LAPORAN AKHIR R & D.

KAJIAN KAWASAN SINARAN TABI'I TINGGI DI PALONG, SEGAMAT.

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Laporan untuk penyelidikan menggunakan geran dari Unit Penyelidikan dan Perundingan (RMC) Vot 71159. 1997 – 99.

ABSTRAK

Pengukuran kadar dos sinar gama daratan, *terrestrial gamma radiation dose-rate* (TGRD) di alam sekitar telah dilakukan di negeri Johor. Dari data yang diperolehi hubungan di antara latarbelakang geologi dan jenis tanah dengan aras TGRD telah dianalisis secara statistik menggunakan kaedah analisis varians sehala, *one way analysis of variance*, ANOVA. Semasa penyiasatan kawasan sinaran latarbelakang tabi'i tinggi telah ditemui di Palong, Daerah Segamat, Johor. Kajian radiologi telah dilakukan untuk menentukan aras TGRD dan dos kepada penduduk di kawasan tersebut. Pengukuran kepekatan uranium-238 dan torium-232 dalam sampel tanah, air, rumput rampai, lumut dan buah kelapa sawit telah dilaksanakan untuk menentukan kemungkinan hazard radiologi yang ada.

ABSTRACT.

Measurements of environmental terrestrial gamma radiation dose-rate (TGRD) have been conducted in the state of Johor, Malaysia. Using the data obtained, relationships between geological background and soil types with TGRD levels were analysed statistically using one way analysis of variance (ANOVA) method. In the course of the investigation an area of high natural background radiation was found in Palong, Segamat District, Johor. Radiological studies to determine the TGRD levels and the dose to the population in the area were conducted. Measurements of uranium-238 and thorium-232 concentrations in samples of soil, water, grass, moss and oil palm fruit were carried out to determine their possible radiological hazards.

PENGHARGAAN.

Segala Puja-pujian hanya sanya kepada Allah s.w.t., Tuhan semesta 'alam. Selawat dan salam kepada rasul junjungan Nabi Muhammad s.a.w.

Penyelidikan ini telah dilaksanakan dengan menggunakan berbagai kemudahan yang terdapat dan disediakan oleh Universiti Teknologi Malaysia, khususnya melalui pemberian peruntukan penyelidikan jangka pendek Vot 71159 dan Vot. 61792. Sewajarnya setinggi-setinggi penghargaan dirakam untuk semua pihak di Universiti Teknologi Malaysia yang telah membantu penyelidikan ini secara langsung dan tidak langsung, terutamanya kepada staf Unit Penyelidikan dan Perundingan (*ketika itu*) dan staf Fakulti Sains.

Penyelidikan ini juga telah memanfaatkan banyak kemudahan Institut Penyelidikan Teknologi Nuklear Malaysia, MINT. Oleh itu setinggi-tinggi penghargaan juga turut dirakamkan untuk semua pihak di Institut Penyelidikan Teknologi Nuklear Malaysia, terutamanya kepada Dr A. Khalik Wood, Puan Jamaliah M. Yatim, Puan Pirmula dan Puan Ecwiat. Semoga kerjasama ini akan berterusan demi untuk kemajuan negara.

Penyelidikan ini telah memanfaatkan data dan maklumat yang telah diperolehi dari penyelidikan sebelumnya yang dibiayai oleh Kerajaan Malaysia dibawah mekanisme IRPA melalui geran no. 4-07-07-040. Sekali lagi dirakamkan penghargaan kepada semua yang terlibat.

Beberapa individu telah memberikan sumbangan yang penting kepada penyelidikan ini diantaranya ialah:-

1. En. Mior Sallehhuddin dan rakan-rakan dari Jabatan Kajibumi, Malaysia.
2. En. Sahibi Mokhtar dan rakan-rakan dari Bahagian Kaji Tanah, Kementerian Pertanian Malaysia.
3. Abdel Wahab M.A. Hussein yang merupakan pelajar M.Sc untuk projek ini.
4. En. Yusof Jasman yang merupakan pembantu penyelidik projek IRPA no. 4-07-07-040.

Sumbangan individu berikut dalam pengumpulan data, yang mungkin mengambil masa berhari-hari, kadang kala di hutan belantara dan di tempat-tempat yang biasanya tidak di lawati manusia turut amat dihargai. Mereka ialah En. Lee Siak Kuan, En. Sulaiman Abdullah, En. Abdullah Yusof, En. Mohd Yasin Sudin, En. Ahmad S$_o$alahuddin Al-Thani, En. Ahmad Al-Faruq, En. Bakri Rosdi dan En. Khairunnadim Ahmad Sekak.

Data untuk penyelidikan ini telah dikumpul dengan bantuan berbagai pihak yang tidak mungkin dapat dirakamkan kesemuanya di sini, kepada kesemuanya diucapkan jutaan terima kasih, khususnya kepada ramai pegawai kerajaan dari pelbagai jabatan, masjid-masjid yang menjadi tempat penginapan dan persinggahan, dan tuan-tuan tanah dan ladang yang telah membenarkan kemasukan ke kawasan mereka. Banyak pihak telah memberi pelbagai bantuan, kadang kala dalam keadaan yang sukar dan mencabar.

ISI KANDUNGAN.

BAB 1.

PENGENALAN.

Kepentingan kajian mengenai keradioaktifan dan aras sinaran semula jadi di alam sekitar telah dikemukakan dalam bahagian pengenalan pada kertas-kertas kerja yang dilampirkan dalam Bab 2 dan Bab 4. Secara ringkasnya kajian ini diperlukan untuk dijadikan rujukan kepada kerja-kerja yang berkaitan dengan keselamatan dan kesihatan radiologi, iaitu ia merupakan keperluan kepada bidang Fizik Kesihatan.

Dalam kertas kerja berkenaan dinyatakan bahawa kajian sebegini telah banyak dilakukan di negara-negara maju, tetapi belum dilakukan secara menyeluruh di Malaysia.

PERNYATAAN MASALAH.

Kajian ini merupakan lanjutan dari penyelidikan sebelumnya, iaitu a) "Perlindungan Radiologi di Industri dan Perlombongan" yang dibiayai oleh geran IRPA No. 4-07-07-040, tahun 1991 – 1994, dan "Keradioaktifan Tabi'i di alam

Sekitar" yang dibiayai oleh geran dari Unit Penyelidikan dan Perundingan Vot. 61792, Universiti Teknologi Malaysia, tahun 1995 - 1996.

Dalam kajian di atas, survei sinaran latarbelakang di seluruh Negeri Johor telah dilakukan. Hasilnya satu kawasan yang mempunyai dos sinaran latar belakang tabi'i yang tinggi telah dikenalpasti di sekitar Palong, Segamat. Penyelidikan ini telah melakukan kajian radiologi alam sekitar khusus terhadap kawasan tersebut. Hasil kajian ini dikemukakan dalam Bab 4.

Kajian sebelumnya telah menunjukkan adanya hubungan diantara jenis tanah, latar belakang geologi dan kadar dos sinar gama daratan di alam sekitar. Kajian ini telah menganalisis hubungan ini secara statistik. Hasilnya dikemukakan dalam Bab 2 dan Bab 3. Hubungkait yang merupakan dapatan dari kajian ini boleh digunakan untuk meramalkan kadar dos sinar gama daratan di alam sekitar berdasarkan maklumat jenis tanah dan latar belakang geologi.

Bagi kebanyakan tempat di Malaysia maklumat jenis tanah dan latar belakang geologi boleh didapati dengan ketepatan yang memadai untuk tujuan penggunaan fizik kesihatan yang biasa. Kaedah ramalan kestatistikan berdasarkan maklumat jenis tanah dan latar belakang geologi ini dijangkakan akan dapat menjimatkan masa dan sumber berbanding dengan sekiranya maklumat hanya diperolehi

melalui pengukuran sebenar yang dilakukan di lapangan. Kaedah ini dijangkakan akan lebih memudahkan pemetaan isodos sinaran di Malaysia dilakukan secara menyeluruh untuk tujuan penggunaan fizik kesihatan dan lain-lainnya (lihat Bahagian Pengenalan pada Bab 2).

OBJEKTIF DAN SKOP KAJIAN.

Objektif kajian ini adalah seperti berikut:-

a) Mendapatkan hubungan kestatistikan diantara data jenis tanah, latar belakang geologi dan aras kadar dos sinaran daratan intuk membolehkan pembinaan asas ramalan terhadap kadar dos sinaran gama daratan dilakukan berdasarkan kepada maklumat jenis tanah dan latar belakang geologi.

b) Untuk mengenal pasti tahap hazard radiologi yang terdapat di kawasan sinaran tinggi di Palong, Segamat, Johor.

Skop Kajian.

Untuk objektif a) skop kajian melibatkan data kadar dos sinaran gama daratan yang terkumpul di Negeri Johor setakat tahun 1999.

Untuk objektif b) skop kajian ialah kawasan yang lingkungi oleh garis lintang di antara 2° 27 dan 2° 50' Utara dan garis bujur di antara 102° 40 dan 102° 52' Timur.

BAB 2.

KESAN JENIS TANAH TERHADAP DOS SINARAN GAMA DARATAN ALAM SEKITAR DI NEGERI JOHOR, MALAYSIA.

Kertas Kerja "Effect of Soil Type on Environmental Terrestrial Gamma Radiation Dose in Johor State, Malaysia."

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Proceedings of the International Meeting on Frontiers of Physics 1998. pp 498 – 512. 2000. Ed. S.P. Chia and D.A. Bradley, World Scientific Publication Co. Pte. Ltd., Singapore. **ISBN 981-02-4490-8.**

Proceedings of the International Meeting on Frontiers of Physics 1998

Editors
S. P. Chia
D. A. Bradley

World Scientific

Effect of Soil Type on Environmental Terrestrial Gamma Radiation Dose in Johor State, Malaysia

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Abstract

Environmental Terrestrial Gamma Radiation (TGR) dose measurements were taken across the State of Johor, Malaysia. Statistical analyses of TGR dose measurements were carried out and the relationship between soil type and the TGR dose levels were determined. The data of the TGR doses were examined before statistical analyses were conducted. Soil types were compared by one way analysis of variance (ANOVA) method. Comparisons revealed that there were significant differences between soil types with respect to the TGR dose readings. Soil types were classified in groups according to specific ranges of gamma ray dose measurements.

Introduction

Natural background dose rate is routinely measured for various reasons. The study of natural terrestrial radiation will be useful for various purposes, among them are: -

1. Determination of radiation doses received by humans from terrestrial sources (Maiello, 1997).
2. Establishment of reference levels from which relative radiological hazards from environmental radioactive materials could be evaluated (Frenzel, 1993) and exposure from all sources could be estimated (Erickson *et al*, 1993).
3. Establishment of pre-operational radiation levels at planned sites for radiation facilities (Ramli, 1997) as required by law.
4. Ramli (1997) reported according to Eisenbud *et al.* (1964) that areas with high natural radiation may be identified and the potential excess cancer risks could be evaluated.
5. The utilization of natural dose surveys in mineral prospecting (Ramli, 1997) and the assessment of the regulatory compliance of laboratories, manufacturing plants, power stations, accelerators and other radiation related facilities (Maiello, 1997)

Important objective of this study is to determine whether soil types have any effect on the TGR dose levels. The purpose was achieved through statistical analysis to the data and the hypotheses were tested to evaluate the assumptions, which were made.

Measurements of the terrestrial γ-radiation dose were started four years ago in various districts of Johor State, Malaysia. Field survey was conducted at sampling-points grid along the latitudinal and longitudinal lines. Where possible dose measurements were made at each crossing point of the grid (Ramli, 1997). Dose readings were recorded using the γ-ray detector model 19, micro roentgen meter (μR), manufactured by Ludlum, USA. The detector which responds mostly to γ-radiation consists of 1" × 1" (2.54 x 2.54 cm) NaI crystal doped with thallium as an activator [NaI(Tl)] . The approximately linear energy response of the detector to gamma radiation (Knoll, 1989) of energies between 40 keV to

1.2 MeV was considered to be suitable for environmental gamma-ray dose measurements, as this covers the majority of significant γ-ray emissions from major terrestrial sources (Ramli, 1997). The detection of γ-rays from cosmic sources is negligible due to the low response of the instrument to high-energy γ-radiation.

Soil types were recorded referring to the location of the points from which γ-ray dose readings were taken. Data file was constructed using points location (latitude and longitude), γ-ray dose and soil types for each point.

Johor State is located in West Malaysia between latitudes 1°16' and 2°50' North, and longitudes 102°28.5' and 104°18' East, in region of tropical climate. Most of the land of the State is utilized for agriculture, mainly oil palm and rubber plantation.

Soil Types in Johore State

The state of Johor is mainly overlaid by seven groups of soil types as classified by FAO/UNESCO (Paramanthan, 1978) table (soil types):

1. *Fluvisols*. This group is consisted of floodplains and alluvial soils, it is found on the coastal areas in the west, south and east, it is characterized as thionic fluvisols and dystric fluvisols.
2. *Gleysols*. This group of mucky soils due to excess of water is found in the eastern and western parts of the state not far away from the coasts. The soils of this group are characterized as plinthic gleysols and humic gleysols (organic and muck).
3. *Nitosols*. Soils of shiny ped surfaces. One type of this group, which characterized as dystric nitosols is the most abundant soil type in the state, it is found in the middle and the south eastern parts.
4. *Cambisols*. The soils of this group are structured and derived from weathering in situ. Two types of this group are found, the first one is characterized as dystric cambisols (peat); this organic soil is found in the areas near the coasts of the western and eastern parts of the state. The second type is characterized as vertic cambisols, it is found beside the river valleys in the interior parts.
5. *Ferralsols*. Soils of a high content of sesquioxides. Four types of this group are found in small areas in the south, north and middle parts of the state. These soil types are characterized as orthic ferralsols, rhodic ferralsols, and plinthic ferralsols.
6. *Acrisols*. Acidic soils of low base saturation. Some soil types of this group are found in the middle parts of the state, these types are characterized as ferric acrisols.
7. *Miscellaneous soils*. (i) Steep Land. (ii) Urban Land. (iii) Mined Land. These types are found in small areas in the eastern, southern and northern parts of the state.

Materials and methods

Data Examination

Number of soil types considered in this study is 23. More data were collected from areas of interest, that is, with high TGR dose levels compared to other normal areas. A few soil types were excluded from the analysis due to their unsuitability for statistical treatment because of insufficient data. A total of 2273 dose readings were used in the present study.

One of the most important factors associated with a set of measurement data, is to know which distribution best describes the data (Liu *et al*, 1996). The shape of the distribution often indicates which statistical tests are most suitable for analyzing the data. Such characteristics are important because they provide a useful visual insight into the data and because many statistical procedures depend on assumptions about the underlying distribution of the variables.

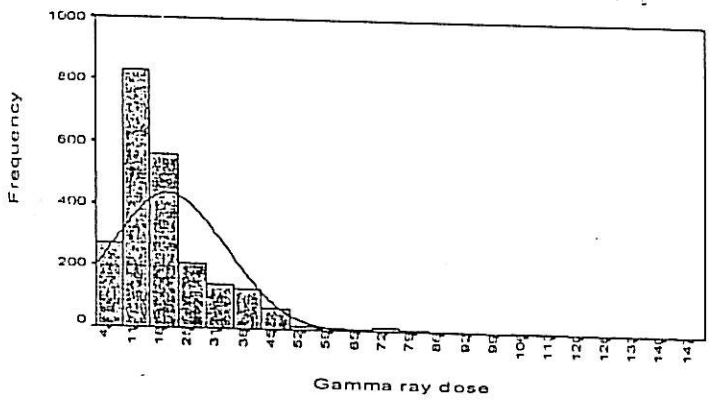

Figure 1. Frequency histogram of γ-radiation dose measurements at Johor State, Malaysia

Frequency histograms were constructed using the terrestrial gamma radiation dose obtained. A typical histogram is shown in Figure 1. The long tail to the right end of the curve suggests that the data are log-normally distributed (Liu *et al*, 1996). The frequency histogram becomes more symmetrical after the dose readings are transformed by using a natural logarithmic transformation, as shown in Figure 2. Another method, which provides examination to the data distribution, is the probability plot. A normal probability plot shown in Figure 3 is a proportion-proportion plot of the log-transformed data. The vertical coordinate represents the log-transformed γ-ray dose readings, and the horizontal coordinate is

$$\phi^{-1}\left[\frac{(r_i - 1/3)}{(n + 1/3)}\right] \qquad (1)$$

where ϕ^{-1} is the inverse of the standard normal distribution function, n is the number of observations, r_i is the rank of the data value ranging 1 to n (Montgomery, 1991). Fig 3 shows the empirical observed cumulative proportion of the data versus the expected cumulative proportion if the data was a sample from a normal distribution.

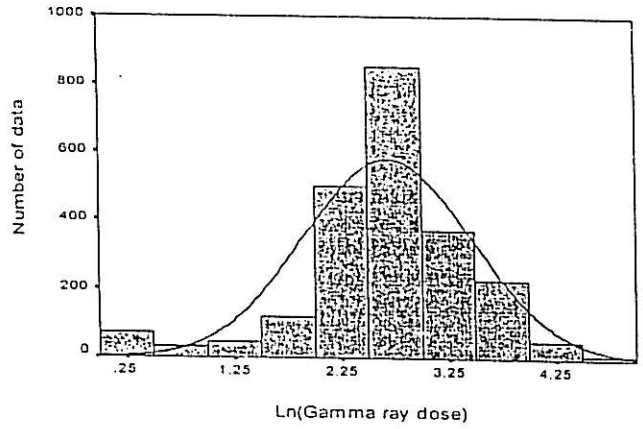

Figure 2. Frequency histogram of log-transformed γ-radiation dose measurements shown in Fig. 1.

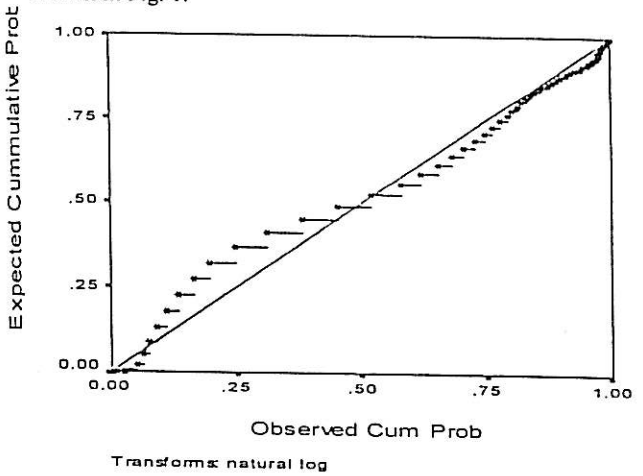

Figure 3. Proportion-Proportion of the natural log-transformed data
(• represent the γ-ray dose measurements)

Theory of the Statistical Analysis

To determine the effects of soil on the terrestrial γ-ray dose, such determination could be made by comparing γ-ray dose levels associated with different soil types. When comparing the γ-ray dose measurement, it should be rather important to know how much of the variance is associated with the soil type (St), and how much is associated with the random error (ε) of the measurements.

Since 23 soil types were selected from several soil types, therefore, each St was considered as random variable. The random measurements of the dose can be expressed by a one way classification method to partition the variance of the measurements, so those components of the variance could be evaluated.

The null hypothesis that there are no differences between the mean dose for soil types will be tested. The appropriate method for testing the equality of several means is the one-way analysis of variance; the data were analyzed using ANOVA (Morris and Fraley, 1994). In this procedure, several observations were taken under a certain level of a factor. Soil type (St) is the individual factor considered in the application of this statistical model. The model was shown in equation 2.

$$d_{ij} = \mu + (St)_i + \varepsilon_{ij} \qquad (i = 1,2,3,\cdots,23) \text{ and } (j = 1,2,3, \ldots, n_i) \tag{2}$$

where d_{ij} is the ijth observation of γ-ray dose under the ith soil type, μ is a common parameter for all types called the over all average, $(St)_i$ is the soil type effect, and ε_{ij} is a random variable representing the difference among the dose measurements at the same type of soil. One assumption associated with this model is that ε_{ij} is normally independently distributed (NID).

Using the mathematical model expressed in equation 2, the variance of the random measurements of the dose can be analyzed.

The parameters $(St)_i$ and ε_{ij} are partially account for the total sum of squares (SS_T) of a group of random measurements of dose. The partitioned total sum of squares can be expressed as: SS (of total) = SS (between groups of soil types) + SS (within groups of soil types) i.e

$$SS_T = SS_{St} + SS_\varepsilon \tag{3}$$

Differentiation between soil types

Since the numbers of dose measurements under each soil type are not equal, the unbalanced one-way ANOVA method was used. Test procedures must be established to determine whether the γ-ray dose differs from soil type to another. Hypotheses about the dose measurement means for soil types will be tested using the analysis of variance. Through testing the hypotheses ie.

$$H_o : (St)_1 = (St)_2 = \cdots = (St)_a = 0$$

$H_1 : (St)_i \neq 0$ at least for one pair (i, j)

or equivalently,

$$H_o : \mu_1 = \mu_2 = \mu_3 = \cdots = \mu_a$$

$H_1 : \mu_i \neq \mu_j$ at least for one pair (i, j)

$(i = 1,2,3,\cdots,a), (j = 1,2,3,\cdots,n_i)$

where H_o and H_1 represent the null hypothesis and the alternative hypothesis respectively. Decision will be made, whether the variation of the measurements depends upon the soil types. If the null hypothesis is true, that is all means are equal and the soil type effects are zero, it will be concluded that the soil types have no effect on the terrestrial γ-ray dose.

The significance of difference between soil types is determined by test statistics F, which is the ratio of the between groups mean square to the within groups mean square dose: $F_{df \text{ of factor}, df \text{ of error}}$ = [(SS of factor/df of factor)/(SS of error/df of error)] i.e.

$$F_{df \text{ of factor} df \text{ of error}} = \frac{(MS \text{ of factor})}{(MS \text{ of error})} \tag{4}$$

where df and MS represent degrees of freedom and mean square respectively. If the value of F at a certain confidence level (α level) is larger than the critical value, or a probability of obtaining F ratio greater than α level, the null hypothesis will be rejected, that is

$$F > F_{\alpha, \text{ df of error}, \text{ df of between groups}} \tag{5}$$

Comparison of soil types

If the null hypothesis was rejected, it should be important to figure which soil types are different from others. Two multiple comparison procedures were used in order to identify differences.

1. Least Significant Difference (LSD) Method

In this procedure, comparisons were made between each pair of average dose d_i and d_j. The least significant different is

$$LSD = t_{(\alpha/2),(N-a)} \left[MS_\varepsilon \left(\frac{1}{n_i} + \frac{1}{n_j} \right) \right]^{\frac{1}{2}} \tag{6}$$

where t is the t statistic, α is the significance level ($\alpha = 0.05$), N is the number of whole population, a is the number of the factor level, MS_ε is the mean square for error, and n_i and n_j are the number of dose readings under the ith and jth level of the soil type respectively. If the observed difference between d_i and d_j is greater than the LSD, it should be concluded that the population means μ_i and μ_j are differ, that is, $|d_i - d_j| > LSD$.

2. Duncan Multiple Range Test

As reported by Montgomery (1991), it the method developed by Duncan in 1955. In this method all pairs of means μ_i, and μ_j were compared and the observed differences between them were tested. The expression least significant range R_p is used i.e

$$R_p = r_\alpha(p, f) Sd_i. \qquad (p = 1,2,3,\cdots,a) \tag{7}$$

where α is the significance level ($\alpha = 0.05$), f is the number of degrees of freedom for th error, and Sd_i. is the standard error for each average. If the observed difference between μ_i and μ_j is greater than the corresponding least significance range R_p, it will be concluded that the pairs of the mean are significantly different i that is, $|d_i - d_j| > R_p$.

Results and Discussion

Data Distribution

The normality of the random readings of dose for each soil type was tested by histograms and normal probability plots. The normal probability plot shows that the empirical data almost compare favorably with the theoretical line indicating the log-normality of dose measurements. Since the points were almost clustered around Straight reference line and the histogram of the log-transformed data became symmetric; it was concluded that the data was drawn from a normal distribution. Data, which deviate significantly from the straight line in the probability plot, will be considered as outlayers and extreme values.

Variability of TGR dose with soil type

The box plot Figure in 4. shows the variability and the distribution of the data for each soil type. The distributions of the dose values are skewed almost for all soil types except for soil types 5, 11, 20, 32, 45, and 49 are almost symmetric.

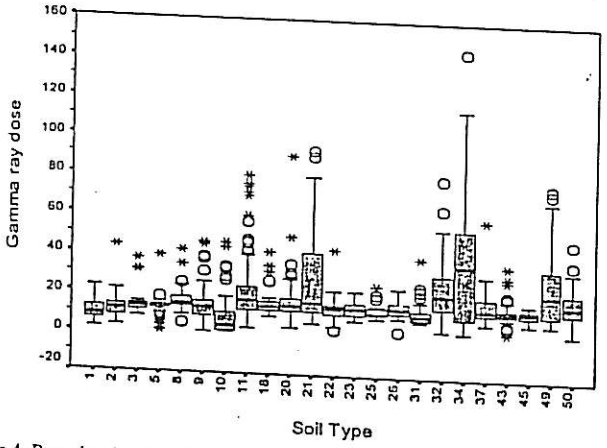

Figure 4. Box plot showing the distribution and the variability of γ-ray dose for each soil type.
(*) represents extreme values, and (o) represents outlayers.

The variability of some data is slightly larger than the others, especially for soil types 21, 32, 34, and 49. Most of the soil types have some large outlayers and extreme values. The large variability in dose measurements and the extreme values are mostly due to the anomalous radioactivity according to the location of the sampling points.

Figure 5 shows the average values of dose and 95% confidence intervals for mean dose for each soil type. The mid points of the vertical lines are the mean values and their lengths represent the 95% confidence interval for the mean to be within this length. The overlapping of some confidence intervals is clearly demonstrates that some values of dose that are reasonable under one soil type will be reasonable under another soil types. Table 1 shows a summary statistics and 95% confidence intervals for mean.

Test of significance among all soil types using the one-way ANOVA model given in equation 2, reveal whether or not the terrestrial gamma ray dose for all soil types are different. Table 2 shows the analysis of variance test results.

The F-ratio and F-probability for the hypothesis test indicate the significance of the differences between soil types, therefore, the null hypothesis was rejected. The rejection of the null hypothesis leads to use methods of comparison in order to mark out soil types, which are different from the others. Two multiple range tests used in this analysis are the least significant difference (LSD) and Duncan methods.

The results of the comparison of means given by each of the two methods at a confidence level $\alpha = 0.05$, are almost in agreement. Results for each method are shown in Tables 3 and 4.

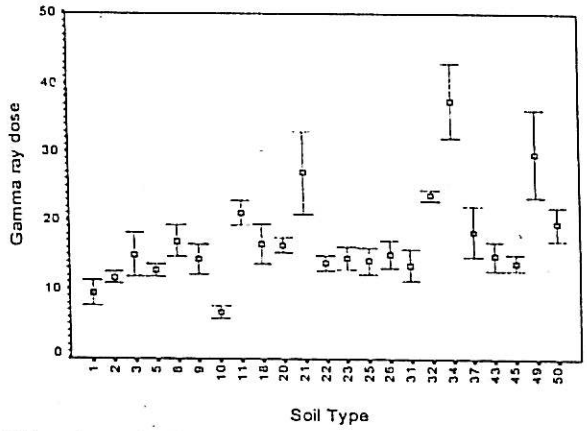

Figure 5. Mean dose and 95% confidence intervals for mean. (SPSS Output)

As reported by Glazovskaya (1983), depending on a specific combination of factors of soil formation such as parent material, water and temperature, nature of plant and animal population, the process of soil formation acquires specific trends. Therefore, differences in the factors of soil formation on the earth's crust lead to different specific soil manifestation including soil radioactivity.

The radioactivity of soil is generally determined by the radioactivity of the source rock which, in turn, composed of radioactive minerals.

Soil types that are exhibit high background radiation such as soil type 34 are expected to contain U-and Th-rich minerals such as uraninite (UO_2), thorianite (ThO_2), and autunite [$Ca(UO_2)(PO_4).10–12\ H_2O$] (Klein and Hurlbut, 1985). Some TGR dose rates are extremely high especially for soil type 34 and some other soil types. These dose rates are up to 145 uR/h (~1262 nGy/h) which is approximately, 15 times greater than the normal world average. These extreme values may be regarded as anomalous values caused by radioactive anomalies especially in the northern areas of the state of Johore.

Since state of Johore is located in an area of heavy rainfall, flood wash down may affects the radioactivity of some areas. Transportation of radioactive materials from places of high radioactive elemental concentration to deposit in areas of low content is of high possibility. On the other hand, areas with very low TGR dose might be washed down by floods, therefore, expected radioactive materials and soil minerals might be eroded and transported to another places making as anomalous radioactive areas.

Table 1. Summary statistics and 95% confidence intervals. (SPSS Output)

	Gamma ray dose (uR/h)					*95% confidence interval for mean*	
Soil Types	*Mean*	*Standard deviation*	*Min.*	*Max.*	*Std. error*	*Lower bound*	*Upper bound*
1	9.43	4.67	2	23	0.85	7.69	11.18
2	11.67	5.00	3	44	0.39	10.90	12.44
3	14.92	7.48	8	37	1.53	11.76	18.08
5	12.71	4.39	1	39	0.48	11.75	13.67
8	16.98	6.64	5	42	1.11	14.64	19.14
9	14.34	9.35	1	46	1.07	12.20	16.47
10	6.73	7.08	1	46	0.48	5.80	7.67
11	21.02	13.31	3	80	0.96	19.13	22.90
18	16.48	7.85	9	42	1.46	13.50	19.47
20	16.36	7.96	4	90	0.57	15.25	17.48
21	26.9	21.96	6	93	3.05	20.79	33.02
22	13.77	4.93	3	44	0.52	12.74	14.80
23	14.24	4.01	8	23	0.79	12.80	16.04
25	14.05	4.08	9	26	0.89	12.19	15.90
26	15.08	4.69	3	25	0.96	13.10	17.06
31	13.49	6.61	8	40	1.09	11.28	15.69
32	23.67	11.08	4	80	0.43	22.82	24.52
34	37.53	30.38	3	145	2.74	32.11	42.95
37	18.39	10.04	8	60	1.80	14.71	22.07
43	14.83	6.52	4	37	1.02	12.77	16.89
45	13.86	2.69	8	18	0.59	12.63	15.08
49	29.79	20.71	8	77	3.20	23.33	36.24
50	19.54	8.67	3	50	1.23	17.08	22.00
Total	18.76	14.04	1	145	0.29	18.18	19.34

Table 2. Analysis of variance results for soil types. (SPSS Output)

Source of variation	Sum of Squares	Degrees of freedom	Mean Square	F Ratio	F Probability
Between groups	123815.6	22	6527.99	39.102	0.000
Within groups	323840.5	2250	134.93		
Total	447656.2	2272			

Table 3. LSD test with significance level ($\alpha = 0.05$).

	Significant of relationship between soil types											
Soil Types	1	2	3	5	8	9	10	11	18	20	21	23
1		0.35	0.10	0.20	0.01	0.06	0.25	0.00	0.02	0.00	0.00	0.09
2	0.35		0.22	0.52	0.02	0.11	0.00	0.00	0.05	0.00	0.00	0.18
3	0.10	0.22		0.43	0.53	0.84	0.00	0.02	0.64	0.58	0.00	0.68
5	0.20	0.52	0.43		0.08	0.39	0.00	0.00	0.15	0.02	0.00	0.56
8	0.10	0.02	0.53	0.08		0.29	0.00	0.06	0.89	0.81	0.00	0.19
9	0.06	0.11	0.84	0.39	0.29		0.00	0.00	0.41	0.21	0.00	0.76
10	0.25	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.02	0.00	0.06	0.00	0.00		0.06	0.00	0.00	0.00
18	0.02	0.05	0.64	0.15	0.89	0.41	0.00	0.06		0.96	0.00	0.29
20	0.00	0.00	0.58	0.02	0.81	0.21	0.00	0.00	0.96		0.00	0.09
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
22	0.09	0.18	0.68	0.56	0.19	0.76	0.00	0.00	0.29	0.09	0.00	
23	0.12	0.28	0.88	0.53	0.53	0.97	0.00	0.01	0.53	0.44	0.00	0.81
25	0.18	0.39	0.81	0.65	0.39	0.92	0.01	0.01	0.48	0.40	0.00	0.92
26	0.09	0.19	0.96	0.39	0.57	0.79	0.00	0.02	0.67	0.62	0.00	0.63
31	0.17	0.41	0.65	0.74	0.23	0.72	0.00	0.00	0.31	0.18	0.06	0.90
32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.29	0.03	0.61	0.11	0.00	0.26	0.54	0.38	0.00	0.06
43	0.06	0.13	0.98	0.35	0.45	0.83	0.00	0.00	0.57	0.46	0.00	0.64
45	0.20	0.43	0.77	0.70	0.36	0.87	0.01	0.01	0.45	0.36	0.00	0.98
49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
50	0.00	0.00	0.12	0.00	0.31	0.17	0.00	0.44	0.28	0.10	0.00	0.01

Table 3, continued

Soil Type	*Significant of relationship between soil types*										
	23	25	26	31	32	34	37	43	45	49	50
1	0.12	0.18	0.09	0.17	0.00	0.00	0.00	0.06	0.20	0.00	0.00
2	0.28	0.39	0.19	0.41	0.00	0.00	0.00	0.13	0.43	0.00	0.00
3	0.88	0.81	0.96	0.65	0.00	0.00	0.29	0.98	0.77	0.00	0.12
5	0.53	0.65	0.39	0.74	0.00	0.00	0.03	0.35	0.70	0.00	0.00
8	0.43	0.39	0.57	0.23	0.00	0.00	0.61	0.45	0.36	0.00	0.31
9	0.97	0.92	0.79	0.72	0.00	0.00	0.11	0.83	0.87	0.00	0.02
10	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
11	0.01	0.01	0.02	0.00	0.01	0.00	0.26	0.00	0.01	0.00	0.44
18	0.53	0.48	0.67	0.31	0.00	0.00	0.54	0.57	0.45	0.00	0.28
20	0.44	0.40	0.62	0.18	0.00	0.00	0.38	0.46	0.36	0.00	0.10
21	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.25	0.00
22	0.81	0.92	0.63	0.90	0.00	0.00	0.06	0.64	0.98	0.00	0.01
23		0.92	0.85	0.76	0.00	0.00	0.21	0.89	0.87	0.00	0.08
25	0.92		0.77	0.86	0.00	0.00	0.20	0.81	0.96	0.00	0.08
26	0.85	0.77		0.61	0.00	0.00	0 31	0.93	0.73	0.00	0.14
31	0.76	0.86	0.61		0.00	0.00	0.09	0.62	0.91	0.00	0.02
32	0.00	0.00	0.00	0.00		0.00	0.02	0.00	0.00	0.00	0.02
34	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
37	0.21	0.20	0.31	0.09	0.02	0.00		0.21	0.18	0.00	0.67
43	0.89	0.81	0.93	0.62	0.00	0.00	0.21		0.76	0.00	0.06
45	0.87	0.96	0.73	0.91	0.00	0.00	0.18	0.76		0.00	0.07
49	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00		0.00
50	0.08	0.08	0.14	0.02	0.02	0.00	0.67	0.06	0.07	0.00	

Table 4. Duncan test with significance level ($\alpha = 0.05$). (SPSS Output)

Soil Type	*Homogeneous subsets of soil types for $\alpha = 0.05$*									
	1	2	3	4	5	6	7	8	9	10
10	6.73									
1	9.43	9.43								
2	11.67	11.67	11.67							
5		12.71	12.71	12.71						
31		13.49	13.49	13.49	13.49					
22		13.77	13.77	13.77	13.77					
45		13.86	13.86	13.86	13.86					
25		14.05	14.05	14.05	14.05					
9		14.34	14.34	14.34	14.34					
23		14.42	14.42	14.42	14.42					
43		14.83	14.83	14.83	14.83					
3		14.92	14.92	14.92	14.92					
26		15.08	15.08	15.08	15.08					
20			16.36	16.36	16.36	16.36				
18			16.48	16.48	16.48	16.48				
8			16.89	16.89	16.89	16.89				
37				18.39	18.39	18.39	18.39			
50					19.54	19.54	19.54			
11						21.02	21.02			
32							23.67	23.67		
21								26.90	26.90	
49									29.79	
34										37.53
Significant	0.068	0.07	0.10	0.07	0.05	0.12	0.06	0.21	0.26	1.00

Conclusion

As a conclusion, strong relationship between soil types and the TGR dose was observed, therefore, TGR dose differs from soil to another. Soil types were classified in subgroups according to specific ranges of γ-ray dose as summarized in table 5. Therefore, results obtained will provide methods of estimation and prediction of terrestrial gamma radiation according to soil type. Results will provide also basic data for the assessment of dose to the population from outdoor exposure to terrestrial gamma radiation in Johore State.

The average value of TGR dose in Johor state was estimated to be 19 μR/h (~165 nGy/h). This value is two times higher compared to the world average of 10μR/h (~88 nGy/h). Using the conversion factor of 0.7 Sv/Gy the average dose of such terrestrial gamma ray dose that an individuals staying outdoors might be expected to receive (Ramli, 1997) was estimated to be approximately 1.0 mSv per year.

north, which are overlaid by soils of Orthic Ferralsols known locally as Segamat – Katong. The highest TGR dose is 145 μR/h (~1262 nGy/h). Such areas will be studied to carry out anomalies, and the environmental impact of TGR will be evaluated to estimate potential human health risk.

Table 5. Soil type groups classified according to specific mean gamma ray dose ranges (based on LSD and Duncan).

Subgroup	*Soil Types*	*Mean gamma ray dose range (nGy/h)*
1	a. Humic Podzols–Dystric Fluvisols b. Dysttric Histosols	58.3 to 81.8
2	a. Thionic Fluvisols c. Vertic Cambisols–Eutric Gleysols d. Ferric Acrisols – Orthic Ferralsols e. Orhtic Acrisols – Plinthic Ferralsols f. Plinthic Acrisols – Ferric Acrisols – Plinthic Ferralsols. g. Plinthic Ferralsols – Plinthic Ferralsols. h. Humic Gleysols – Dystric Histosols. i. Plinthic Acrisols – Plinthic Acrisols j. Orthic Acrisols – Ferric Acrisols k. Thionic Fluvisols. l. Plinthic Ferralsols – Ferric Acrisols – Orthic Ferralso.	101.8 — 125.3
3	a. Ferric Acrisols – Ferric Acrisols. b. Xanthic Ferralsols – Dystric Gleysols. c. Dystric Gleysols – Humic Gleysols. d. Ferric Acrisols - Orthic	142.7 — 169.7
4	a. Ferric Acrisols – Orthic Ferralsols b. Urban Land c. Dystric Fluvisols – Dystric Gleysols.	181.8 — 206.2
5	a. Dystric Nitosols – Orthic Ferralsols b. Ferric Acrisols – Ferric Cambisols c. Steep Land	236.6 — 241.9
6	Rhodic Ferralsols – Xanthic Ferralsols.	330.6

Acknowledgements.

We the authors, would like to record our gratitude to Malaysia Government for providing the fund for this research under the IRPA mechanism No. 4-07-07-040, the Universiti Teknologi Malaysia for providing various facilities and its Reseach Management Center for the research grant Vot. 71159.

The data obtained in this research have been obtained with the help of countless number of people directly and indirectly. It is impossible to list all of them but we must record special thanks to various government officials, various owners of lands, plantations and estates who have allowed us access to their properties and have rendered various valuables assistance, sometimes in difficult and challenging circumstances.

Special gratitude also must be recorded for En. Yusof Jasman, En. Lee Siak Kuan, En. Sulaiman Abdullah, En. Abdullah Yusof, En. Mohd Yasin Sudin, En. Ahmad Soalahuddin Al-Thani and En. Ahmad Al-Faruq with whom we have spent long hours day and night sometimes in jungles and places not normally visited by human beings.

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Appendix

Soil types in Johore State

Soil type label	*FAO Units*
1	Humic Podzols-Dystric Fluvisols
2	Thionic Fluvisols
3	Thionic Fluvisols
5	Vertic Cambisols-Eutric Gleysols
8	Dystric Gleysols-Humic Gleysols
9	Humic Gleysols-Dystric Histosols
10	Dystric Histosols
11	Dystric Fluvisols-Dystric Gleysols
18	Xanthic Ferralsols-Dystric Gleysols
20	Ferric Acrisols-Ferric Acrisols
21	Orthic Acrisols-Ferric Acrisols
22	Orthic Acrisols-Plinthic Ferralsols
23	Plinthic Acrisols- Plinthic Acrisols
25	Plinthic Ferralsols- Plinthic Ferralsols- Plinthic Ferralsols
26	Plinthic Ferralsols-Ferric Acrisols-Orthic Ferralsols
31	Ferric Acrisols- Ferric Acrisols- Orthic Ferralsols
32	Dystric Nitosols- Orthic Ferralsols
34	Rhodic Ferralsols-Xanthic Ferralsols
37	Ferric Acrisols- Orthic Ferralsols
43	Orthic Acrisols-Ferric Acrisols
45	Plinthic Acrisols- Ferric Acrisols- Plinthic Ferralsols
49	Steep Land
50	Urban Land

BAB 3

PENGARUH GEOLOGI TERHADAP KADAR DOS SINARAN GAMA DARATAN DI NEGERI JOHOR, MALAYSIA.

Kertas kerja "Geological Influence on Terrestrial Gamma Radiation Dose rate in the Malaysian State of Johore."

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Applied Radiation and Isotopes, Vol. 54, No. 2, pp. 327 - 433, 2001, Elsevier Science Ltd, Exeter, United Kingdom. **ISSN 0969-8043, [PII: S0969-8043(00)00103-2].**

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Journal of Environmental Radioactivity 80 (2005) 287–304
JOURNAL OF ENVIRONMENTAL RADIOACTIVITY
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Environmental ^{238}U and ^{232}Th concentration measurements in an area of high level natural background radiation at Palong, Johor, Malaysia

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Received 1 June 2003; received in revised form 1 May 2004; accepted 1 June 2004

Abstract

Concentrations of uranium-238 and thorium-232 in soil, water, grass, moss and oil-palm fruit samples collected from an area of high background radiation were determined using neutron activation analysis (NAA). U-238 concentration in soil ranged from 4.9 mg kg^{-1} (58.8 Bq kg^{-1}) to 40.4 mg kg^{-1} (484.8 Bq kg^{-1}), Th-232 concentration ranged from 14.9 mg kg^{-1} (59.6 Bq kg^{-1}) to 301.0 mg kg^{-1} (1204 Bq kg^{-1}). The concentration of U-238 in grass samples ranged from below the detection limit to 0.076 mg kg^{-1} (912 mBq kg^{-1}), and Th-232 ranged from 0.008 mg kg^{-1} (32 mBq kg^{-1}) to 0.343 mg kg^{-1} (1.372 Bq kg^{-1}). U-238 content in water samples ranged from 0.33 mg kg^{-1} (4.0 Bq L^{-1}) to 1.40 mg kg^{-1} (16.8 Bq L^{-1}), and Th-232 ranged from 0.19 mg kg^{-1} (0.76 Bq L^{-1}) to 0.66 mg kg^{-1} (2.64 Bq L^{-1}). It can be said that the concentrations of environmental U-238 and Th-232 in grass and water samples in the study area are insignificant. Mosses were found to be

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0265-931X/$ - see front matter
doi:10.1016/j.jenvrad.2004.06.008

possible bio-radiological indicators due to their high absorption of the heavy radioelements from the environment.

Keywords: Environmental; Soil; Uranium-238; Thorium-232; Radiation; Activity concentration

1. Introduction

The most common terrestrial radioelements that produce gamma-rays are uranium-238, thorium-232 and potassium-40. The study of natural terrestrial radiation is useful for various reasons as have been reported by many authors including Eisenbud (1964), Frenzel (1993), Erickson et al. (1993), Ramli (1997) and Maiello (1997). Around the world there are some areas having extremely high background radiation levels. High external radiation levels have been found in Austria, Brazil, China, France, India, Italy and other countries as pointed by Hanson and Kamarov in 1983 (Malanca et al., 1993). Highest concentrations of radioactive minerals in soil are found in Brazil and India (Radhakrishna et al., 1993).

Most of the radioactivity in the terrestrial environment whether it is natural or man-made, is bound to the components of the soil. Transportation of this radioactivity from soil is possible to vegetation via dust deposition or root uptake, water sources by flood wash-down, and forward to humans through inhalation, breathing and soil ingestion. Therefore, all pathways of exposure that originate from soil are potentially important for the purpose of radiation risk assessment. Considerable attention has been given to the soil radioactivity, mainly for the purposes of establishing baseline data for future radiation impact assessment, radiation protection and exploration.

Radhakrishna et al. (1993) studied natural background radiation in the southwest coast of India. Systematic gamma spectrometric analysis indicated that the presence of monazite is the cause of the observed high natural background radiation in the area. In the same area, Narayana et al. (1995) studied the distribution and enrichment of radionuclides, and have observed that the monazite deposit in the area is predominant in the upper (0–10 cm) layer. The source of the monazite may be traced to the rocks in the area that were weathered and the released minerals were transported by the river and deposited on the coastal areas. Ibrahim et al. (1993) measured the radioactivity levels in the soils of the Nile Delta and middle Egypt. It was shown that the highest radionuclide activity occurs in clay soils and the lowest occurs in sandy soils. The highest Cs-137 activity was found in the region of the dark clay and muddy clay soils.

Various studies concerning radioactivity bound to soil were carried out in European countries. For example, Quindos et al. (1994) studied on the natural radioactivity in Spanish soils. Concentrations of Ra-226, Th-232, and K-40 were obtained and the radionuclides were correlated to the external exposure rates from terrestrial gamma radiation measured throughout Spain. Bonazzola et al. (1993)

studied the downward migration of Cs-137 and Ru-106 deposited on Italian soils after Chernobyl accident. It was indicated that 60% of the ruthenium (Ru-106) and 60–80% of cesium (Cs-137) contamination from Chernobyl accident are contained in the first 1-cm-thick layer of undisturbed grassland soil, while more than 95% of contamination is contained in the first 5-cm-thick layer for both radionuclides.

Albering et al. (1996) carried out a survey of Rn-222 concentrations in dwellings and soils in the Dutch Belgian border region. Varley and Flowers (1998) did a similar study in southwest England, and have considered the influence of geology, meteorological variables, spatial and depth variation. They have established that the soil represents the chief source of indoor radon. Morales and Buenfil (1996) carried out an environmental gamma dose measurements in Mexico City. The environmental gamma dose rates were found to be between 83 nGy h^{-1} and 112 nGy h^{-1}. The outdoor dose rates were found to be 85 nGy h^{-1} for sites having soil of either volcanic or lacunars origin, and 107 nGy h^{-1} at nearby hill belonging to a volcanic chain.

Malanca et al. (1993) studied the natural radioactivity in Brazilian State of Rio Grande do Norte. The average concentrations of Ra-226, Th-232 and K-40 in soil samples in the area of the study were 29 Bq kg^{-1}, 46.6 Bq kg^{-1} and 677 Bq kg^{-1}, respectively. The bed rock of Santana do Matos showed high radioactivity, which was about 90 Bq kg^{-1}, 285.6 Bq kg^{-1} and 1414 Bq kg^{-1}, respectively for Ra-226, Th-232 and K-40. The external gamma radiation dose rate for the downtown area in the region ranged from 200 nGy h^{-1} to 330 nGy h^{-1}.

Radioactivity levels vary greatly depending on soil type and mineral make-up. The higher concentrations of uranium, thorium and potassium are associated with soil developed from acid magmatic rocks and clay (Kogan et al., 1971) and probably, majority of uranium is associated with the phosphatic sands and clays of these formations (Roessler et al., 1993).

The primary objective of the present study is to determine uranium-238 and thorium-232 concentrations in environmental samples of soil, grass, oil-palm fruits, moss and water collected from an area of relatively high background radiation. Such kind of study could assist environmental radiological assessments in the future. The interest behind the study in the area is mainly due to its contribution to food production, the existence of water sources and the presence of human life. The concentration ratios of uranium-238 and thorium-232 obtained in this study are compared with those published in United Nations Scientific Committee on Effects of Ionizing Radiations Report (UNSCEAR, 2000).

The study area (Fig. 1) is the Palong area in the District of Segamat, northern part of Johor State, Malaysia. It is an agricultural area located between latitudes 2°27′ and 2°50′ North; and longitudes 102°40′ and 102°52′ East. The main agricultural products are oil palm and rubber. The area is overlaid mainly by soils of Orthic Ferralsols known locally as *Segamat-Katong*, and underlied by tertiary rocks of continental deposits and volcanics.

Environmental radiation data acquired over a period of four years from various research programs involving various districts of Johor, Malaysia, have been reported in details elsewhere (Ramli, 1997). The high background radioactivity of the study

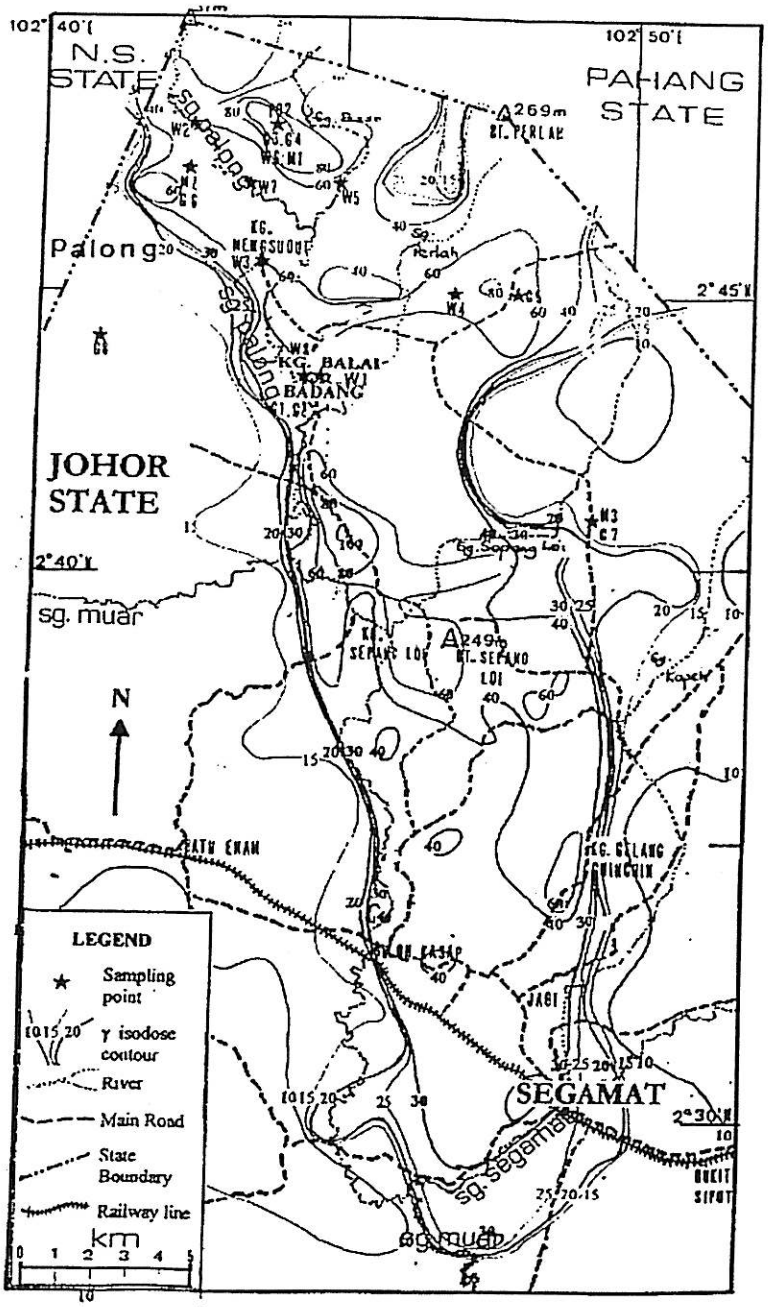

Fig. 1. Map of the study area, in Palong-Johor, where the ground gamma dose rate survey has been conducted. The isodose is in $\mu R\ h^{-1}$ (1 μR–9 nGy).

area, in particular, has been identified during the ground gamma-ray survey conducted by Ramli et al. (2000).

2. Methods and materials

To represent locality of sampling point in the study area, at each sampling location, additional three or four points surrounding the main spot (located by the longitudinal and latitudinal line grids where terrestrial gamma-ray, TGR, dose was measured), about 1 m away each, were marked. Samples of soil, grass, moss, water and oil-palm fruits were collected from various locations, with differing TGR dose rates as shown in Fig. 1. The concentrations of U-238 and Th-232 were determined in each sample.

2.1. Measurement of TGR dose rates

The terrestrial gamma radiation (TGR) dose rate measurement points were located according to the longitudinal and latitudinal lines, where possible, readings were made at each crossing point of the grid. The TGR dose measurements were done by using two identical gamma-ray detectors at each point and the average value was recorded. The detector used is model 19, micro roentgen (μR) meter, manufactured by Ludlum, USA. It uses 1″ × 1″ (2.54 × 2.54 cm) sodium iodide (NaI) crystal doped with thallium (Tl) as an activator. The approximate linear energy of the detector falls between 40 keV and 1.2 MeV, this range covers the majority of significant gamma-ray emissions from terrestrial sources. The detection of gamma-rays from cosmic rays is negligible due to the detectors' low response to high-energy gamma radiation.

2.2. Soil samples

The topsoils, from each of the previously marked point at the sampling location, at ~5-cm depth were taken and mixed together to obtain a representative sample of about 2 kg mass. Samples were dried in an oven at 100 °C for 24 h, then crushed, ground to fine powder and homogenized by passing through a 200 mm/150 μm test sieve. Samples were sealed in plastic containers and left for at least one month, before preparation for neutron irradiation, to ensure secular equilibrium between ^{226}Ra and the noble gas radon (^{222}Rn) and its decay products (Mollah et al., 1987; Ibrahim et al., 1993).

2.3. Grass, moss and oil-palm fruit samples

Representative samples of grass, oil-palm fruits and moss were obtained. They were collected from selected locations as mentioned at the beginning of Section 2 where the TGR doses have been measured and the soils were sampled. Distilled water was used to clean grass and oil-palm fruit samples. Moss samples were further

washed thoroughly with distilled water several times to ensure removal of all visible soil contaminants. The samples were air-dried for one week and were then dried further by placing them in an oven at 90 °C for 24 h. Their dry weights were determined. Grass and moss samples were turned into ashes in a furnace at 450 °C for 24 h. The ashes were powdered and homogenized. Each sample was packed in a plastic container and was left for several days before NAA analysis was performed.

2.4. Water samples

Water samples were collected from rivers, streams, one traditional well and one fishpond. Two liters of water from each sampling site were taken and filtered using filter paper with 4.5 μm pore size, and then about 2 mL of nitric acid (HNO_3) were added immediately to avoid ions from being adsorbed by the container. After a few days and before the NAA process, samples were evaporated by boiling to a volume of about 25 mL. An aliquot of 2.0 g of this water were evaporated to dryness in a polyethylene vial in an oven at 60 °C for 24 h in preparation for neutron irradiation.

2.5. Determination of U-238, Th-232 and K concentrations

Neutron activation analysis (NAA) has been employed in this study to determine U-238, Th-232 and K-40 concentrations in samples. NAA is a sensitive multi-element analytical technique useful for performing both quantitative and qualitative analysis. The technique is most useful because of its reliability for accurate and precise determination of elemental concentrations in unknown materials (William, 1972; Clemente, 1976; Alamin and Spyrou, 1997).

Samples were prepared for NAA according to the procedures recommended by the International Atomic Energy Agency, IAEA (1990). Standard for quantification of U-238 and Th-232 in the samples was prepared from stock solution consisting of 100 mg kg^{-1} and 98 mg kg^{-1}, U-238 and Th-232, respectively. An aliquot of 0.1 mL of the stock solution was transferred onto 0.1 silicon oxide contained in a polyethylene vial. It was dried in an oven set at 60 °C for about 24 h. To ensure quality of generated data, two certified reference materials, i.e. IAEA-312 and NBS-1633a, each weighted 0.100 g were prepared into polyethylene vials and were used as quality control materials (Gladney et al., 1987).

The following standards have been prepared for the determination of K-40 contents in soil, water and vegetation materials: first, 300 mg of KNO_3 solution (1000 ppm K) was transferred into polyethylene vial and was dried at 60 °C in an oven for 24 h; second, 100 mg of NBS-1633a as well as 200 mg of tomato leaves (NBS-1573) were used as quality control material. The entire unknown and the standard samples were sealed in labeled polyethylene vials of the same size before neutron irradiation.

Each prepared batch of the unknown samples together with the standards were irradiated for 6 h simultaneously in a fast neutron flux of 3×10^{12} n cm^{-2} s^{-1} at MINT's TRIGA nuclear reactor operated at 750 kW power (Auu, 1983). After

irradiation, samples were left at least for three days cooling period before starting counting and measurements. Some selected samples from each batch were irradiated together with the standards sequentially for 2 min in a flux of 2×10^{12} n cm^{-2} s^{-1}, and then left for 24 h before starting the counting for the determination of K concentration. The irradiated samples were counted for gamma-rays using lead shielded hyperpure germanium (HPGe) detectors with 1.90 keV resolution adjusted for the full width at half maximum (FWHM) of the 122 keV photo peak of cobalt-57 and the 1332 keV photo peak of cobalt-60. The detector efficiency is ~20% compared to NaI(Tl) detectors. The counting time for each sample was 1 h. The ambient background count was monitored and was found to be negligible.

The activity concentrations of U-238, Th-232 and K were determined using the formula,

$$A = (C_e \lambda_e N_A f_a)/M_a C \quad (1)$$

where, A is the specific activity of the radioisotope (Bq kg^{-1}), C_e is the elemental concentration (mg kg^{-1}), λ_e is the decay constant (s^{-1}) of the parent radioisotope, N_A is the Avogadro's number (6.023×10^{23} atoms mol^{-1}), f_a is the fractional atomic abundance in nature (% or ppm), M_a is the atomic mass (kg mol^{-1}) and C is a constant (with value of 100 or 10^6) that converts the ratio of the mass of the element to mass of the soil into a percentage or parts per million (ppm).

3. Results and discussion

The result of TGR dose survey is presented in Fig. 1. Elevated TGR dose rates were found in the study area, particularly in Balai Badang village, which was inhabited by about 500 persons. The highest dose recorded in this village was 1440 ± 100 nGy h^{-1} (160 μR h^{-1}) and the average was estimated to be 500 ± 35 nGy h^{-1} (56 μR h^{-1}). These values are, respectively, ~24 and ~8 times higher than the world average terrestrial dose rate of 59 nGy h^{-1} (UNSCEAR, 2000). This is the highest TGR dose discovered so far in Johor State. TGR dose rate in the area as a whole ranges from 72 ± 7 nGy h^{-1} to 1440 ± 100 nGy h^{-1} (dose conversion factor of 1 μR h^{-1} ≈ 9 nGy h^{-1} has been used).

Results from the present measurements of the certified samples and the standard certified values were comparable, leading to a conclusion that the technique was properly performed (Table 1).

3.1. Uranium-238 and thorium-232 content in soil

Concentrations of U-238 and Th-232 in soil samples are given in Table 2 and their corresponding activity concentrations are presented in Table 7. Concentrations of U-238 in all soil samples were in the range of 4.9–40.4 mg kg^{-1} with the activity ranging from 58.8 Bq kg^{-1} (1.59 pCi g^{-1}) to 484.8 Bq kg^{-1} (13.1 pCi g^{-1}). The concentrations of Th-232 were in the range of 14.9–300.7 mg kg^{-1} with the activity being in the range of 59.6 Bq kg^{-1} (1.61 pCi g^{-1}) to 1203 Bq kg^{-1} (32.5 pCi g^{-1}). Soil samples S2

Table 1
Elemental concentration in the standard samples measured for quality assurance/control

Element	Elemental concentration in mg kg^{-1} unless % is indicated					
	NBS-1573 (tomato leaves)		NBS-1633a (coal fly ash)		IAEA-312 (soil)	
	NBS certified value	Value from the experiment	NBS certified value	Value from the experiment	NBS certified value	Value from the experiment
U	–	–	10.20 ± 0.30	11.3 ± 1.4	16.50 ± 0.85	17.30 ± 0.75
Th	0.205 ± 0.003	0.22 ± 0.05	24.70 ± 0.30	29.0 ± 1.0	91.4 ± 10.1	93.2 ± 7.2
K (%)	4.34 ± 0.16	3.90 ± 0.30	1.88 ± 0.06	1.70 ± 0.13	–	–

Error terms appearing in the table are analytical standard deviations unless % is indicated.

and S5 are the lowest in both U-238 (4.9 and 5.2 mg kg^{-1}) and Th-232 (14.9 and 22.2 mg kg^{-1}) concentrations. U-238 and Th-232 content in most of these soil samples are quite high leading to the same conclusion of Agcos and Paton (1959) from their aerial survey, that this area has anomalous radioactivity. This appears to be caused by the intermediate to basic volcanic rocks rich in heavy minerals such as monazite. Potassium contribution to TGR dose can be regarded as a constant. No area of abnormal potassium presence was observed in this study. Potassium variation in the environment will not affect its human body composition, since its presence and concentration in a human body is strictly regulated by the body.

Linear regression analysis has been employed and the percentages of the variation of the TGR dose with the concentration of U-238 and/or Th-232 were obtained according to Walpole (1982). Eq. (2) (Montgomery, 1982) expresses the straight line that fits the linear relationships between TGR dose and U-238 or Th-232.

$$D=\beta_0+\beta_1 C+\varepsilon \tag{2}$$

Table 2
Concentration of uranium and thorium in soil samples

Soil sample	Concentration of U and Th (mg kg^{-1})		Th to U ratio	TGR dose rate at the sampling point ± 10% (nGy h^{-1})
	U	Th		
S1	10.0 ± 0.5	95.1 ± 3.0	9.51 ± 0.17	339
S2	4.9 ± 0.3	14.9 ± 0.3	3.04 ± 0.13	96
S3	22.4 ± 0.8	181.5 ± 17.0	8.10 ± 0.47	609
S4	21.5 ± 0.4	128.5 ± 6.0	5.98 ± 0.17	357
S5	5.2 ± 0.4	22.0 ± 2.0	4.23 ± 0.06	113
S6	26.1 ± 0.6	155.0 ± 16.0	5.92 ± 0.48	653
S7	18.5 ± 1.1	208.0 ± 16.0	11.24 ± 0.20	931
S8	18.6 ± 4.0	119.0 ± 35.0	6.39 ± 0.51	548
S9	20.4 ± 0.3	159.5 ± 10.0	7.82 ± 0.38	609
S10	40.4 ± 0.3	221.0 ± 23.0	5.47 ± 0.53	1001
S11	22.9 ± 1.1	242.5 ± 9.0	8.59 ± 0.09	914
S12	31.4 ± 0.5	300.7 ± 12.0	9.58 ± 0.23	1262

Error terms appearing in the table are analytical standard deviations unless % is indicated.

where β_0 and β_1 are unknown constants representing the intercept and the slope of the line, respectively; D and C are, respectively, variables for gamma dose and concentration of uranium-238 or thorium-232; and ε is a random error component.

The linearity between U-238 and/or Th-232 content in soil and the TGR dose are shown in Figs. 2 and 3, respectively (see R and R^2 values given). Accordingly, simple linear models have been derived relating TGR dose with U-238 and Th-232 concentrations in soil as given in Eqs. (3) and (4), respectively.

$$D = 30.39 \times C_U \tag{3}$$

$$D = 4.04 \times C_{Th} \tag{4}$$

where D is the TGR dose and C_U and C_{Th}, respectively, represent concentrations of uranium-238 and thorium-232.

Since the detection of gamma-rays from other sources such as cosmic rays is negligible due to the nature of the detector used in our survey, Eqs. (3) and (4) could possibly be used to estimate uranium and thorium activity in surface soil directly from measuring the TGR dose.

3.2. Concentrations of U-238 and Th-232 in plant materials

Traces of U-238 and Th-232 are known to transfer from soil to plant materials mainly through root uptake and wind erosion. The purpose of obtaining U-238 and

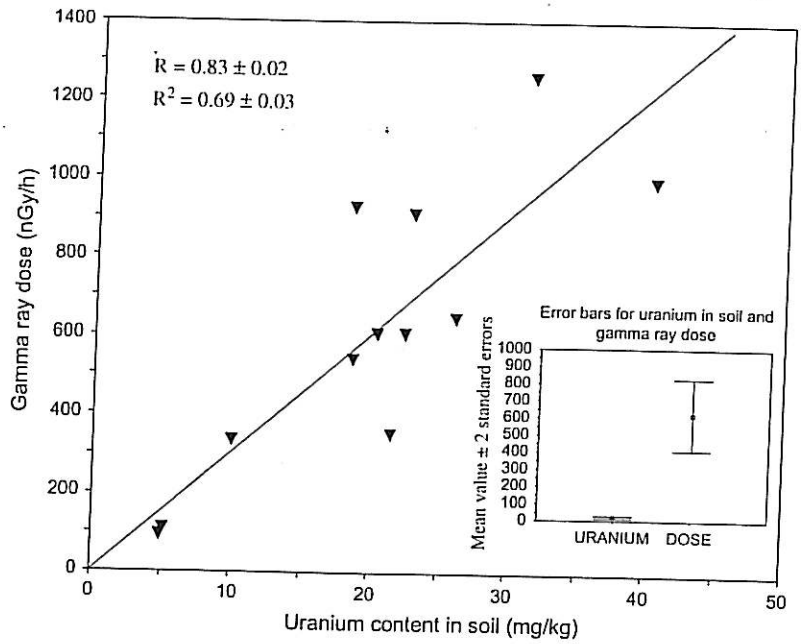

Fig. 2. Relationship between uranium content in soil and gamma-ray dose. Error bar plots for uranium and gamma-ray dose are shown in the figure (lower right corner).

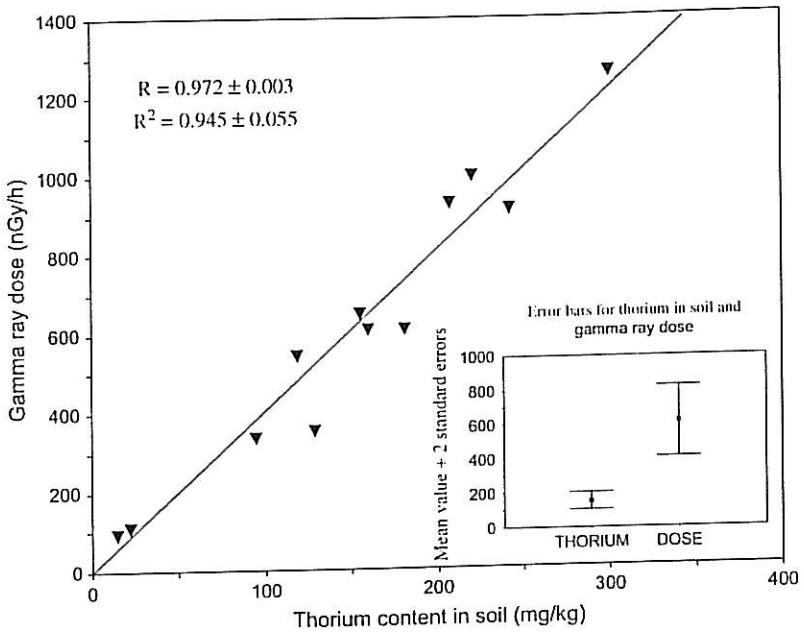

Fig. 3. Relationship between thorium content in soil and gamma-ray dose. Error bar plots for thorium and gamma-ray dose are shown in the figure (lower right corner).

Th-232 in vegetation materials was to observe their effect on the food sources of the area. Tables 3 and 4 show uranium-238 and thorium-232 content in grass and oil-palm fruit samples, respectively.

Concentrations of U-238 and Th-232 in soil, grass and moss samples collected from same sites are shown in Table 5 for comparison. Dried general grasses labeled "gv" show relatively low uranium-238 content ranged from 0.001 mg kg^{-1} to 0.035 mg kg^{-1}, and a porous fern-type vegetation known locally as *paku pakis* and

Table 3
Concentration of uranium and thorium in grass samples (dry weight)

Grass sample	Elemental concentration in mg kg^{-1}		Th to U ratio	TGR dose rate at the sampling point ± 10% (nGy h^{-1})
	U	Th		
G1	0.003 ± 0.001	0.017 ± 0.003	5.67 ± 0.43	1340
G2	0.026 ± 0.003	0.131 ± 0.004	5.04 ± 0.43	1340
G3	0.035 ± 0.004	0.155 ± 0.003	4.43 ± 0.41	1001
G4	0.076 ± 0.004	0.343 ± 0.003	4.51 ± 0.16	1001
G5	0.002 ± 0.001	0.008 ± 0.003	4.00 ± 1.44	653
G6	0.010 ± 0.003	0.047 ± 0.005	4.70 ± 0.91	374
G7	0.005 ± 0.003	0.024 ± 0.003	4.80 ± 2.28	105
G8	0.001 ± 0.001	0.011 ± 0.001	1.38 ± 0.48	113

Error terms appearing in the table are analytical standard deviations unless % is indicated.

Table 4
Concentration of uranium and thorium in oil-palm fruit samples (dry weight)

Oil palm sample	Elemental concentration in mg kg^{-1}		Th to U ratio	TGR dose rate at the sampling point ± 10% (nGy h^{-1})
	U	Th		
OP1	0.031 ± 0.002	0.023 ± 0.003	0.74 ± 0.05	653
OP2	0.005 ± 0.003	0.011 ± 0.002	2.22 ± 0.91	931
OP3	0.007 ± 0.002	0.011 ± 0.001	1.57 ± 0.33	70

Error terms appearing in the table are analytical standard deviations unless % is indicated.

labeled "pp" shows uranium-238 content in the range of 0.005 mg kg^{-1}–0.076 mg kg^{-1}. Thorium-232 content in dried grass samples varied from 0.011 mg kg^{-1} to 0.046 mg kg^{-1}. Figs. 4 and 5, respectively, depict comparison between U-238 and Th-232 content in dried grass samples with respect to U-238 and Th-232 content in soil.

From Table 6, uranium-238 activity in dried grass samples ranged from below the minimum detection limit to 0.912 Bq kg^{-1} (0.025 pCi g^{-1}) (average value = 0.244 Bq kg^{-1}), and thorium-232 activity ranged from 0.032 Bq kg^{-1} (0.009 pCi g^{-1}) to 1.372 Bq kg^{-1} (0.037 pCi g^{-1}) (average value = 0.379 Bq kg^{-1}). For leafy vegetables, reference values of 0.02 and 0.015 Bq kg^{-1}, respectively, for U-238 and Th-232, have been reported by UNSCEAR (2000). Reference value given by UNSCEAR indicates the world average. Therefore, the estimated average uranium activity in fresh grass (0.061 Bq kg^{-1}) is about 3 times the reference values and the estimated average thorium activity in fresh grass (0.095 Bq kg^{-1}) is about 6 times the reference value. At this level of concentrations, significant contamination of meat and milk products from the grazing animals is not expected. Nevertheless, it is a good idea to carry out further investigations to determine the actual level of contamination.

Although no statistically meaningful relationship could be deduced from the only three oil-palm fruit samples analyzed, they did indicate that the level of uranium and thorium in oil palms fruit from the area is not health wise significant.

Uranium-238 content in oil-palm fruit dried samples varies from 0.005 mg kg^{-1} to 0.031 mg kg^{-1} with activity concentration ranging from 0.06 Bq kg^{-1} to 0.37 Bq kg^{-1}. Thorium-232 content varies from 0.011 mg kg^{-1} to 0.023 mg kg^{-1} with activity concentration ranging from 0.044 Bq kg^{-1} to 0.092 Bq kg^{-1}. UNSCEAR (2000) has reported reference values of 0.003 (with the range of 0.0004–2.90) Bq kg^{-1} and 0.0005 (with the range of 0.00008–0.0071) Bq kg^{-1} for U-238 and Th-232, respectively, for root vegetables and fruits.

From the average activity of U-238 (0.177 Bq kg^{-1}) in the dried processed sample, activity in the fresh oil-palm fruit was estimated to be ~0.04 Bq kg^{-1}. This value is ~12 times higher than the above reference value for U-238. From the average Th-232 activity (0.06 Bq kg^{-1}) in the dried processed sample, activity in the fresh oil-palm fruit was estimated to be around 0.015 Bq kg^{-1}. This value is about 30 times higher than the above reference value for Th-232. These higher values should be

Table 5
Uranium and thorium content in soil and grass/moss collected from same sites

Site	Soil sample	Grass/moss sample	U_s (mg kg^{-1})	U_v (mg kg^{-1})	U_v to U_s ratio	Th_s (mg kg^{-1})	Th_v (mg kg^{-1})	Th_v to Th_s ratio	TGR dose rate at the sampling point ± 10% (nGy h^{-1})
1	S2	G7(pp)	4.9	0.005	1.0×10^{-3}	14.9	0.015	1.0×10^{-3}	96
		M3		0.120	0.024		0.668	0.045	
2	S5	G8(gv)	5.2	0.001	2.0×10^{-4}	22.0	0.014	6.0×10^{-4}	113
3	S9	G5(gv)	20.4	0.002	1.0×10^{-3}	159.5	0.009	6.0×10^{-5}	609
4	S6	G6(gv)	26.1	0.010	4.0×10^{-4}	154.5	0.046	3.0×10^{-4}	653
		M2		0.636	0.024		2.878	0.019	
5	S10	G3(gv)	40.4	0.035	8.7×10^{-4}	221.0	0.016	7.0×10^{-5}	1001
		G4(pp)		0.076	1.9×10^{-3}		0.028	1.2×10^{-4}	
		M1		0.578	0.014		3.547	0.016	
6	S12	G1(gv)	31.4	0.003	9.6×10^{-5}	300.7	0.011	3.7×10^{-5}	1262
		G2(pp)		0.026	8.3×10^{-4}		0.045	1.5×10^{-4}	

U_s, U_v, Th_s and Th_v represent U in soil, U in vegetation, Th in soil and Th in vegetation, respectively.

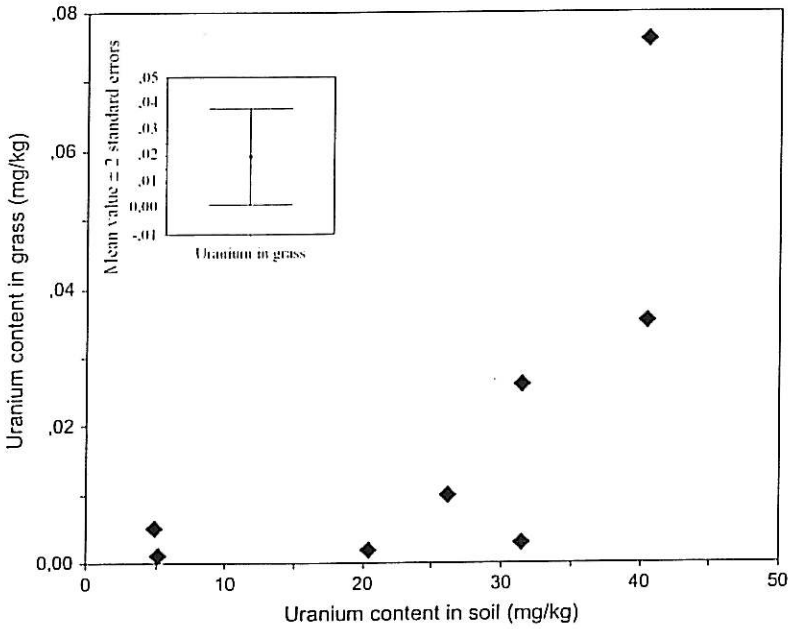

Fig. 4. Comparison between uranium content in soil and uranium content in grass.

expected given the higher level of U-238 and Th-232 in the soil concerned. They should not cause alarm, as they are far below the annual limit of intake (ALI) for members of public. More than a few 10^5 kg of oil-palm fruits would be needed to reach the relevant ALI values for an individual member of public.

3.3. U-238 and Th-232 concentrations in water sources

Concentrations of U-238 and Th-232 in eight water samples collected from different water sources in the study area are given in Table 7.

The content of U-238 in water samples from rivers and streams varies between 0.325 $\mu g\,L^{-1}$ and 0.977 $\mu g\,L^{-1}$. Its concentration was found to be 0.671 $\mu g\,L^{-1}$ and 1.395 $\mu g\,L^{-1}$ for ground and fishpond water, respectively. The concentration of Th-232 was below the detection limit in ground water and in one sample of river water. Its concentration varies between 0.189 $\mu g\,L^{-1}$ and 0.478 $\mu g\,L^{-1}$ in the remaining samples of river and stream water, and was 0.661 $\mu g\,L^{-1}$ in the fishpond water.

It was observed that U-238 and Th-232 content in fishpond water (1.395 $\mu g\,L^{-1}$ and 0.661 $\mu g\,L^{-1}$, respectively) was ~2 times the average U-238 concentration (0.597 $\mu g\,L^{-1}$) as well as Th-232 concentration (0.34 $\mu g\,L^{-1}$). These excess concentrations in fishpond water might be due to the fact that the water was stagnant allowing deposition and accumulation of elements washed down from soil and rocks.

The specific activities of U-238 in water samples were found to be ranging from 4.02 $mBq\,L^{-1}$ to 16.8 $mBq\,L^{-1}$. Th-232 activities ranged from below the detection

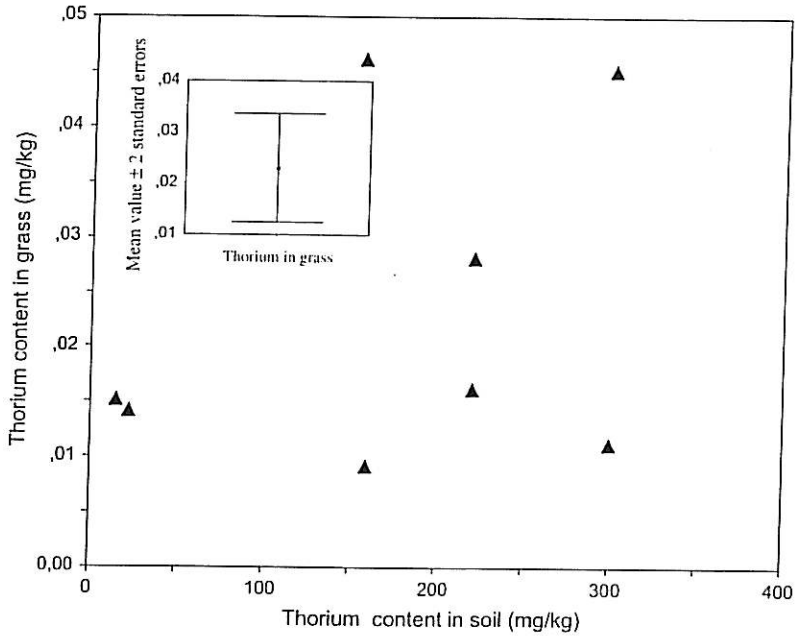

Fig. 5. Comparison between thorium content in soil and thorium content in grass. Error bar plot for thorium in grass is shown in the figure (top left corner).

limit to 2.64 mBq L^{-1}. These values are higher than the reference values of 1 mBq kg^{-1} for ^{238}U and 0.05 mBq kg^{-1} for Th-232 given by UNSCEAR (2000). It can be concluded that water sources in Palong area are affected by the higher uranium and thorium levels from the surroundings, but the levels involved were much less than the maximum permitted levels recommended by the US Environmental Protection Agency (EPA) as reported by Holbert et al. (1995). For uranium in drinking water, the permitted radioactivity level recommended was 1.1 Bq L^{-1} (1100 mBq L^{-1}).

3.4. Absorption of U-238 and Th-232 by moss

Moss or bryophyte is a nonvascular plant. The concentrations of U-238 and Th-232 were determined in three samples of moss collected from three different sampling sites (Table 8). Suitable amount of moss was difficult to find. The concentrations in moss were compared with the U-238 and Th-232 concentration in soil, grass and oil-palm fruit. The results from the three samples indicated that U-238 and Th-232 concentrations in moss vary almost proportionally with TGR doses.

The average U-238 content in dried moss samples (0.445 mg kg^{-1}) is about 17 times the average U-238 content in dried grass samples (0.026 mg kg^{-1}) and about 31 times the average in dried oil-palm fruit samples (0.014 mg kg^{-1}). And the average Th-232 content in dried moss samples (2.36 mg kg^{-1}) is about 23 times the average

Table 6
Activity concentrations of uranium and thorium in soil, grass, oil palm, moss and water samples

	Uranium activity	Thorium activity
Soil samples	($Bq\,kg^{-1}$)	($Bq\,kg^{-1}$)
S1	120.0 ± 6.0	380.4 ± 12.0
S2	58.8 ± 3.6	59.6 ± 1.2
S3	268.8 ± 9.6	726.0 ± 68.0
S4	258.0 ± 4.8	514.0 ± 24.0
S5	62.4 ± 4.8	88.0 ± 8.0
S6	313.2 ± 7.2	620 ± 64
S7	222.0 ± 13.2	832 ± 64
S8	223.2 ± 48.0	476 ± 140
S9	244.8 ± 3.6	640 ± 40
S10	484.8 ± 3.6	884 ± 92
S11	274.8 ± 13.2	970 ± 36
S12	376.8 ± 6.0	1204 ± 48
Grass samples	($Bq\,kg^{-1}$)	($Bq\,kg^{-1}$)
G1	0.036 ±0.012	0.068 ± 0.012
G2	0.312 ±0.036	0.524 ± 0.016
G3	0.420 ±0.048	0.620 ± 0.012
G4	0.912 ±0.048	1.372 ± 0.012
G5	0.024 ±0.012	0.032 ± 0.012
G6	0.120 ±0.036	0.188 ± 0.020
G7	0.060 ±0.036	0.096 ± 0.012
G8	<0.001	0.132 ± 0.004
Oil palm samples	($Bq\,kg^{-1}$)	($Bq\,kg^{-1}$)
OP1	0.372 ± 0.024	0.092 ± 0.012
OP2	0.060 ± 0.036	0.044 ± 0.008
OP3	0.084 ± 0.024	0.044 ± 0.004
Moss samples	($Bq\,kg^{-1}$)	($Bq\,kg^{-1}$)
M1	6.96 ± 0.12	14.0 ± 1.2
M2	7.68 ± 0.12	11.6 ± 1.2
M3	1.44 ± 0.24	2.8 ± 1.2
Water samples	($mBq\,kg^{-1}$)	($mBq\,kg^{-1}$)
W1	8.04 ± 2.40	<0.048
W2	4.02 ± 0.12	1.24 ± 0.04
W3	11.76 ± 1.08	<0.048
W4	16.80 ± 0.48	2.64 ± 0.88
W5	7.08 ± 0.36	1.72 ± 0.04
W6	6.48 ± 0.84	1.16 ± 0.20
W7	3.90 ± 0.12	0.76 ± 0.48
W8	8.88 ± 0.36	1.92 ± 0.08

Error terms appearing in the table are analytical standard deviations unless % is indicated.

Th-232 content in dried grass samples ($0.104\,mg\,kg^{-1}$), and about 157 times the average in dried oil-palm fruit samples ($0.015\,mg\,kg^{-1}$). Uranium-238 activity in moss samples varies from $1.44\,Bq\,kg^{-1}$ to $7.68\,Bq\,kg^{-1}$, and thorium-232 activity varies from $2.8\,Bq\,kg^{-1}$ to $14.0\,Bq\,kg^{-1}$. These values indicated that moss is a significant absorber of uranium and thorium compared to grass and the oil palms.

Table 7
Concentration of uranium and thorium in water samples

Water source	Water sample	Elemental concentration in $\mu g\,L^{-1}$		Th to U ratio	TGR dose rate at the sampling point ± 10% ($nGy\,h^{-1}$)
		U	Th		
Ground water	W1	0.67 ± 0.20	<0.012		827
Palong River	W2	0.34 ± 0.01	0.31 ± 0.10	0.91 ± 0.01	296
Palong River	W3	0.98 ± 0.09	<0.012		291
Fishpond	W4	1.40 ± 0.04	0.66 ± 0.22	0.47 ± 0.14	609
Bado River	W5	0.59 ± 0.03	0.43 ± 0.01	0.73 ± 0.02	357
Stream	W6	0.54 ± 0.07	0.29 ± 0.05	0.54 ± 0.06	1001
Palong River	W7	0.33 ± 0.01	0.19 ± 0.01	0.58 ± 0.01	287
Stream	W8	0.74 ± 0.03	0.48 ± 0.02	0.64 ± 0.01	957

Error terms appearing in the table are analytical standard deviations unless % is indicated.

Many authors including Say and Whitton (1983), Mouvet (1984), Tremolieres et al. (1994) and Nelson (1996) have reported that bryophytes are superior in locating metal sources in intermittent and groundwater because of their capability to integrate metal concentrations allowing for easier detection. Therefore, moss tissue analysis could play significant role in locating sources of uranium and thorium contamination or in monitoring uranium and thorium based pollutants in the environment.

4. Conclusions

From the ground gamma-ray survey conducted in the study area, elevated TGR dose rates were found, particularly in Balai Badang village where the highest TGR dose recorded was 1440 ± 100 $nGy\,h^{-1}$ (160 $\mu R\,h^{-1}$). Some areas with significant population have doses higher than 1000 $nGy\,h^{-1}$. According to the UNSCEAR (2000) formulation and based on tropical rural settings, an individual in the village could be expected to receive an annual average dose due to TGR of 3.1 $mSv\,yr^{-1}$. At the location of the highest dose, which is populated, the annual dose due to TGR would be 8.8 $mSv\,yr^{-1}$. This is not an insignificant amount of radiation dose; it is equivalent to 44 times of a typical dose received from a chest X-ray examination. Based on the quantity of dose received and the number of people involved, it is

Table 8
Concentration of uranium and thorium in moss samples (dry weight)

Moss sample	Elemental concentration in $mg\,kg^{-1}$		Th to U ratio	TGR dose rate at the sampling point ± 10% ($nGy\,h^{-1}$)
	U	Th		
M1	0.58 ± 0.01	3.5 ± 0.3	6.14 ± 0.42	1001
M2	0.64 ± 0.01	2.9 ± 0.3	4.53 ± 0.40	374
M3	0.12 ± 0.02	0.7 ± 0.3	5.57 ± 1.57	104

Error terms appearing in the table are analytical standard deviations unless % is indicated.

important that a thorough biological impact assessment study could be carried out to ascertain the effect of relatively high TGR doses on the villagers. The suggested study is beyond the ability of the current researches.

Uranium and thorium were found to be the main cause of the high radioactivity of the area. The specific activity of uranium in soil was estimated to be in the range from 58.8 Bq kg^{-1} to 484.8 Bq kg^{-1}, and the thorium activity in the range from 59.6 Bq kg^{-1} to 1204 Bq kg^{-1}. Significant linear relationships between TGR doses and uranium and/or thorium content in soil have been observed.

Plant materials and water sources of the area are affected by the terrestrial radioactivity, but they were far below the permitted levels. Therefore, agricultural products from the area, especially the economically important oil-palm fruits, are safe for consumption.

Acknowledgements

We would like to record our gratitude to the Malaysian Government for funding this study under IRPA No. 4-07-07-040, and the Universiti Teknologi Malaysia for providing various facilities and grant Vot-71159. Special thanks to the Malaysian Institute of Nuclear Technology Research (MINT) for the NAA analysis. Our thanks go also to owners of various lands for allowing us access to their properties; and to Mr. Zhari Minit and the villagers of Kampong Balai Badang for their cooperation and helps. Our gratitude to Ms. Jamaliah M. Yatim, Ms. Pirmula Devi and Ms. Ecwiat of MINT; Mr. Yusof Jasman, Mr. S.K. Lee, Mr. Sulaiman Abdullah, Mr. Yasin Sudin, Mr. Bakri Rosdi and Mr. Khairunnadim A. Sekak of UTM; for their contributions in various ways. We are indebted to Dr. Hisham Lee for his help with the statistics.

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BAB 4.

PENGUKURAN KEPEKATAN ^{238}U DAN ^{232}TH ALAM SEKITAR DI KAWASAN SINARAN LATAR BELAKANG TABI'I ARAS TINGGI DI PALONG, JOHOR, MALAYSIA.

Kertas kerja, "Environmental ^{238}U and ^{232}Th Concentration Measurements in an Area of High Level Natural Background Radiation at Palong, Johor, Malaysia."

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Journal of Environmental Radioactivity, 80 (2005) pp 287 – 304, Elsevier Science Ltd, United Kingdom. **ISSN 0265-931X**

BAB 5

RUMUSAN UMUM.

Kedua-dua objektif kajian telah berjaya dicapai.

a) Bentuk hubungan kestatistikan di antara jenis tanah, latarbelakang geologi dan aras kadar dos sinar gama daratan telah berjaya diperihalkan sebagaimana yang dibentangkan dalam Bab 2 dan Bab 3.

Hubungan yang telah diperolehi di atas telah digunakan dalam penyelidikan seterusnya (Ramli et al, 2003, Ramli et al, 2005). Konsep yang telah dikemukakan dalam penyelidikan ini seterusnya sedang dimanfaatkan dalam penyelidikan kontrak dengan pihak Lembaga Perlesenan Tenaga Atom, bertajuk "Risiko Kesihatan Penduduk Persekitaran Kilang Amang di Lembah Kinta." Ianya dikendalikan dibawah Vot. 68876 melalui Pusat Pengurusan Penyelidikan, RMC.

b. Tahap hazard radiologi di kawasan Palong dari segi fizik kesihatan di dapati secara keseluruhannya berada pada tahap yang rendah dan hasil

pertaniannya tidak menjadi ancaman kepada kesihatan secara umumnya, sebagaimana yang dibentangkan dalam Bab 4.

Walaubagaimana pun terdapat lokasi di mana dos sinaran kepada penduduk agak tinggi, iaitu setinggi 8.8 mSv setahun. Sebagaimana yang dicadangkan dibawah, penyiasatan lanjut perlu dilakukan di sini.

Disamping kertas kerja yang dikemukakan dalam Bab 2, 3 dan 4, penyelidikan ini juga telah dimanfaatkan untuk menghasil 1 tesis M.Sc (Hussein, 1999) dan 2 Laporan Projek Sarjana Muda (Syafizal b. Said, 2000, dan Khairunnadim Ahmad Sekak, 1998).

CADANGAN.

Sebagaimana yang di kemukakan dalam Bab 4, ada terdapat lokasi di kawasan kajian yang dos sinaran semula jadinya bernilai 8.8 mSv setahun. Nilai ini agak tinggi berbanding dengan nilai biasa di Semenanjung Malaysia, iaitu pada sekitar 1 sehingga 2 mSv setahun.

Berdasarkan kepada kuantiti dos sinaran yang diterima dan jumlah penduduk yang terlibat adalah mustahak penilaian impak biologi yang teliti dilakukan

dengan menyeluruh untuk menentukan kesan dos sinaran yang secara relatifnya agak tinggi ini. Kajian seterusnya ini perlu melibatkan pakar perubatan. Jenis dan sifat penyiasatan yang perlu dilakukan seterusnya adalah di luar dari skop dan kemampuan (termasuk dari segi kemudahan dan peralatan) yang ada pada penyelidik projek ini.

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Rujukan lain adalah sebagaimana yang terdapat dalam Bab 2, 3 dan 4.

Pergamon

PII: S0969-8043(96)00264-3

Appl. Radiat. Isot. Vol. 48, No. 3, pp. 407–412, 1997

0969-8043/97 $17.00 + 0.00

Environmental Terrestrial Gamma Radiation Dose and its Relationship with Soil Type and Underlying Geological Formations in Pontian District, Malaysia

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(Received 21 March 1995; accepted 23 July 1996)

An environmental terrestrial gamma radiation dose survey has been conducted, covering the Pontian district of Peninsular Malaysia. Results have allowed construction of a terrestrial gamma-ray isodose contour map of Pontian. Relationships between the gamma radiation dose levels measured at various locations and the soil type and underlying geology are discussed. © 1997 Elsevier Science Ltd. All rights reserved

Introduction

Interests in natural background radiation include:

1. A need to establish reference levels, from which relative radiological hazards due to future possible releases of radioactive material might be evaluated (Frenzel, 1993).
2. A need to establish pre-operational radiation levels at planned sites of radiation facilities. This is a legal requirement in many countries.
3. A need to identify areas with high natural radiation (Roser and Cullen, 1964; Erickson *et al.*, 1993), and evaluate potential excess cancer risks (Eisenbud *et al.*, 1964).
4. Utility of natural radiation dose surveys in mineral prospecting, especially for uranium.

The current study examines relationships between background radiation dose, soil type and underlying geological formations (Roser *et al.*, 1964; Wollenberg *et al.*, 1994; Quindos *et al.*, 1994; Ibrahim *et al.*, 1993) in Pontian, a district in Peninsular Malaysia. Particular focus is upon environmental terrestrial gamma radiation doses.

Pontian is located between latitudes 1°16′ and 1°46′ North and longitudes 103°11′ and 103°35′ East, and also represents the southernmost tip of mainland Asia. With an area of 919 km^2 and a population of about 139,000 the main land utilisation is for agriculture.

From the geological point of view Pontian district is young and simple, being mostly quartenary, with one exception being a small section towards the middle of its eastern border known as Triassic. The quartenary part, formed in the main, by recent (less than 2 million years ago) alluvium, can be divided into two areas representing: (i) marine clay and silt which are to be found mostly on the coastal plain; and (ii) peat, humic clay and silt, which are to be found in the more interior parts of the district (Fig. 1).

The Pontian district is overlaid by four main types of alluvial soils:

1. A clayey mixed isohyperthermic member of Typic Sulfaquent, classified by FAO/UNESCO (Paramanathan, 1978) as Thionic Fluvisol, and locally referred to as Kranji. Kranji is found on the coastal plain, in mostly tidal swamps covered by mangrove.
2. A clayey mixed acid isohyperthermic member of Typic (Sulfic) Tropaquept, classified by FAO/UNESCO as Dystric Gleysols and Thionic Fluvisol, and locally referred to as *Selangor*-kangkong. Selangor-kangkong is yet another type of soil found on the coastal plains, being less watery than Kranji.
3. Organic clay.
4. *Peat*. This organic soil is found in areas where drainage is poor with the consequence that its water content is high.

A number of smaller areas in the middle part of the eastern border are covered by various other types of alluvial and sedentary soils (Fig. 2).

Method and Detectors Used

By aligning the sampling-points grid along the latitudinal and longitudinal lines, the district was divided into squares of ~ 1.85 km × 1.85 km (1′ × 1′). Dose measurements were made at each crossing point of the grid. As far as possible dose measurements were made away from sites of human development such as roads, building and foundation soils.

The main detector used in this study was a gamma-ray detector manufactured by Ludlum of the U.S.A., model 19, Micro R Meter. This instrument, which responds to gamma radiation (with inappreciable β particle response), consists of a 1 × 1″ (2.54 × 2.54 cm) NaI crystal doped with thallium [NaI(T1)] as the gamma detector. A valid manufacturer's certified calibration was available for this instrument.

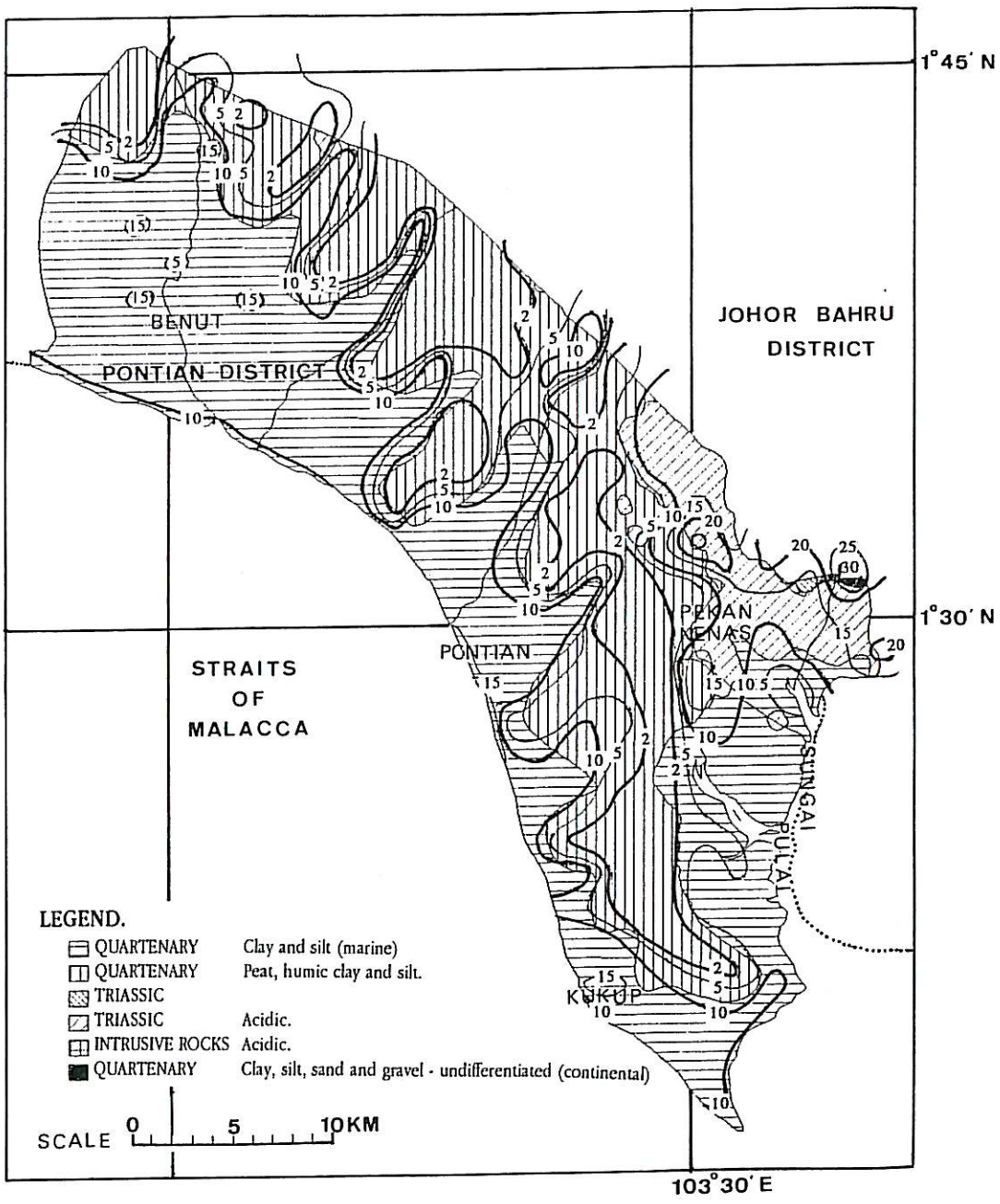

Fig. 1. Terrestrial natural gamma radiation dose distribution and geological background of the Pontian district, Malaysia. From the main detector in $\mu R\ h^{-1}$. 1 μR ~ 8.7 nGy.

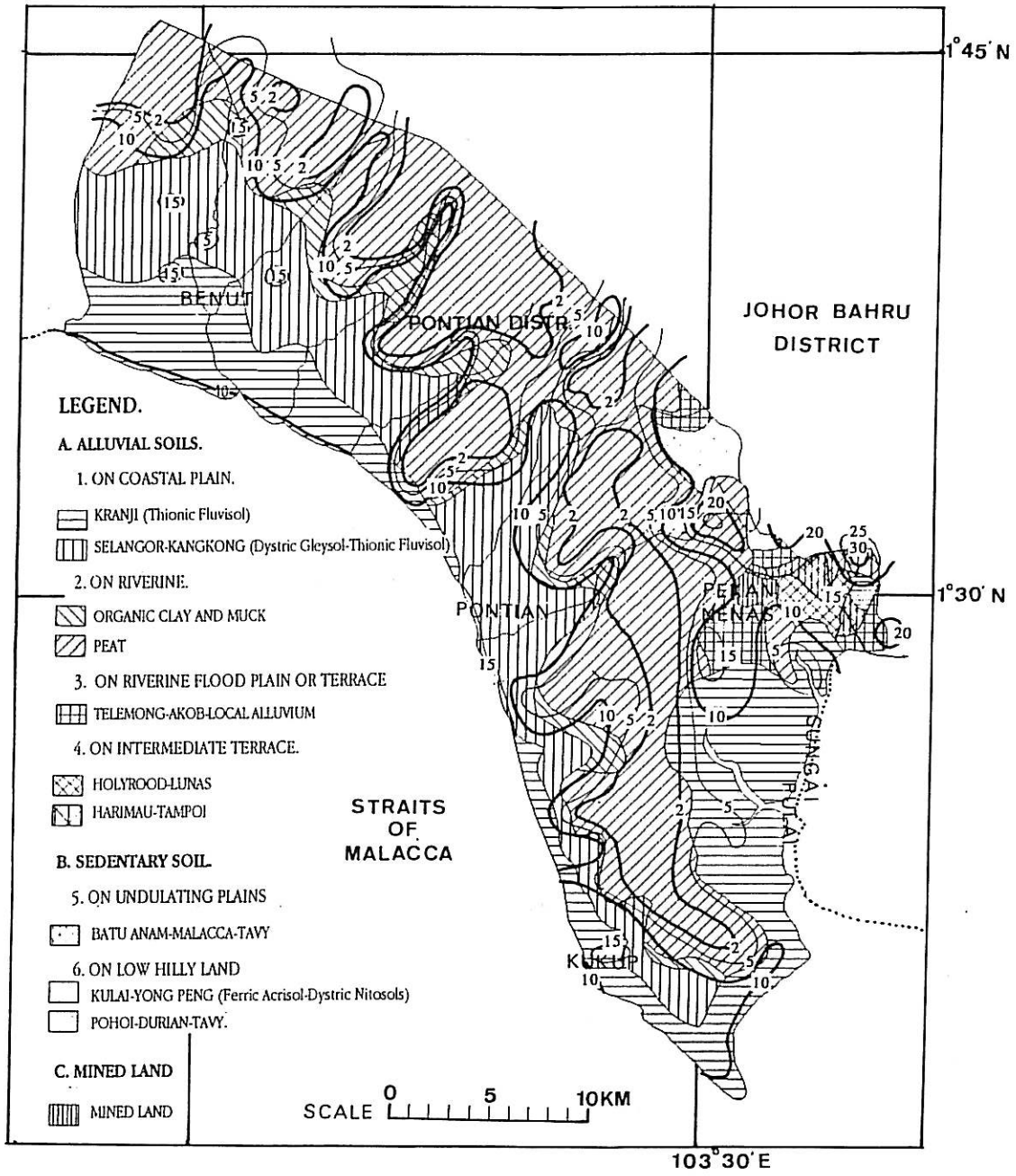

Fig. 2. Terrestrial natural gamma radiation dose distribution and soil types of the Pontian district, Malaysia. Results from the main detector in $\mu R\ h^{-1}$. 1 μR ~ 8.7 nGy.

The approximately flat energy response of the detector to gamma radiation of energies between 40 keV to 1.2 MeV, was considered to be acceptable as this covers the majority of the significant γ emissions from major sources of natural gamma radiation (Table 1). The low response of the instrument to high energy gamma radiation implies that contributions from cosmic sources are negligible. Thus, for instance, measurements performed directly above a river, at points with depths > 5 m registered readings of the order of 1 μR/h (~ 9 nGy h^{-1}), this being the smallest scale division for this particular instrument. At such levels, readings are within instrument fluctuations. The uncertainties of readings observed on the maximum sensitivity scale of the instrument are to the order of 10%.

A second instrument, sensitive to gamma, beta and alpha radiations, and manufactured by Ludlum of

the U.S.A., Model 3, was used for purposes of comparison. This instrument utilises a Geiger–Muller tube as the radiation detector. Readings are represented in terms of counts per second (cps) with 1 cps $\sim$ 18 μR ($\sim$ 160 nGy)/h. Uncertainty in reading was of the order of 30% at maximum sensitivity (using manufacturer's calibration). In general the readings from the two instruments were comparable, except on occasions when gamma readings from the main instrument were either very low or relatively high. In these situations the second detector provided higher readings whenever readings from the primary detector were very low, and gave much lower readings whenever readings from the main detector were relatively high. These discrepancies can be attributed to the differing penetrating power of beta and gamma radiation.

Results and Discussion

Iso gamma dose-rate contour lines constructed from measurements using the main detector are presented graphically in Figs 1 and 2, whilst Fig. 3 provides counterpart measurements of gamma + beta radiation count rate.

From Fig. 2 it can be observed that gamma doses are lower in quarternary areas than in other geological areas. Gamma doses were lowest in quartenary areas formed from peat, humic clay and silt, achieving values which were below 2 μR h^{-1} (20 nGy h^{-1}). Significant differences in gamma doses due to Kranji when compared to other soil types could be clearly seen around Sungai (i.e. river) Pulai. The gamma dose here was 6 ± 2 μR h^{-1} (50 ± 20 nGy h^{-1}). In other Kranji areas such doses were not measured with the exception of reclaimed tidal swamps along the coast which had been drained and protected by embankments to prevent ingress of tidal water. As a result of the very much reduced water content it was quite difficult to distinguish between Kranji and Selangor-Kangkong soils, gamma dose rates for both being within the range 13 ± 3 μR h^{-1} (120 ± 30 nGy h^{-1}). Gamma dose levels for areas covered by organic clay, generally being in locations between Selangor-kangkong and peat areas, were between those due to Selangor-kangkong and peat soils, at 6–12 μR h^{-1} (50–110 nGy h^{-1}).

In a small quartenary area with associated gravel, and situated to the East of the town of Pekan Nenas, gamma dose-rates were found to be relatively high, at up to 30 μR h^{-1} (270 nGy h^{-1}).

Also of geological significance is the mainly acidic Triassic area located around the vicinity of Pekan Nenas. Gamma doses here were measured as 14 ± 3 μR h^{-1} ($130 + 30$ nGy h^{-1}), being generally higher than that measured in quartenary areas. A peat covered area of relatively high gamma dose [up to 26 μR h^{-1} (230 nGy h^{-1})] was located to the North of Pekan Nenas. Here gamma-ray contributions from the deeper geological structure dominated the thin peat soil contributions to dose-rate.

Natural terrestrial gamma dose-rates in peat area are very low. Values are dependent upon the thickness and purity of the peat soil. In areas where the peat is thick and pure, the gamma dose measured can be as low as 1 μR h^{-1} (9 nGy h^{-1}) but are generally closer to 2 ± 1 μR h^{-1} (20 ± 10 nGy h^{-1}). In areas where the peat soils are thin and mixed with clay gamma dose rates have been found to be within the range of 4–8 μR h^{-1} (40–70 nGy h^{-1}).

Conclusion and Possible Further Work

A close relationship between soil types, underlying geology and the distribution of natural background gamma radiation dose has been established in this study. As such it might be possible to make reasonable and informed estimates of background gamma radiation dose for other areas based upon the soil type and geological information already available.

Quartenary areas are the product of recent sedimentation. Sedimentation has exposed geological material to oxidation processes that have transformed uranium compounds into more mobile forms

Table 1. Main gamma energies from natural radioactivity sources. %, refers to intensity as % of disintegration, with reference to U-238 and Th-232 series respectively (Beck, 1979)

Radionuclide	Energy (keV)	%	Radionudide	Energy (keV)	%
	Thorium-232 series			Uranium-238 series	
Bi-212	727.2	7.0	Th-234	92.6	5.6
Pb-212	74.8	10.7	Pb-214	77.1	10.7
	77.1	19.0		241.9	7.3
Tl-208	510.7	9.0		295.2	18.7
	583.1	30.0		352.0	36.6
	2614.7	36.0	Bi-214	609.4	45.0
Th-228	12.3	9.6		768.4	5.0
Ac-228	338.5	12.3		1120.4	15.2
	911.1	29.0		1238.2	5.9
	964.6	5.5		1764.7	15.4
	966.0	23.0			
	968.9	17.5	Uranium-235	185.7	54.0
				205.3	47.0
Potassium-40	1460.8	10.7			

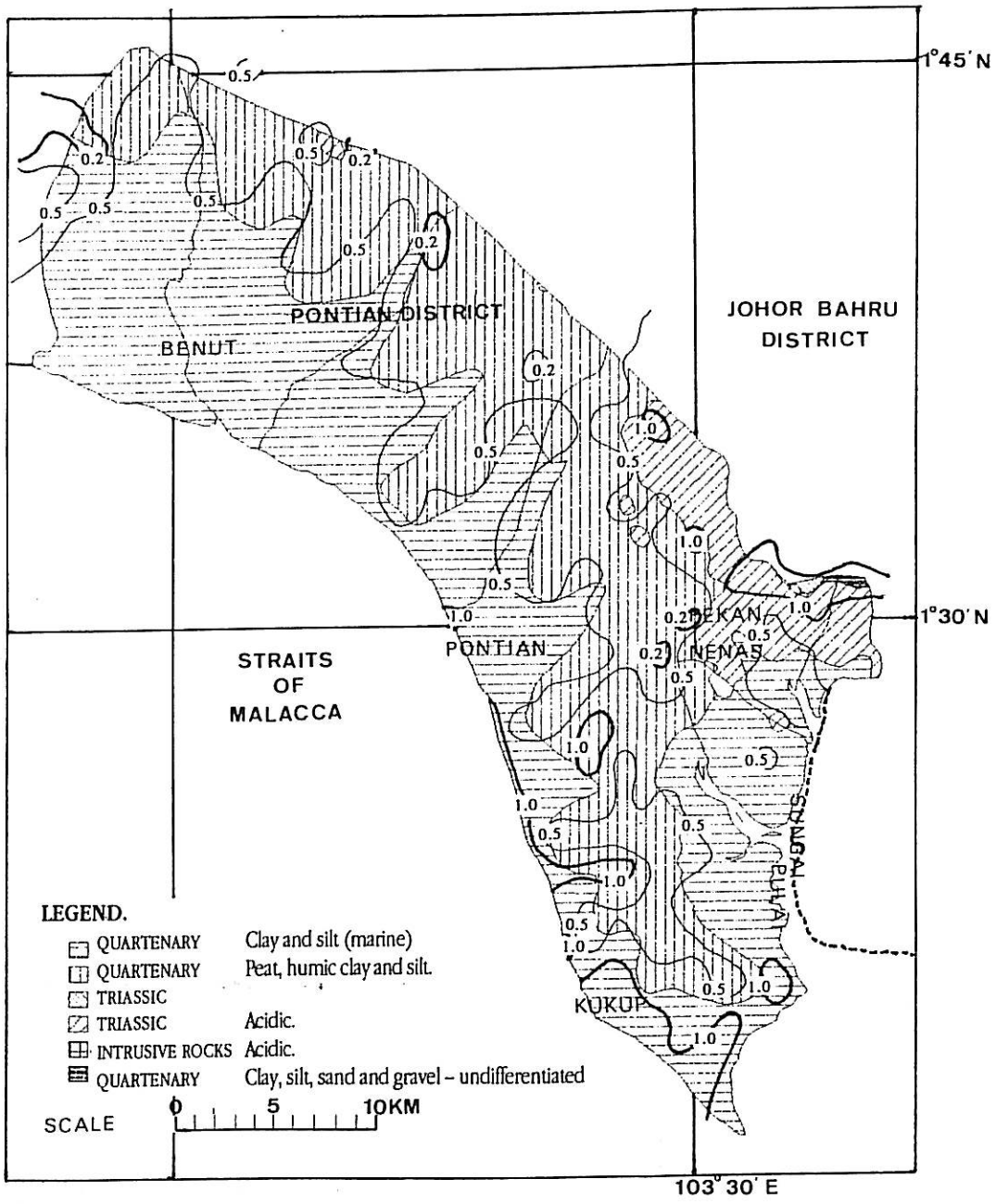

Fig. 3. Gamma and beta dose distribution and geological background. Pontian district, Malaysia. In counts per second (cps). From the second detector: 1 cps ~ 157 nGy h^{-1}.

that are more amenable to transportation through aqueous means and which can lower the uranium content of an area. Reduction of uranium and thorium content is even more significant whenever geological sedimentation process involves organic materials, a situation that possibly represents the Pontian district.

The average value of natural terrestrial gamma dose in Pontian district has been estimated to be 7.7 μR (~ 67 nGy) h^{-1}. This value is comparable to the world average of 30–70 nGy h^{-1} or 88 nGy h^{-1} (Vaupotic *et al.*, 1994; United Nations, 1977). Using the conversion factor of 0.7 Sv/Gy (UNSCEAR, 1988) the average dose of such terrestrial natural gamma dose that an individual staying outdoors might be expected to receive was estimated to be 422 μSv per year. The low radiation areas ~ 1 μR (~ 9 nGy) h^{-1} that were found in this district could be suitable sites for environmental radiation contamination monitoring.

Acknowledgements—This study was funded by the Ministry of Science, Technology and Environment, Malaysia, through research grant IRPA No. 4-07-07-040. Contributions from Mr Yusof Jasman as Research Assistant for geological aspects and Mr Abdullah Othman on the mapping, are gratefully acknowledged.

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