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Study the influences of the radionuclide depth distributions on the FEPE for the measurements of the soil activity using in situ HPGe gamma spectrometry

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Abstract: In this work, the influences of the soil densities and the radionuclide depth distributions (RDD) on the Full Energy Peak Efficiency (FEPE) calculation of the in-situ gamma ray spectrometer using the In Situ Object Counting Systems (ISOCS) software were studied. The data of the RDDs at the sites were investigated by using laboratory HPGe gamma spectrometer. Six different RDDs of ^{40}K, ^{226}Ra and ^{232}Th were found at four studied sites with radionuclide deposition moving from surface to deeper positions. The results show that FEPE values vary strongly for the different RDDs, especially for the low gamma ray energies. Use of the uniform model for calculating FEPEs can result in noticeable errors from 29% to 101% for the realistic RDD of the exponential form (surface radionuclide deposition), negative variations from 14% to 30% for the realistic RDD of having a radionuclide deposition at the 30 cm depth, and negligible variations of less than 5 % for the realistic RDD of quasi uniform form in the range of gamma ray energies of interest.

Keywords: *HPGe gamma spetrometer, radionuclide depth distributions, full energy peak efficiency.*

I. INTRODUCTION

In-situ gamma ray spectrometry using a HPGe detector is an effective method to determine natural and artificial radionuclide concentration in geophysical field, assessment of doses due to radioactive fallout or pollutants as well as estimation of soil erosion [1] [2]. It allows the direct and quick qualitative and quantitative determination of gamma emitting radioactive pollutants. The advantages of this method involve obtaining prompt available results about the average activity of radionuclides over large area [3]. On the contrary, the main disadvantage of the method is that the accuracy and the precision of the analysis results strongly depend on the radionuclide depth distribution within the soil [4,5].

In this work we study in details the influence of soil density and the radionuclide depth distribution on the FEPE ~~s~~ of the in-situ gamma ray spectrometer using the ISOCS software [6]. The RDD of ^{238}U, ^{232}Th and ^{40}K at the survey areas are estimated by laboratory HPGe gamma spectrometer using the LabSOCS software [7]. First of all, some measurement conditions for in-situ gamma ray spectrometer are studied using the ISOCS software.

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II. SUBJECTS AND METHOD

A. Introduction to ISOCS and its characteristics

The In Situ Object Counting Systems (ISOCS) was developed by Canberra Industries, Inc. It involves the coaxial p-type HPGe detector of GC2518, standard acquisition electronics, shielding, collimators, detector carrier and detector stand (Figure 1).

Fig. 1. In situ object counting system (ISOCS) using HPGe of GC2518 detector.

Fig. 2. Laboratory gamma spectrometry using HPGe of GC3520 detector.

The ISOCS/LabSOCS software is used for calibrating the HPGedetector efficiency as a function of energy for over a photon energy range of 45 keV through 7 MeV, for a wide variety of source geometries and activity distributions that could be encountered in in-situ measurements (ISOCS) and laboratory measurements (LabSOCS) for environmental analysis [7].

In this study, the detector was located at 1 m above the ground surface, with its collimator opening angle of 90^0, the view of the detector covers a soil column of 2 m diameter. This selected set-up may be expected to reduce the influences of radioactivity background from plants or buildings, walls surrounding the surveyed locations.

B. Sampling in depths and laboratory measurements

At four sites of the in-situ measurements, four soil cores were collected. The core tube was inserted vertically to sample soil in depth up to 30 cm. Each core was sectioned into 3 cm increments to provide more detailed information on the RDD of these radionuclides. The samples from the sectioned core were dried, ground and analyzed in the laboratory using high resolution HPGe gamma detector of GC3520 (Figure 2), with count times set to 24 hours. The FEPEs of the laboratory detector were calibrated by using LabSOCS software.

C. Models of density and radionuclide depth distribution

The following four models of density and RDD were proposed for studying the influence of RDD on the FEPEs:

- UNI model uses the uniform density and radionuclide depth distribution. The soil density and its activity were averaged over the whole of the interested soil column of 200 cm x 30 cm (see Table I). The surveyed soils are alluvial with the composition of Dirt 1 [8].

- DEN model uses the same averaged activity as UNI model but its density varies with layer depth (Table 5). Each layer has 200 cm diameter and thickness of 3 cm. The soil composition is of Dirt 1 for grey soil at the above 12 cm layer and of Dirt 4 for the red soil at the rest depth layer [8].

- RAD model takes into account for radionuclide depth distribution, but the soil density is averaged over the whole of the interested soil column of 200 cm x 30 cm. The soil composition is of Dirt 1 and Dirt 4 [8].

- DEN-RAD model takes in account for both density and radionuclide depth distributions. Its density and activity are averaged for each 3 cm layer (Table 5). The soil composition is of Dirt 1 and Dirt 4 [8].

After inputting these parameters in ISOCS, FEPEs for gamma ray energies from the natural radionuclides in soils and fallout ^{137}Cs were calculated for four models combined with six typical depth profiles of density and radionuclide based on the laboratory HPGe gamma measurements. The comparisons of FEPE – energy curves from the different models with the realistic DEN-RAD models were studied and discussed.

III. RESULTS AND DISSCUSION

A. The radionuclide depth distribution using laboratory measurements

The depth distribution of ^{40}K, ^{226}Ra and ^{232}Th in four soil cores collected at the areas of Thu Duc, Ho Chi Minh city, Viet Nam were investigated by using laboratory HPGe spectrometry. The results show that radioactivity distributions are functions of soil depths in an exponential form, a quasi Lorentz distribution, a quasi uniform distribution, and a linearly activity increase to the 30 cm depth (Figure 3). In details, the RDD of ^{40}K at site 2 (A type) having an exponential form with its maximum activity of 74 Bq/kg at the ground surface was explained by soils in these areas has been often fertilized for planting [9]. Potasium is easy to dissolve. Watering and rainfall can make them penetrate into the deeper layer of the soil and form a distribution of the activity in the soil decreasing exponentially with depth. By the time, the position of the maximum of the radionuclide distribution in soil can move from the surface to deeper positions make it may be approximated by Lorentz distribution as in case of ^{40}K at the site 3 (B type) and of ^{40}K at the site 1 (C type). In another case, ^{40}K and ^{226}Ra at the site 4 has quasi uniform distribution (D and E type respectively) because of the physical, chemical and biological nature of the soil, the climate, streaming and human interventions [10]. In the meanwhile, primordial radionuclides of ^{232}Th at the site 1 which have an increase of activity to the 30 cm depth (F type) was explained by wash out of ^{232}Th in soil for a long time.

B. The influence of the different realistic radionuclide depth distribution on FEPEs

Six typical radionuclide depth distributions obtained from laboratory measurements which were selected to study their influences on FEPE in the range of gamma ray energies of interest were presented in Figure 3.

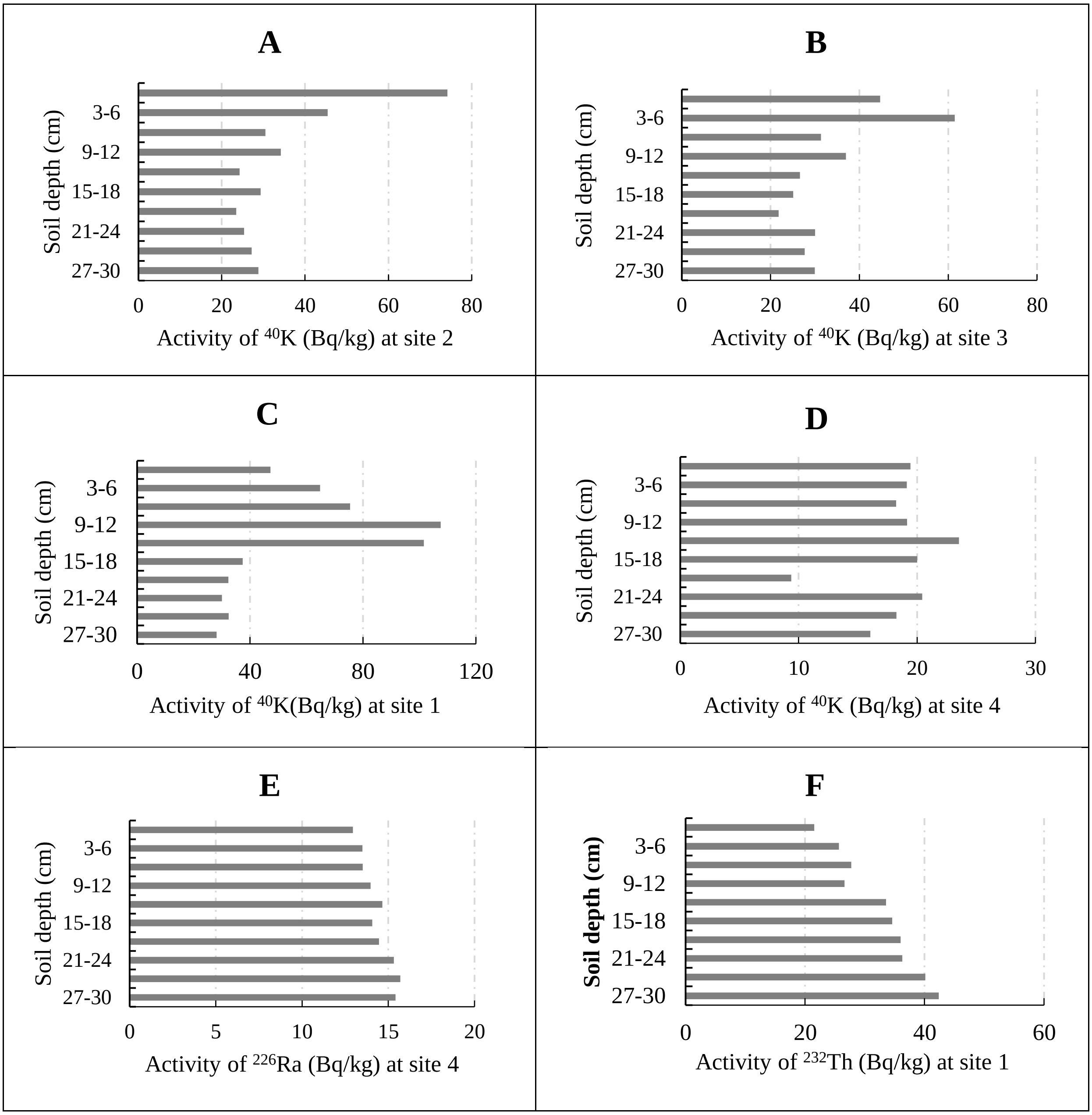

Fig. 3. The radionuclide distributions of ^{232}Th, ^{226}Ra, ^{40}K as a function of depth estimated by laboratory HPGe spectrometer (spectroscopy) for the in-situ surveyed sites.

The percentages of the activity at each 3 cm layer relative to the sum of the activities of the whole soil core of 30 cm depth were calculated from data of the laboratory HPGe gamma measurements at section B.2 and given in Table I. These percentages with the collected data of density depth profile respectively were used to input in the Geometry Composer interface of ISOCS. The data of the whole soil column of 30 cm depth at the surveyed sites are listed in the final row of the Table I.

Table I. The densities (D) and the percentages of activities (PA) in depth y (cm) for six RDDs

RDD	**A Type**		**B Type**		**C Type**		**D Type**		**E Type**		**F Type**	
y (cm)	D (g/cm^3)	PA (%)	D (g/cm^3)	PA (%)	D (g/cm^3)	PA (%)	D (g/cm^3)	PA (%)	D (g/cm^3)	PA (%)	D (g/cm^3)	PA (%)
0-3	1.66	0.22	1.32	0.13	1.51	0.08	1.02	0.11	1.02	0.09	1.51	0.07
3-6	2.00	0.13	1.81	0.18	2.07	0.12	1.58	0.10	1.58	0.09	2.07	0.08
6-9	2.23	0.09	1.81	0.09	1.47	0.14	1.58	0.10	1.58	0.09	1.47	0.09
9-12	2.41	0.10	1.89	0.11	1.47	0.19	1.58	0.10	1.58	0.10	1.47	0.08
12-15	1.92	0.07	1.85	0.08	2.30	0.18	1.47	0.13	1.47	0.10	2.30	0.10
15-18	2.11	0.09	1.92	0.07	2.30	0.07	1.70	0.11	1.70	0.10	2.30	0.11
18-21	2.00	0.07	2.34	0.07	2.75	0.06	1.74	0.05	1.74	0.10	2.75	0.11
21-24	2.04	0.07	1.58	0.09	2.15	0.05	1.66	0.11	1.66	0.11	2.15	0.11
24-27	2.19	0.08	1.70	0.08	2.68	0.06	1.77	0.10	1.77	0.11	2.68	0.12
27-30	1.96	0.08	2.45	0.09	2.41	0.05	2.30	0.09	2.30	0.11	2.41	0.13
0-30	2.05	1.00	1.87	1.00	2.11	1.00	1.64	1.00	1.64	1 .00	2.11	1.00

Figure 4 illustrates ratios of FEPEs computed by the different models to FEPEs computed by the realistic DEN-RAD model for six typical RDDs and in the range of interested gamma ray energies. The results show remarkable variations of relative FEPE values based on the UNI and DEN models, especially for the low gamma ray energies. The negative deviations were found mainly for FEPEs of the UNI model compared with FEPEs of the DEN-RAD model of A, B, C type which has the maximum activity of radionuclide deposition lies from the ground surface to a half of a 30 cm depth. The positive deviations were found mainly for FEPEs from UNI model compared with DEN-RAD model of E, F type which has the maximum activity at the bottom (30cm depth). In the meanwhile, the negligible deviations of FEPEs were found for FEPEs of UNI model compared with FEPEs of DEN, RAD, and DEN-RAD models of D type. Figure 6 also indicates that there is negligible variation between FEPEs of UNI model and FEPEs of DEN model or FEPEs of DEN-RAD model and FEPEs of DEN model because densities of the layers do not much change. Besides, in the histograms of A, B, F in Figure 3 and Figure 4 it seems that the more radioactivity the more negative or positive deviation of FEPEs when UNI model was used instead of the realistic DEN-RAD models.

In details, FEPE-energy curve obtains the highest values for the DEN-RAD of A type and the lowest values for the DEN-RAD model of F type. FEPE values vary strongly for the different RDDs, especially for the low gamma ray energies. In calculating FEPEs, using the uniform model instead of the realistic RDD can result in noticeable errors from 29 % to 101 % for the exponential form, negative deviations from 14 % to 30 % for radionuclide deposition at the 30 cm depth, negative or positive variations from 2 % to 21 % for the quasi Lorentz form.

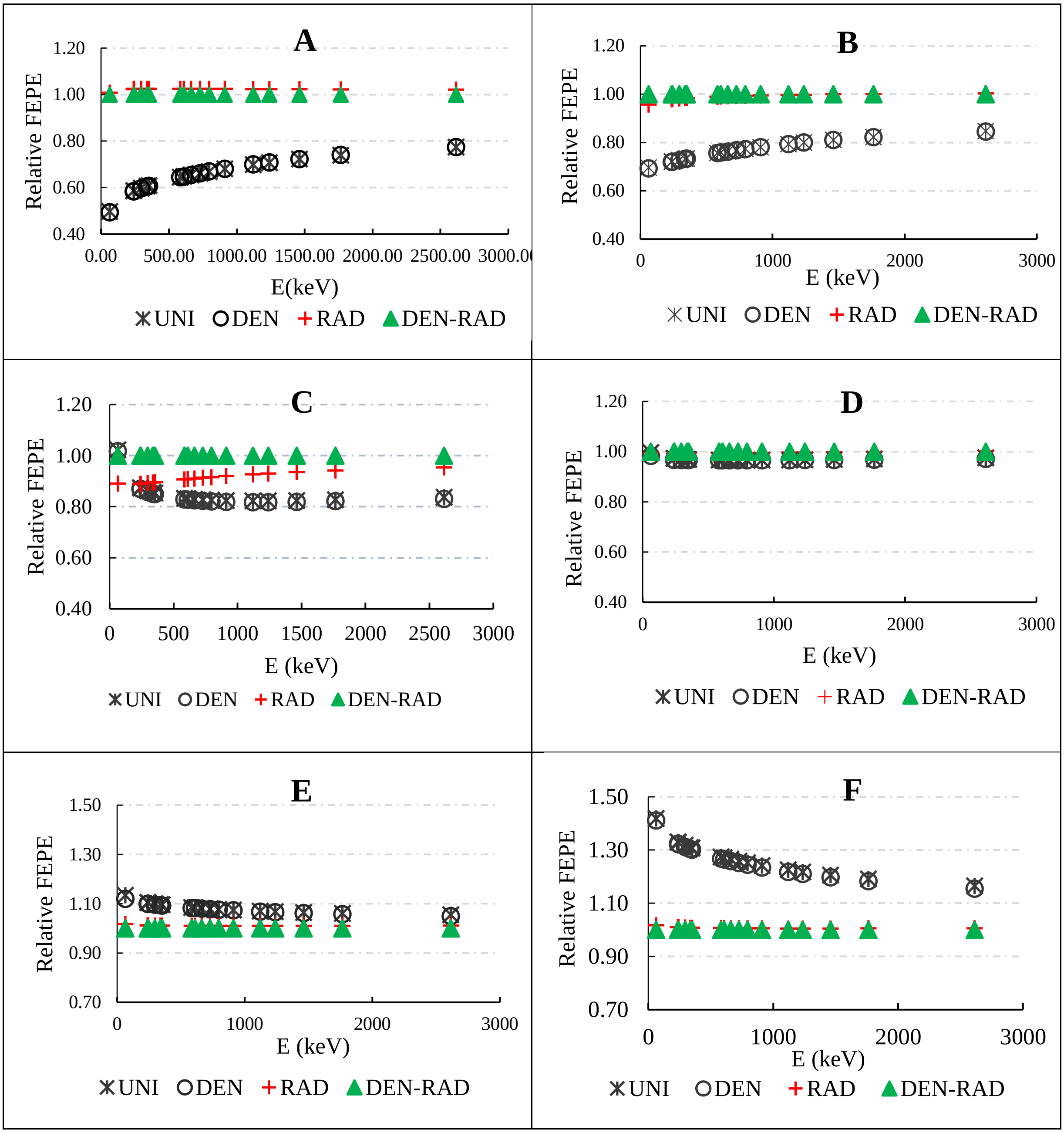

Fig. 4. The ratios of FEPEs (relative FEPE) for the different models to the realistic DEN-RAD model with gamma ray energies from 63.83 keV to 2614.51 keV for six typical RDDs.

IV. CONCLUSIONS

The calculated FEPEs vary strongly for the different realistic models of radionuclide depth distribution, such as exponential form, quasi Lorentz distribution, quasi uniform, or deeper depositions. The surface deposition can result in more errors of FEPEs (with a positive deviation of 70% for gamma ray energies less than 238 keV) than the radionuclide deposition at a 30 cm depth (with negative deviation of 25% for energies higher than 238 keV respectively) using the uniform radionuclide depth distribution model for calculating FEPEs.

Although the knowledge of the site history, the properties as well as the origin of radionuclides within soils can help predict an appropriate model of the radionuclide depth distribution, the depth sampling and using laboratory measurements to obtain the radionuclide depth distribution at the surveyed site is still an selected manner for having a more accurate quantification of the soil activity.

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