	911.0	25.80	0.2747	5.2	12.0	169		
6.	Ac228	965.0	15.80	0.2546	5.6	10.4	258		

3. Results and Discussion

The observed average gamma radiation effective dose from terrestrial radioactive sources and cosmic rays, at one foot above the earth surface in open atmosphere, in mSv/y and nSv/h at twenty six different places in Sindhudurg district of Maharashtra state is presented in Table No.4. The activity of U-238 and Th-232 and the uranium thorium activity ratio at the places is also presented in Table No.4

The mean effective gamma radiation dose at the places of observation is found to be 0.5244 mSv/y with range of variation, from 0.2864 mSv/y to 0.8044 mSv/y. The mean effective dose is slightly higher than the effective mean dose reported for Maharashtra state and is close to the mean value reported for Goa state.[4,9] For the coastal places such as Vijayadurg, Devgad, Chidar, Vengurla, Parule the effective dose is found to be higher while for the places near to the Sahyadri ghat mountain such as Bhuibawada, Nandgaon, Phonda, Natal, Dukanwad, Godagewadi have lower value of effective dose. The coastal region contain porous rocks, in

local language called as Jamba and the soil formed from it while the region near the Sahyadri ghat contain black and hard igneous rocks and soil formed from it. Uranium-238 activity varies from 0.466 KBq/m² to 1.133 KBq/m² with mean value of 0.751 KBq/m². Thorium-232 activity varies

from 0.552 KBq/m² to 1.267 KBq/m² with mean 0.8466 KBq/m². The U238 to Th232 activity ratio varies from 0.494 to 1.2 with mean 0.886. The variation in uranium thorium ratio is found to be high than the global ratio of 0.3

Table 4: Effective gamma radiation dose, U-238 and Th-232 activity and activity ratio

Sr. No.	Place of observation	Effective gamma dose In mSv/y	Effective gamma dose In nSv/h	Activity of U-238 KBq/m ²	Activity of Th-232 KBq/m ²	U-238 to Th-232 Activity Ratio
1	Vijayadurg	0.6025 $\pm$ 0.0540	68.77	0.929	1.267	0.733
2	Padel	0.5379 $\pm$ 0.0409	61.40	0.757	0.636	1.189
3	Devgad	0.5925 $\pm$ 0.0312	67.63	1.133	1.111	1.019
4	Talebazar	0.4889 $\pm$ 0.0364	55.81	0.937	1.009	0.928
5	Phanasgaon	0.4866 $\pm$ 0.0224	55.54			
6	Nandgaon	0.3301 $\pm$ 0.0224	37.68	0.493	0.592	0.833
7	Bhuibawada	0.3670 $\pm$ 0.0220	41.89	0.466	0.702	0.664
8	Vaibhavwadi	0.4428 $\pm$ 0.0340	50.54	0.870	0.899	0.967
9	Phonda	0.3630 $\pm$ 0.0156	41.43	0.811	0.522	1.470
10	Kankavali	0.4936 $\pm$ 0.0770	56.34	0.658	0.632	1.040
11	Nathal	0.2864 $\pm$ 0.0046	32.69	0.533	0.705	0.756
12	Chindar	0.7510 $\pm$ 0.03180	85.73	0.949	1.053	0.901
13	Malvan	0.3847 $\pm$ 0.0115	43.91	0.576	1.168	0.492
14	Kasal	0.7408 $\pm$ 0.0239	84.56	0.875	0.934	0.936
15	Oros	0.3815 $\pm$ 0.0270	43.55			
16	Salagaon	0.8044 $\pm$ 0.0424	91.82	0.674	1.053	0.640
17	Dukanwad	0.4665 $\pm$ 0.01500	53.25	0.751	0.828	0.907
18	Vetora	0.6269 $\pm$ 0.0610	71.76	0.746	0.887	0.755
19	Vengurla	0.5843 $\pm$ 0.0190	66.70	0.789	0.658	1.2
20	Kerawada	0.5259 $\pm$ 0.0380	60.03	0.727	0.972	0.748
21	Parule	0.7627 $\pm$ 0.0280	87.06	1.115	1.103	1.011
22	Sangeli	0.4258 $\pm$ 0.0300	48.60	0.676	1.162	0.848
23	Majagaon	0.6868 $\pm$ 0.0540	78.40	0.746	0.927	0.804
24	Dodamarg	0.5595 $\pm$ 0.0210	63.86	0.650	0.727	0.894
25	Banda	0.5466 $\pm$ 0.0384	62.39			
26	Godagewadi	0.3973 $\pm$ 0.0210	45.35	0.614	0.731	0.84

4. Conclusions

The measured absolute activities of U-238 and Th-232 at different places of observation have presented in this paper and it forms the baseline data for these places. The variation in U-238 to Th-232 ratio is larger; the change in activity of U-238 is smaller while Th-232 activity changes by larger amount. Effective gamma radiation dose changes from place to place. Higher level is observed for the coastal region and lower level in the region near to the Sahyadri Mountain. At all these places radiation level is well within prescribed limits recommended by ICRP.

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