Measurement of terrestrial gamma radiation dose-rate (TGRD) level in soil samples from the district of Rembau, Malaysia, using high-purity Germanium detectors

N E Norbani¹, N A Abdullah Salim² and A T Abdul Rahman¹,³,⁴.
¹Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia
²Malaysian Nuclear Agency, 43000 Bangi, Malaysia
³Department of Physics, University of Surrey, GU27XH Guildford, United Kingdom
⁴Institute of Science, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia

E-mail: ahmadtaufek@salam.uitm.edu.my

Abstract: This study assesses the gamma radiation levels and associated dose rates from the naturally occurring radionuclides \(^{232}\text{Th}\), \(^{238}\text{U}\) and \(^{40}\text{K}\) in soil samples collected from the district of Rembau, Malaysia using High-purity Germanium (HPGe) Detectors. A 105 measurement were performed on surface soil using NaI (Tl) gamma-ray detector with crystal size 1”x1”, covering about 83% land of the Rembau district. The concentration of the naturally occurring radionuclides \(^{232}\text{Th}\), \(^{238}\text{U}\) and \(^{40}\text{K}\) in soil samples collected were determined by using HPGe detector based on high-resolution gamma spectrometry system at Malaysia Nuclear Agency. The range of natural gamma radiation measured was from 114±14 nGy h\(^{-1}\) to 857±14 nGy h\(^{-1}\). The range of activity concentrations of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) in soil from the studied areas varies from 151-401 Bq kg\(^{-1}\), 113-342 Bq kg\(^{-1}\) and 674-1526 Bq kg\(^{-1}\) with mean values of 245 Bq kg\(^{-1}\), 186 Bq kg\(^{-1}\) and 1152 Bq kg\(^{-1}\) respectively. The mean values of terrestrial gamma radiation dose rate measured in Rembau district is 383±18 nGy h\(^{-1}\) compared to the Malaysian average is 92 nGy h\(^{-1}\) and world average is 59 nGy h\(^{-1}\) (UNSCEAR, 2000). The average annual dose from such terrestrial gamma radiation dose rates to an individual in Rembau district, assuming a tropical rural setting is estimated to be 0.78 mSv per year, which is considered to be within the normal range for doses from natural sources. An isodose map for the Rembau district has been plotted.

1. Introduction
Knowledge of various radionuclides in soil and rocks plays an important role in health physics and geo-scientific research [1]. The naturally occurring radionuclides \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) are the main sources of radiation in soils and rocks from which traditional building materials are derived. These radionuclides cause exposure risks externally due to their gamma-ray emissions [2]. Even though these radionuclides are widely distributed, their concentrations have been available depend on the local geological conditions and as such they vary from place to place [3]. This study assesses the level of terrestrial gamma radiation dose rate (TGRD) and associated dose rates from the naturally occurring radionuclides \(^{232}\text{Th}\), \(^{238}\text{U}\) and \(^{40}\text{K}\) in soil samples collected from the district of Rembau, Malaysia using High-purity Germanium (HPGe) Detectors.
The study examines relationship between TGRD levels, soil types and underlying geological formations in the district of Rembau, Malaysia. Studies agree that specific levels of TGRD are related to the composition of each lithological areas separated, and to the content of the rock from which the soils originate [4]. Yet, there is still no complete data of TGRD for the district of Rembau, Malaysia. The information provided will be used as a base line data for future reference as well as to predict the external gamma-ray dose rates throughout Malaysia without resorting to the full scale, laborious measurement from the ground. There is no doubt that the rapid development of the city of Kuala Lumpur has contributed towards the development of a new town in the district of Rembau. Accordingly, the TGRD information is very important as reference data for the background radiation dose, especially after reclamation is done for the development. This is also important in case of radioactive contamination occurred in the district of Rembau. Rembau district is located between latitudes 2° 25’ and 2° 43’ North and longitude 102° 00’ and 102° 13’ East. It has an area approximately 440 km$^2$ and a population of about 41 000 persons [5]. Seventy per cent of the area is covered by forest and the main land use is for agriculture. However the development of new town throughout the district of Rembau has been started recently.

Rembau district can be divided into three major geological formations of different geological age [6] as shown in Figure 1 and Table 1. The geological formations overlaid are, (a) Devonian, (b) Silurian and (c) Acid Intrusive Rock. Devonian (G5) and Acid Intrusive Rock (G7) are most abundant in Rembau district, about 60 per cent of the area.

| Geological Label | Geological Name | Composition |
|------------------|-----------------|-------------|
| G5               | Devonian        | Phyllite, schist and slate, limestone and sandstone, locally prominent. Some interbeds of conglomerate, chert and rare volcanic. |
| G6               | Silurian        | Schist, phyllite, slate and limestone. Minor intercalations of sandstone and volcanic. |
| G7               | Acid Intrusive  | Undifferentiated of granite and intrusives rock. |

Rembau district is overlaid by six group of soil types as classified by FAO/UNESCO [7] as shown in Figure 2 and Table 2. The soil types are;

(a) Nitosol: Nitosols is a soil of shiny pad surfaces. There are three types of Nitosols, namely Dystric Nitosols (Renggam), Rhodic Nitosols (Tavy) and Haplic Nitosols (Serdang). Dystric Nitosols is the most abundant soil type in Rembau district.

(b) Ferralsols: Ferralsols is a soil with high content of sesquioxides. There are two types found in the Rembau district. These soil types are characterized as Orthic Ferralsols and Plinthic Ferralsols. It is also called Munchong and Malacca.

(c) Acrisols: Acrisols is an acidic soil of low base saturation. Two types are found in the southern part of Rembau district. They are characterized, as Orthic Acrisols and Plinthic Acrisols, and the local names are Batu Anam and Durian respectively.

(d) Fluvisols: Fluvisols; this group consists of flood plains and alluvial soils. There is one type of Fluvisols, namely Thionic Fluvisols, and the local names is Kranji. Most of these groups are found on the coastal plain, mostly in tidal swamps covered by mangrove.

(e) Leptosols: This group consists of clay in all horizons to a depth of 100cm or more. There is only one type of this group in Rembau district. Dystric Leptosols or local name called Seremban Series.

(f) Miscellaneous soils, (i) Steep Land. (ii) Local Alluvium: Most of Rembau district is steep land with forested area above 30 m in height [8].
Figure 1. Map of geological features in Rembau district of Negeri Sembilan state, Malaysia [6].

Figure 2. Map of soil types in Rembau district of Negeri Sembilan, Malaysia [7].

Table 2. Soil types of Rembau district, Malaysia.

| Soil types label | FAO units | Local name               |
|------------------|-----------|--------------------------|
| S2               | Dystric Nitosols | Renggam                  |
|                  | Orthic Acrisols-Plinthic Acrisols-Plinthic | Batu Anam-Durian-       |
| S12              | Ferrasols         | Malacca                  |
| S14              | Plinthic Acrisols-Plinthic Ferrasols       | Durian-Malacca         |
| S16              | Plinthic Acrisols-Dystric Leptosols         | Durian-Seremban        |
|                  | Plinthic Ferrasols-Rhodic Nitosols-Orthic  |                         |
| S19              | Ferrasols         | Malacca-Tavy-Munchong   |
| S26              | Orthic Ferrasols-Plinthic Ferrasols         | Munchong-Malacca       |
| S29              | Haplic Nitosols-Orthic Ferrasols-Rhodic    | Serdang-Munchong-Tavy  |
| S36              | Nitosols          | Kranji                   |
| S43              | Thionics Fluvisols | Local Alluvium          |
| S48              | Steep Land        | Steep Land               |
2. Methods
Measurement of gamma radiation levels will made at each crossing point of the latitude and longitude lines. Rembau district will align the grid into squares of area around 1’ x 1’ (about 1.85 km x 1.85 km). The location for each sampling point will establish by global positioning system (GPS) (Garmin eTrex HC series) [9] and survey gamma radiation levels at the field.

Measurements of the gamma radiation levels were conducted with gamma ray detectors manufactured by Ludlum of the U.S.A using model 19, Micro R Meter. The equipment uses a 2.54 x 2.54 cm NaI crystal doped with thallium [NaI(Tl)], which responds to gamma radiation. The smallest scale division for the instrument is 1 µR h\(^{-1}\) (~ 9 nGy h\(^{-1}\)) [10]. The instrument had almost a flat energy response to gamma radiations between 40 keV to 1.2 MeV [11]. It is suitable for environmental gamma radiation measurements. It covers majority of significant gamma radiations emitted from terrestrial sources [12]. The uncertainty of reading observe on the maximum scale of the instrument is of the order of 10%. The measurements of TGRD survey is taken away from sites of developments such as road, building and foundation soils.

Six soils samples were collected covering the high, medium and low level of terrestrial gamma radiation dose-rate measured in situ. The soil samples were collected at a depth of 5 cm of surface soils. The samples were packed in a plastics bag, label with the date, location and bring in the laboratory for analysis. Move the stones, pebbles and organic materials from the sample then the samples will dry in an oven at about 100 ºC for 24 hours to remove the moisture content and crush to pass through a fine mesh sieve (315 µm) to homogenize size. Then, it was deposited into a marinelli beaker and seal with a PVC tape and store about a month before counting. The marinelli beaker is use because of their ability to provide good detection sensitivity. Each sample will analyze; this is done as part of quality assurance and quality control of the analytical technique and as test of analytical precision [9]. \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K concentration will be measure using high-purity germanium detectors.

The activities of these samples and standards will be measured by using a horizontal hyper germanium detector coupled to an Analog to Digital Convertor (ADC) facilities at radiation laboratory, Agency Nuclear Malaysia. A Nuclear Data 66 computerised Multi-channel analyser will use for pulse height analysis. This counting system has an energy resolution of 1.00 keV adjust to the full width at half maximum (FWHM) of the 1332 keV gamma ray of \(^{60}\)Co [9].

Count rates were recorded for seven gamma energies: 0.239 MeV (\(^{212}\)Pb, with a 44.6% gamma yield); 0.352 MeV (\(^{214}\)Pb, 37.1%); 0.609 MeV (\(^{214}\)Bi, 46.1%); 0.911 MeV (\(^{228}\)Ac, 27.7%); 1.461 MeV (\(^{40}\)K, 10.7%); 186 keV (\(^{226}\)Ra, 3.41%) and 583.1 keV (\(^{208}\)Tl, 86.0%). Concentrations of \(^{232}\)Th were determined from the average concentrations of \(^{228}\)Ac, \(^{212}\)Pb and \(^{208}\)Tl in the sample, and \(^{238}\)U was determined from the average of the \(^{226}\)Ra, \(^{214}\)Bi and \(^{212}\)Pb concentration.

Finally, using the WinSurf 32 (Golden Software Company), the isodose map of the terrestrial gamma radiation dose rate levels has been plotted for Rembau district.

3. Results
The distribution of the gamma radiation levels data is presented by histogram in Figure 3. The most frequently recorded value were at 300 and 600 nGy h\(^{-1}\).

![Figure 3. Frequency histogram of gamma radiation levels in the district of Rembau, Negeri Sembilan.](image-url)
Table 3 and Table 4 show mean gamma radiation levels for each different geological features and for each different soil types. Acid Intrusives Rock (G7) gives the highest mean gamma radiation levels, which is 536 nGy h\(^{-1}\). Dystric Nitosols (S2), Local Alluvium (S43) and Steep Land (S48) were the most abundant soil types covering of Rembau district. They give the highest mean gamma radiation levels measured that are 493 nGy h\(^{-1}\), 506 nGy h\(^{-1}\) and 547 nGy h\(^{-1}\) respectively. The lower mean gamma radiation levels were found in the areas covered by soil types Haplic Nitosols-Orthic Ferrasols-Rhodic Nitosols (S29) and Plinthic Ferrasols-Rhodic Ferrasols (S19), that is 221 nGy h\(^{-1}\) and 229 nGy h\(^{-1}\) respectively. The area in Rembau district covered by Devonian geological features show the lowest mean gamma radiation levels measured, which is 274 nGy h\(^{-1}\).

The highest gamma radiation levels measured in Rembau district is 857 ± 14 nGy h\(^{-1}\). It was found in area covered by soil type Dystric Nitosols (S2) and Local Alluvium (S43) with underlying geological features Acid Intrusive (G7). These soil type of high gamma radiation levels is abundant in granitic areas, which are extensively intruded by schist, shale, quartzite and siltstone. Granites usually have U, Th and K contents higher than other crustal rocks [13]. Dysitrict Nitosols or locally named Renggam also has 43% clay content and the highest K concentration in 0 – 8 cm depth from surface [8]. Both of these soil type are found in area with underlying of Acid Intrusive Rock (G7). Acid Intrusive Rock is rock that has crystallized from molten rock material called magma. These rocks contain higher monazite, basalt and rhyolite [12]. Therefore the highest gamma radiation levels were found in the area covered by those soil types and geological features. It was found in area covered by Haplic Nitosols-Orthic Ferrasols-Rhodic Nitosols (S29) with underlying geological features Devonian (G5).

Table 3. Mean gamma radiation levels measured for each different geological features covering the Rembau district, Malaysia.

| Geologic features | Gamma Radiation Levels (nGy h\(^{-1}\)) | 95% confidence interval for mean |
|------------------|--------------------------------------|---------------------------------|
|                  | Mean | Standard deviation | Minimum | Maximum | Standard error | Lower bound | Upper bound |
| G5               | 274  | 114               | 114     | 629     | 15              | 244         | 304         |
| G6               | 400  | 149               | 300     | 571     | 86              | 30          | 770         |
| G7               | 536  | 19                | 214     | 857     | 19              | 498         | 674         |

Table 4. Mean gamma radiation levels measured for each different soil types covering the Rembau district, Malaysia.

| Soil types | Gamma Radiation Levels (nGy h\(^{-1}\)) | 95% confidence interval for mean |
|------------|--------------------------------------|---------------------------------|
|            | Mean | Standard deviation | Minimum | Maximum | Standard error | Lower bound | Upper bound |
| S2         | 493  | 106               | 257     | 686     | 23              | 446         | 540         |
| S12        | 264  | 71                | 214     | 314     | 50              | 294         | 234         |
| S14        | 245  | 82                | 157     | 629     | 14              | 216         | 274         |
| S16        | 288  | 90                | 214     | 486     | 34              | 205         | 371         |
| S19        | 229  | 40                | 200     | 257     | 29              | 199         | 259         |
| S26        | 295  | 71                | 214     | 243     | 41              | 245         | 345         |
| S29        | 221  | 214               | 114     | 543     | 107             | 181         | 261         |
| S43        | 506  | 169               | 214     | 857     | 51              | 392         | 620         |
| S48        | 547  | 130               | 214     | 714     | 30              | 484         | 610         |
The lowest gamma radiation levels measured in Rembau district is 114 ± 14 nGy h\(^{-1}\). Lower gamma radiation levels were registered on Haplic Nitosols-Orthic Ferrasols-Rhodic Nitosols (S29) and Plinthic Ferrasols-Rhodic Nitosols-Orthic Ferrasols (S19) with underlying of geological features Devonian (G5) in certain location along the river. These soil types was overlaid by Devonian geological structure, which was formed from phyllite, schist and slate, limestone and sandstone, locally prominent as peat, humic clay and silt. Gamma radiation levels generally are lower in Devonian area. This is similar to the previous study at Melaka [14].

Following the spectrum analysis, the count rates for each detected photopeak and activity per mass unit (specific activity or radiological concentration) for each of the detected nuclides are calculated. The specific activity (in Bq kg\(^{-1}\)), \(A_{Ei}\), of a nuclide I and for a peak at energy E, is given below:

\[
A_{Ei} = \frac{N_{Ei}}{(M_{E} \times t \times Y_d \times M)}
\]

where \(N_{Ei}\) is Net Peak Area of a peak at energy E, \(M_{E}\) is the detection efficiency at energy E, \(t\) is the counting livetime, \(Y_d\) is the number of gammas per disintegration efficiency of this nuclide for a transition at energy E, and \(M\) is the mass in kg of the measured sample [10].

**Table 5.** The activities concentrations of the \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K in Bq kg\(^{-1}\) for the soil samples in Rembau district.

| Sample No. | \(^{238}\)U [Bq kg\(^{-1}\)] | \(^{232}\)Th [Bq kg\(^{-1}\)] | Ratio U/Th | \(^{40}\)K [Bq kg\(^{-1}\)] |
|------------|-----------------------------|-----------------------------|------------|-----------------------------|
| 1          | 230                         | 149                         | 2:1        | 674                         |
| 2          | 285                         | 152                         | 2:1        | 894                         |
| 3          | 402                         | 342                         | 1:1        | 1136                        |
| 4          | 188                         | 150                         | 1:1        | 1455                        |
| 5          | 214                         | 213                         | 1:1        | 1526                        |
| 6          | 151                         | 113                         | 1:1        | 1226                        |
| **Mean**   | **245**                     | **186**                     | **1:1**    | **1152**                    |

Table 5 shows the range of activity concentrations of \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K in soil from the studied areas varies from 151-402 Bq kg\(^{-1}\), 113-342 Bq kg\(^{-1}\) and 674-1526 Bq kg\(^{-1}\) with overall mean values of 245 Bq kg\(^{-1}\), 186 Bq kg\(^{-1}\) and 1152 Bq kg\(^{-1}\) respectively. The ratio of uranium to thorium is calculated to be 1:1 compared to the world average is 3:1[15]. Figure 4(a) shows the graph of uranium concentration vs. thorium concentration obtained in Rembau. Increase concentration of uranium, thorium and potassium in the crust is generally when the content of SiO\(_2\) and K\(_2\)O [16]. It is important to assess the gamma radiation hazards to human associated with the used these samples for buildings; these were done by calculating the different radiation hazard indices.

The absorbed dose-rate, \(D_c\) (nGy h\(^{-1}\)), at the surface soil due to the concentrations of \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K in soil in all sampling locations is presented in Figure 4(b). The dose can be calculated using the absorbed dose-rate activity conversion factors depending on the radionuclides studies in the soil. The convesion factor by [15] was adopted and calculated using the equation given below:

\[
D_c = 0.427 A_U + 0.662 A_{Th} + 0.043 A_K
\]

where \(A_U\), \(A_{Th}\) and \(A_K\) are the activity concentrations of primordial radionuclide \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K) existing in the soil in Bq kg\(^{-1}\). The straight line from Figure 4(b) show that the correlation
coefficient indicates good general agreement between measured and calculated dose rates obtained.

The ultimate use of the measured activities in building materials is to estimate the radiation dose expected to be delivered externally if a building is constructed using these materials. To limit the annual external gamma-ray dose to 1.5 mSv y\(^{-1}\) [15], the external hazard index (H\(_{ex}\)) is given by the following equation:

\[
H_{ex} = \frac{A_U + A_{Th} + A_K}{740 + 520 + 9620} \leq 1
\]  

(3)

where \(A_U\), \(A_{Th}\) and \(A_K\) are the concentrations of \(^{238}\)U, \(^{232}\)Th and \(^{40}\)K, respectively, in Bq kg\(^{-1}\). Radiation hazard are assume negligible if the value is less than unity.

![Graph of log dose-rate measured, lnD\(_m\) versus log dose-rate calculated, lnD\(_c\).](image)

**Figure 4.** (a) Ratio of uranium and Thorium in soil sample of Rembau district and (b) Correlation graph of log dose-rate measured, lnD\(_m\) versus log dose-rate calculated, lnD\(_c\).

From Table 6 also recorded the external hazard index (H\(_{ex}\)) for the study area. The calculated values of H\(_{ex}\) for the soil samples in this studied are in range 0.54-1.32. The value of this index must be less than unity in order to keep the radiation hazard to be insignificant. Since the values of the study area are less than unity, therefore, according to Radiation Protection 112 report, this region is assume safe to population.

Outdoor gamma radiation levels measured throughout of Rembau district was conducted in this study. Figure 5 shows the isodose map of gamma radiation levels measured was drawn to present environmental gamma radiation levels distribution in Rembau district. A comprehensive understanding of spatial distribution of gamma dose rate is essential in assessing potential human risk associated with surface soil contamination by radionuclide. It is important for determining radiation detriment to the population as a whole.
Table 6. The measured values of dose rates ($D_m$) and external hazard index ($H_{ex}$) of the samples under investigation in Rembau district.

| Sample No. | Soil | Geology | Measured dose-rate, $D_m$ [nGy h$^{-1}$] | External Hazard Index ($H_{ex}$) |
|------------|------|---------|--------------------------------------|----------------------------------|
| 1          | S2   | G7      | 686                                  | 0.66                             |
| 2          | S43  | G7      | 857                                  | 0.77                             |
| 3          | S43  | G7      | 486                                  | 1.32                             |
| 4          | S2   | G7      | 486                                  | 0.69                             |
| 5          | S14  | G5      | 200                                  | 0.85                             |
| 6          | S14  | G5      | 171                                  | 0.54                             |
| Mean       |      |         | 383                                  | 0.80                             |

Figure 5. Isodose map district of Rembau, Negeri Sembilan.

4. Conclusions
The average terrestrial gamma radiation dose rates measured in Rembau district is 383 ± 18 nGy h$^{-1}$ and the population weighted mean dose rate Rembau is 316 nGy h$^{-1}$. The Malaysian average is 92 nGy h$^{-1}$ and world average is 59 nGy h$^{-1}$ [15]. The finding show the average was 4 times higher than Malaysian average and 6 times higher than world average. The range of activity concentrations of $^{238}$U, $^{232}$Th and $^{40}$K in soil from the studied areas varies from 151-402 Bq kg$^{-1}$, 113-342 Bq kg$^{-1}$ and 674-1526 Bq kg$^{-1}$ with overall mean values of 245 Bq kg$^{-1}$, 186 Bq kg$^{-1}$ and 1152 Bq kg$^{-1}$ respectively. The total absorbed dose rates in air calculated from the concentrations of the three radionuclides ranged from 192 nGy h$^{-1}$ to 447 nGy h$^{-1}$ and the external annual effective dose rate of the areas were determined to be between 0.39-0.91 mSv y$^{-1}$. The results can be considered as base values for distribution of natural radionuclides in the region and will be used as reference information to assess any changes in the radioactive background level due to geological processes. Using the conversion factor of 0.7 Sv/Gy  [15] the average dose from such terrestrial gamma radiation dose rate to an
individual assuming a tropical rural setting is estimated to be 0.78 mSv per year, which is considered to be within the normal range for doses from natural sources. It is not expected to cause statistical significance radiology health impact.

Acknowledgement

The authors would like to thank the Universiti Teknologi MARA, Malaysia (UiTM) for the Excellent Research Fund Scheme under Grant 600-RMU/ST/DANA 5/3/DST (12/2012) and the Ministry of Education Malaysia for supporting a research studentship for Nor Eliana Norbani under Mymaster [KPT (B) 890521115338]. A special gratitude goes to the State Government of Negeri Sembilan especially various government officials, and also to various owners of the lands, plantations and estates who have allowed us access to their properties to complete the ground survey.

References

[1] M Eisenbud. Environmental Radioactivity. New York : McGraw-Hill Book Company, 1963. pp. 135-163.
[2] UNSCEAR. Sources and Effects of Ionizing Radiation. United Nations, New York. : United Nations Scientific Committee on the Effects of Atomic Radiation, 1988.
[3] A C Tennesseen. Nature of earth materials. Printice-Hall, 1994. pp. 333-334. NJ07632.
[4] A T Abdul Rahman, M Z Jaafar, A T Ramli, M N Hasan. Kusadasi Turkey : The International Nuclear Chemistry Congress 2005; 22 May - 30 May 2005, 2005.
[5] Department Geological and Geophysics, 2000.
[6] Director General of Geological Survey. Map of Geological Features in Negeri Sembilan, Malaysia. 1985.
[7] Director General of Agriculture Peninsular Malaysia. Map of Soil Types in Negeri Sembilan, Malaysia. 1973.
[8] Yaacob and Jusop. Soil Science. Kuala Lumpur : Dewan Bahasa and Pustaka, 1982.
[9] A T Ramli, A T Abdul Rahman, Abd Khalik Wood. Johor Bharu : s.n., 2003. The Proceeding of Annual Fundamental Science Seminar 2003; Towards the Fundamental Research. 20-21 May 2003. pp. 247-256.
[10] A T Ramli. Environmental Terrestrial Gamma Radiation Dose and its Relationship with Soil Type and Underlying Geological Formations in Pontian District, Malaysia. 1997, Pergamon, pp. 407-412.
[11] G K Knoll. Radiation Detection and Measurement (second edition). New York : Wiley and Sons, 1989.
[12] Radiological Characteristics of a Village on Uraniferould Granitic Ground in Finland. A Voutileinen, O Castren, I Makelainen, K Winqvist and H Arvela. 1988, Radiation Protection Dosim., pp. 333-337.
[13] Zaini Hamzah, Ahmad Saat, Noor Hayati Mashuri and Seh Datul Redzuan. Surface radiation dose and radionuclide measurement in-ex-tin mining area, Kg Gajah, Perak. 2008, The Malaysian Journal of Analytical Sciences, pp. 419 - 431.
[14] A T Ramli, Sallehudin Sahrone and Husin Wagiran. Terrestrial gamma radiation dose study to determine the baseline for environmental radiological health practices in Melaka state, Malaysia, 2005, Radiological Protection.
[15] UNSCEAR. United Nation Scientific Committee Of The Effect Atomic Radiation Report on The General Assembly. New York : United Nation, 2000. pp. 1-112.
[16] Y Narayana, H M Somashekarappan, N Karunakara, D N Avadhani, H M Mahesh and K Siddhappa Natural Radioactivity In The Soils Sample Of Coastal Karnataka Of South India. 2001, Health Physics, pp. 24-33.
[17] Director of National Mapping. Map of Negeri Sembilan, Malaysia c type 2nd ed. Kuala Lumpur, Malaysia. 1989.