Transfer factor of $^{226}$Ra, $^{232}$Th and $^{40}$K from soil to Alpinia Galangal plant grown in northern Thailand

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Abstract. This paper reports the activity concentration of three natural radionuclides, $^{226}$Ra, $^{232}$Th and $^{40}$K, found in Alpinia Galangal plants which are widely used in various Asian cuisines and traditional medicine. The galangal plants and their relevant soils were collected from four provinces in the north of Thailand under natural field conditions. The activity concentration of radionuclides was determined using gamma-ray spectrometry. Soil-to-plant transfer factors (TFs) for $^{226}$Ra, $^{232}$Th and $^{40}$K were investigated in rhizome and aerial parts of the galangal plants. The activity concentration in the soils ranged from 22 to 88 Bq kg$^{-1}$ for $^{226}$Ra, 27 to 157 Bq kg$^{-1}$ for $^{232}$Th and 58 to 1157 Bq kg$^{-1}$ for $^{40}$K. In Alpinia Galangal, the concentration ranged from $<0.2$ to 2.0 Bq kg$^{-1}$ for $^{226}$Ra, $<0.1$ to 2.9 Bq kg$^{-1}$ for $^{232}$Th and 205 to 2247 Bq kg$^{-1}$ for $^{40}$K. The TF ranged from $<0.002$ to 0.073 for $^{226}$Ra, $<0.001$ to 0.061 for $^{232}$Th and 0.26 to 7.9 for $^{40}$K. The TFs in the aerial parts were higher than those for the rhizomes. The obtained values can be considered as a baseline data for activity concentrations of natural radionuclides and their TFs in Thailand for future environmental radiation monitoring. The Annual effective ingestion dose due to ingestion of $^{226}$Ra, $^{232}$Th and $^{40}$K in galangals is significantly below the worldwide value reported by UNSCEAR 2000.

1. Introduction
The consumption of plants containing radionuclides represents the main way leading to human ingestion of radionuclides and consequently contributing to a long-term internal radiation exposure [1, 2, 3]. Radionuclides are incorporated into plants as a result of direct deposition from the atmosphere onto external plant surfaces and indirectly from re-suspension of soil on aerial parts as well as direct uptake of radionuclides through the root system [3, 4, 5]. Radionuclides in soil are then transferred to plants along with essential nutrients during mineral uptake and are trans-located to various parts of plants including the edible portions [1, 6, 7]. These plants when consumed by man would lead to continuous radiation dose. Thus, Soil-to-plant is recognized as one of the major pathways for transferring radionuclides to humans. Concentration of radionuclides in soil is a significant factor influencing the concentration in plants. Therefore, it is important to investigate the distribution of radionuclides in plants and associated soils together with the radionuclide long-term behaviour, such as mobility, transfers and translocation [5].

The uptake of radionuclides from soil to plants is difficult to quantify and complex [2]. Soil-to-plants transfer factor (TF) is a convenient approach used to describe the amount of radionuclides expected to enter a certain plant from the soil [8, 9]. It has been widely used in the estimation of the transport of radionuclides and other elements of interest through the food chain and also in assessment of the contribution to internal radiation dose through an ingestion pathway. TF is regarded as one of the most important parameters used in mathematical models for the radiological risk and...
environmental safety assessment needed for nuclear facilities [10]. The transfer factor is defined as the ratio of the concentration of a radionuclide in a plant to the activity concentration of that same radionuclide in the soil [11]. Since the TF can vary from location to location due to different climates, soil types, and vegetation, local transfer factors should also be observed. Several studies have been carried out in different regions of the world about the distribution and transfer of radionuclides from soils to plants [1-15]. However, there are only few data sets for tropical countries in South East Asia. Since there is no record of radioactive contamination in the environment of Thailand, it is a great deal to establish a baseline radioactivity data in the environmental samples in Thailand.

The terrestrial radionuclides, $^{238}$U, $^{232}$Th and their decay products as well as $^{40}$K, occur naturally and exist in sufficient quantities to contribute a significant natural radiation dose to humans. They are considered to be the main source of internal and external exposure of terrestrial radiation except for radon [8]. Thus, determining the distribution of these radionuclides in environmental samples and their possible pathways to human exposure is necessary for assessing the effects of radiation exposure.

*Alpinia galangal*, commonly known as greater galangal, is a perennial, robust and tillting rhizomatous herb belonging to the ginger family (Zingiberaceae). The plant grows up to 3.5 m in height with a subterranean and branching aromatic rhizome. The rhizomes are 2.5–10.0 cm thick and reddish brown externally with branch out in several directions. The aerial leafy stem, pseudo-stem, is erect, formed by the rolled leaf sheaths. Leaves are long, narrow and green blade-shaped with 23–45 cm long and 3.8–11.5 cm board. Flowers develop on top of the flowering stem. They are white with red lip in terminal panicles and emit sweet aroma which attracts insects. Fruit is an ovuled capsule and 1-1.5 cm in diameter.

Galangal occurs wild, semi-wild and under commercial cultivation. It is also grown as a foliage garden plant along the fence lines. The optimum growing environment for galangal is tropical and subtropical conditions. It can be cultivated easily in sunny to moderately shady areas with deep, fertile and moist but not swampy soils. Sandy or clayey soils rich in organic matter and with good drainage are preferred. Galangal is cultivated in many parts of Thailand and throughout South and Southeast Asia [16]. The galangals cultivated in Thailand are not only distributed across the country but also exported to foreign countries such as Japan, America and European countries. It has been widely used as a culinary (e.g., Tom Yum and green curry) and as traditional medicinal spice in Asian and medieval European countries for a long time. Its well-documented human medicinal effects include antiallergic activity, antimicrobial activity, anti-inflammatory activity, carcinogenesis inhibition, gastroprotective effect, and cardiovascular effect [16]. From Thailand and other Asian countries, the uses of galangal spread throughout some European countries, America and Russia.

Therefore, the present study was aimed to establish a baseline data on the activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in soils and *Alpinia galangal* (Greater galangal) as well as soil-to-plant TF collected in four provinces of Northern Thailand under natural field conditions. Furthermore, to estimate the risk from internal radiation exposure through the ingestion of *Alpinia galangal*, an annual effective ingestion dose due to individuals consuming galangal in the study areas was determined.

2. Material and Methods

2.1. Sample collection

Twenty-five soil samples and ten *Alpinia galangal* plant samples were collected on March 3-13, 2015 from four selected provinces in the northern part of Thailand as shown in figure 1. The selected provinces include Chiang Mai, Chiang Rai, Lampang and Phayao. These provinces are the major plantation zones of Northern Thailand. There are a lot of vegetables, grain and fruits cultivated in these areas as well as the galangals. Galangal is an annual plant which can be found in almost all commercial farming and home gardening not only in the study areas but also across the country. All the parts of galangal both fresh and dry form can be used for medicinal and culinary purposes. There are dried sliced and powdered galangal produced from the northern part of Thailand are exported to the overseas markets. Therefore galangal plants and their cultivated soil in the study areas were proposed to collect. All part of galangal, leaves, stem and rhizome, as well as its relevant soil from 0 to 20 cm depth of top soil were taken.
2.2. Sample preparation and analysis

Twenty-five soil samples were oven dried at a temperature of 110 °C until constant weight. The dried samples were pulverized into a fine powder and sieved through a 250 µm mesh size sediment sieve. Ten *Alpinia galanga* plant samples were washed with pure water for removing dust and soil and then were separated into rhizome, stem and leaves. The plant samples also were dried in an oven at 110°C until a constant dry weight was obtained and were ground into a fine powder. All homogenized samples were analyzed for activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K using gamma spectroscopy. The samples were packed into airtight plastic containers and sealed to prevent the escape of radon ($^{222}$Rn) and thoron ($^{220}$Rn) gases. Prior to measurement, the sample was stored for at least four weeks in order to establish secular equilibrium between $^{226}$Ra and $^{232}$Th and their radioactive progenies. Activity concentrations in the samples were measured using one of two high-purity germanium (HPGe) detectors with a relative efficiency of 25 and 30 % in a low background configuration. Energy and efficiency calibrations of the detector were carried out using three different IAEA standard reference materials including IAEA-RGU-1, IAEA-RGTh-1 and IAEA-RGK-1. Counting time for each sample was set at 12 hours for soil and 48–60 hours for plants. By assuming secular equilibrium with their progenies in the $^{238}$U and $^{232}$Th decay chain, the activity concentration of $^{226}$Ra and $^{232}$Th was calculated using gamma-rays associated with decays of $^{214}$Bi (609.3 keV) and $^{228}$Ac (911.2 keV), respectively. The activity concentration of $^{40}$K was derived directly from the measured intensity of its gamma peak at energy 1,460.8 keV.

Statistical data, range, arithmetic mean and standard deviation, of activity concentrations in soil and plant samples were calculated to present the distribution of radionuclides in the samples and compared with the worldwide average values reported by UNSCEAR. In order to consider the significance differences in the mean, mean comparisons of the activity concentrations in samples among four provinces as well as between the obtained overall mean and worldwide values were performed by T-test using SPSS 19.0 (IBM Corp., Armonk, NY, USA).

Soil-to-plant transfer factor (TF), representing the transfer mechanism of radionuclides, is widely used to describe plant uptake from soil. The activity concentrations of radionuclides in galangals and their relevant soil are assumed to be linear and they were used for calculating TFs according to the following equation [1, 9, 14]:

$$TF = \frac{\text{Activity concentration of radionuclides in plant (Bg kg}^{-1} \text{ dry weight)}}{\text{Activity concentration of radionuclides in soil (Bg kg}^{-1} \text{ dry weight)}}$$
The annual effective ingestion dose to man due to consumption of galangal as medicine and food is calculated using the following equation [17]:

\[
\text{Dose (}\mu\text{Sv y}^{-1}\text{)} = \text{Activity concentration (Bq kg}^{-1}\text{)} \times \text{Annual intake (kg y}^{-1}\text{)} \times \text{DCF (}\mu\text{Sv Bq}^{-1}\text{)}
\]

where DCF is the dose convection factor for ingestion, 0.28 \(\mu\text{Sv Bq}^{-1}\) for \(^{226}\text{Ra}\), 0.23 \(\mu\text{Sv Bq}^{-1}\) for \(^{232}\text{Th}\) and 0.0014 \(\mu\text{Sv Bq}^{-1}\) for \(^{40}\text{K}\) [9].

The appropriate dose of galangal depends on several factors. At this time there is not enough scientific information to provide a basis of dosage recommendations for medicinal plants. Generally, for medicinal purpose, the recommended intake of dry galangal rhizome is 1–6 g daily. It is meant that the annual intake is approximately 0.4–2.2 kg y\(^{-1}\). A survey of food ingredient labels available in domestic markets was found that galangal is used approximately 2.5-9 g in one dish. If man eats food contained galangal every day, in one year a consumption rate of galangal should be 0.9-3.3 kg y\(^{-1}\). A well-accepted consumption rate of galangal as both medical plants and food is not available, however, the annual intake rate of 3.3 kg y\(^{-1}\) was assumed for all purpose used in this study.

3. Results and discussion

3.1. Activity concentration in soils

Mean and standard deviation in mean as well as range values of activity concentrations of natural radionuclides in soils are summarized in table 1. The lowest concentration of \(^{226}\text{Ra}\) (22±1 Bq kg\(^{-1}\)), \(^{232}\text{Th}\) (27±1 Bq kg\(^{-1}\)) and \(^{40}\text{K}\) (58±3 Bq kg\(^{-1}\)) was found in samples collected from Chiang Rai province. The highest activity concentrations of \(^{226}\text{Ra}\) (88±1 Bq kg\(^{-1}\)), \(^{232}\text{Th}\) (157±3 Bq kg\(^{-1}\)) and \(^{40}\text{K}\) (1157±22 Bq kg\(^{-1}\)) was found in samples collected from Chiang Mai province. The activity concentrations of radionuclides were non uniform distribution.

| Sampling location (no. of sample) | \(^{226}\text{Ra} \) (Bq kg\(^{-1}\)) | \(^{232}\text{Th} \) (Bq kg\(^{-1}\)) | \(^{40}\text{K} \) (Bq kg\(^{-1}\)) |
|----------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Chiang Mai (4)                  | 78±14                           | 130±27                          | 958±210                         |
|                                  | (56–88)                         | (94–157)                        | (706–1157)                      |
| Chiang Rai (9)                  | 38±18                           | 47±15                           | 493±396                         |
|                                  | (22–75)                         | (27–69)                         | (58–1015)                       |
| Lampang (9)                     | 37±7                            | 53±11                           | 404±180                         |
|                                  | (25–44)                         | (39–74)                         | (98–611)                        |
| Phayao (3)                      | 40±3                            | 50±2                            | 378±102                         |
|                                  | (36–42)                         | (48–52)                         | (308–495)                       |
| Overall (25)                    | 44±19                           | 63±33                           | 521±320                         |
|                                  | (22–88)                         | (27–157)                        | (58–1157)                       |
| Thailand [UNSCEAR 2000]         | 48                              | 51                              | 230                             |
|                                  | (11–78)                         | (7–120)                         | (7–112)                         |
| Worldwide [UNSCEAR 2000]        | 35                              | 30                              | 400                             |
|                                  | (16–110)                        | (11–64)                         | (140–850)                       |

Assuming normal distribution, Independent two-sample \(t\)-test was performed to examine the mean difference of activity concentrations between all pairs of four provinces. The results of statistical analyses indicated that the mean concentrations of \(^{226}\text{Ra}\) (78±14 Bq kg\(^{-1}\)), \(^{232}\text{Th}\) (130±27 Bq kg\(^{-1}\)) and \(^{40}\text{K}\) (958±210 Bq kg\(^{-1}\)) of soil samples collected from Chiang Mai province were significantly higher \((p<0.05)\) than those collected from three other provinces while the mean concentrations among these others, Chiang Rai, Lampang and Phayao, were comparable. One-sample \(t\)-test was performed to determine the difference between the mean concentrations obtained from this study and the worldwide
average values reported by UNSCEAR 2000. The difference of mean $^{232}\text{Th}$ concentration was significantly different with the worldwide average values for all provinces. The mean concentration of $^{226}\text{Ra}$ and $^{40}\text{K}$ of Chiang Mai were significantly higher than the worldwide average but others were comparable. The overall mean concentration of all radionuclides, $44\pm 19\ Bq\ kg^{-1}$ for $^{226}\text{Ra}$, $63\pm 33\ Bq\ kg^{-1}$ for $^{232}\text{Th}$ and $521\pm 320\ Bq\ kg^{-1}$ for $^{40}\text{K}$, were significantly higher than those in the southern Thailand obtained from the previous study ($29\ Bq\ kg^{-1}$ for $^{226}\text{Ra}$, $49\ Bq\ kg^{-1}$ for $^{233}\text{Th}$ and $344\ Bq\ kg^{-1}$ for $^{40}\text{K}$) [18]. Comparing with worldwide average values, only the overall mean of $^{226}\text{Ra}$ and $^{232}\text{Th}$ obtained from this study were significantly higher than the worldwide average values ($35\ Bq\ kg^{-1}$ for $^{226}\text{Ra}$ and $30\ Bq\ kg^{-1}$ for $^{232}\text{Th}$), whereas the overall mean of $^{40}\text{K}$ was not significantly different with the worldwide average values (400 Bq kg$^{-1}$).

The activity concentrations of natural radionuclides in all soil samples were in the order $^{40}\text{K} > ^{232}\text{Th} > ^{226}\text{Ra}$. $^{40}\text{K}$ dominates over others since it is a minor isotope of naturally occurring potassium which is the seventh most abundant element on the earth, making up 2.6% of the weight of the Earth’s crust. The higher activity concentration of $^{232}\text{Th}$ compared to $^{226}\text{Ra}$ may be related to difference in chemical speciation and solubility of their parents, $^{232}\text{Th}$ and $^{235}\text{U}$ respectively, in a natural environment. In the Earth’s crust, thorium and uranium tend to occur together due to similar ionic size and bond character. However, they are commonly fractionated during surficial processes, i.e. weathering, transportation and deposition. In almost all natural environments, thorium has a very low solubility and preferentially accumulated on particular phases due to limited stability of Th(IV) complexes; whereas under an oxidizing environment, U(VI) is oxidized to U(VI). The latter is chemically more soluble and mobile; therefore, well redistributed and transported in surface and groundwater under certain environmental conditions [19].

3.2. Activity concentration in *Alpinia galangal* plant

The activity concentrations of radionuclides in *Alpinia galangal* plant varied from sample to sample and location to location and were generally several orders of magnitude lower than in the associated soils as shown in table 2. The activity concentrations of $^{226}\text{Ra}$ in most galangal samples and those of $^{232}\text{Th}$ in few samples were lower than the detection limit, 0.2 Bq kg$^{-1}$ and 0.1 Bq kg$^{-1}$ for $^{226}\text{Ra}$ and $^{232}\text{Th}$ respectively, of the analytical techniques utilized in the present study. The activity concentration of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in all galangal samples were very low compared to their relevant soils, since only trace amounts of these radionuclides can diffuse through Casparian strips (a waxy layer structural for the control of uptake of substances into roots) and then may be transported to the aerial organs of plants. The plant roots serves as a semipermeable filter controlling the transport of radionuclides to the aerial parts [1].

Range and mean of activity concentrations in each galangal part, rhizome, stem and leaf are shown in table 3. The overall concentrations obtained from the present study ranged from $0.2$ to $2.0\ Bq\ kg^{-1}$ with a mean of $0.9\pm 0.7\ Bq\ kg^{-1}$ for $^{226}\text{Ra}$, $0.1$ to $2.9\ Bq\ kg^{-1}$ with a mean of $0.9\pm 0.9\ Bq\ kg^{-1}$ for $^{232}\text{Th}$ and $205$ to $2247\ Bq\ kg^{-1}$ with a mean of $785\pm 576\ Bq\ kg^{-1}$ for $^{40}\text{K}$. The mean value of $^{226}\text{Ra}$ was not significantly different with that of $^{232}\text{Th}$ ($p<0.05$). The activity concentrations of $^{40}\text{K}$ in all samples and their mean value were significantly higher than those of $^{226}\text{Ra}$ and $^{232}\text{Th}$ which indicate the essential nutrient status of potassium for the plants. Although $^{226}\text{Ra}$ and $^{232}\text{Th}$ are not essential to plant growth, plants may absorb these nuclides, which are similar to calcium, and translocate them to the aerial parts [13].

3.3. Transfer factors (TFs)

Estimated transfer factors are presented in table 4. There was a wide variation of TFs for the same plant or same species. The overall TF values ranged from $0.002$ to $0.073$ with a mean of $0.023\pm 0.027$ for $^{226}\text{Ra}$, $0.001$ to $0.061$ with a mean of $0.015\pm 0.018$ for $^{232}\text{Th}$ and $0.26$ to $7.9$ with a mean of $2.2\pm 2.1$ for $^{40}\text{K}$. TFs of $^{226}\text{Ra}$ and $^{232}\text{Th}$ obtained from the present study were not significantly different ($p<0.05$) and they were in the same range of soil-to-galangal TF reported in a previous study (0.004-0.068 for $^{238}\text{U}$, parent nuclide of $^{226}\text{Ra}$, and 0.003-0.059 for $^{232}\text{Th}$) [2]. TFs for $^{40}\text{K}$ were significantly higher than those of the other radionuclides in all samples and most of them were higher than 1 which suggests higher levels of $^{40}\text{K}$ uptake. This may be due to the continuous accumulation of $^{40}\text{K}$ through
root uptake over a period of time. It is well known that potassium is an essential macronutrient for metabolism and taken up by plants from soil in varied amounts depending upon their metabolism and 40K respectively. From TFs values of each sample, it was observed that the activity concentrations of 226Ra, 232Th and 40K and their TFs in the aerial part (leaf and stem) were higher than those in the rhizome, whereas t-test determined that there is no difference between the mean values among those parts for all radionuclides.

Table 2. Activity concentration of natural radionuclides in *Alpinia galangal* and their corresponding soil.

| Plant Sample | Concentration (Bq kg⁻¹) | ²²⁶Ra | ²³²Th | ⁴⁰K |
|--------------|-------------------------|-------|-------|------|
| CMI-1-Soil   |                         | 84    | 142   | 1157 |
| CMI-1-Rhizome|                         | 0.2   | 1.1   | 767  |
| CMI-1-Leaf   |                         | 1.2   | 1.1   | 1038 |
| CMI-2-Soil   |                         | 88    | 157   | 1103 |
| CMI-2-Rhizome|                         | <0.2  | 0.6   | 599  |
| CMI-2-Stem   |                         | 1.0   | 0.7   | 1051 |
| CMI-2-Leaf   |                         | <0.2  | <0.1  | 619  |
| CRI-1-Soil   |                         | 75    | 27    | 58   |
| CRI-1-Rhizome|                         | 0.4   | 0.2   | 205  |
| CRI-1-Stem   |                         | <0.2  | 0.4   | 459  |
| CRI-2-Soil   |                         | 27    | 42    | 955  |
| CRI-2-Rhizome|                         | <0.2  | 1.5   | 294  |
| CRI-2-Stem   |                         | <0.2  | 2.6   | 252  |
| CRI-2-Leaf   |                         | 2.0   | 0.4   | 275  |
| CRI-3-Soil   |                         | 61    | 65    | 517  |
| CRI-3-Stem   |                         | <0.2  | <0.1  | 1130 |
| LPG-1-Soil   |                         | 25    | 39    | 529  |
| LPG-1-Rhizome|                         | <0.2  | 0.1   | 624  |
| LPG-1-Stem   |                         | 0.8   | 0.4   | 1605 |
| LPG-1-Leaf   |                         | <0.2  | 0.4   | 2127 |
| LPG-2-Soil   |                         | 26    | 46    | 98   |
| LPG-2-Rhizome|                         | <0.2  | 0.2   | 606  |
| LPG-3-Soil   |                         | 44    | 74    | 611  |
| LPG-3-Rhizome|                         | <0.2  | 0.2   | 678  |
| LPG-3-Stem   |                         | <0.2  | 2.5   | 2247 |
| LPG-4-Soil   |                         | 42    | 55    | 153  |
| LPG-4-Rhizome|                         | <0.2  | 0.3   | 550  |
| PYO-1-Soil   |                         | 41    | 52    | 308  |
| PYO-1-Rhizome|                         | <0.2  | 0.6   | 372  |
| PYO-1-Stem   |                         | <0.2  | 0.3   | 442  |
| PYO-1-Leaf   |                         | <0.2  | 2.9   | 541  |

CMI= Chiang Mai; CRI= Chiang Rai; LPG= Lampang; PYO= Phayao
3.4. Annual effective ingestion dose
The annual effective ingestion dose due to ingestion of $^{226}$Ra, $^{232}$Th and $^{40}$K in galangals obtained from the present study are shown in Table 5. The ingestion dose was calculated by assuming the annual intake rate is 3.3 kg y$^{-1}$. The annual effective ingestion dose varied from <0.2 to 1.9 µSv y$^{-1}$ with a mean of 0.8±0.6 µSv y$^{-1}$ for $^{226}$Ra, <0.1 to 2.2 µSv y$^{-1}$ with a mean of 0.6±0.7 µSv y$^{-1}$ for $^{232}$Th and 0.9 to 10 µSv y$^{-1}$ with a mean of 3.6±2.7 µSv y$^{-1}$ for $^{40}$K. These obtained values is significantly below the total worldwide annual effective ingestion dose for $^{40}$K and both uranium and thorium series (280 µSv y$^{-1}$) reported by UNSCEAR 2000.


### Table 5. Annual effective ingestion dose of natural radionuclides in each part of *Alpinia galangal*.

| Galangal part | Annual effective ingestion dose (µSv y⁻¹) |
|---------------|------------------------------------------|
|               | ²²⁶ Ra | ²³² Th | ⁴⁰ K  |
| Rhizome       | 0.3±0.1 | 0.4±0.4 | 2.4±0.9 |
| n=2           | (<0.2–0.3) | (0.1–1.1) | (0.9–3.5) |
| Stem          | 0.8±0.1 | 0.8±0.8 | 4.7±3.3 |
| n=2           | (<0.2–0.7) | (<0.1–1.9) | (1.2–10) |
| Leaf          | 1.0±0.5 | 0.9±0.9 | 4.1±3.4 |
| n=2           | (<0.2–1.9) | (<0.1–2.2) | (1.3–9.8) |
| Overall (Present study) | 0.8±0.6 | 0.6±0.7 | 3.6±2.7 |
| n=6           | (<0.2–1.9) | (<0.1–2.2) | (0.9–10) |
| n=19          |                     |                     |
| n=21          |                     |                     |  

n=number of samples

### 4. Conclusions

The activity concentration of ²²⁶ Ra, ²³² Th and ⁴⁰ K were determined in soil and *Alpinia galangal* collected from four provinces in the north of Thailand. Our results showed a large variation and non-uniform distribution in soil and *Alpinia galangal* plant samples for each of the natural radionuclides investigated. The activity concentrations of ²²⁶ Ra and ²³² Th in *Alpinia galangal* were much lower than in the associated soils, whereas ⁴⁰ K concentration of not all samples were higher than those of their associated soils. It also found that the activity concentration and the uptake of ⁴⁰ K was significantly higher than other radionuclides in all galangal samples. The annual effective ingestion dose values obtained from the present study were much below the worldwide dose of 280 µSv y⁻¹. This study indicates the uses of the *Alpinia galangal* in cuisines and medicines should not pose any potential health hazards to people who consume galangal cultivated in the study area. The results obtained from this study can be considered as baseline data for TFs of natural radionuclides in Thailand and may also serve as a guideline for future monitoring and assessment of naturally occurring radioactive material (NORM) discharges from any industrial activities. The distribution of natural radionuclides in soil and plant is valuable information therefore we will carry out this study with various types of plant. Since plant uptake from soil was probably influenced by various factors such as soil characteristics, amount and physico-chemical form of radionuclides in soil, plant species, temperature, rainfall, and agricultural management, these parameters should be further investigated in the future.

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### References

[1] Mollah A S 2014 Radionuclide uptake from soil to plants: Influence of soil classification *Radionuclide contamination and remediation through plants* vol 1 ed D K Gupta and C Walther (Switzerland: Springer)

[2] Krisanauwatt R, Sahoo S K and Arae H 2015 Distribution of ²³⁸ U and ²³² Th in selected soil and plant samples as well as soil to plant transfer factors around Southern Thailand *J. Radioanal. Nucl. Chem.* **303** 2571–77
[3] Al-Masri M S, Al-Akel B, Nashawani A, Amin Y, Khalifa K H and Al-Ain F 2008 Transfer of $^{40}$K, $^{238}$U, $^{210}$Pb, and $^{210}$Po from soil to plant in various locations in south of Syria J. Environ. Radioact. 99(2) 322–31

[4] Al-Masri M S, Amin Y, Ibrahim S and Nasri M 2015 Transfer of $^{210}$Po, $^{210}$Pb and $^{238}$U from some medicinal plants to their essential oils J. Environ. Radioact. 141 51–6

[5] Vera Tome F, Blanco Rodriguez M P and Lozano J C 2003 Soil-to-plant transfer factors for natural radionuclides and stable elements in a Mediterranean area J. Environ. Radioact. 65 161–75

[6] Marčuliuniene D, Lukšienė B and Jefanova O 2015 Accumulation and translocation peculiarities of $^{137}$Cs and $^{40}$K in the soil – plant system J. Environ. Radioact. 150 86–92

[7] Vandenhove H, Olyslaegers G, Sanzharova N, Shubina O, Reed E, Shang Z and Velasco H 2009 Proposal for new best estimates of the soil-to-plant transfer factor of U, Th, Ra, Pb and Po J. Environ. Radioact. 100 721–32

[8] United Nations Scientific Committee on the Effects of Atomic Radiation 2000 Sources and effects of ionizing radiation New York United Nations

[9] International Atomic Energy Agency 2009 Quantification of radionuclide transfer in terrestrial and freshwater environments for radiological assessments (IAEA-TECDOC-1616) Vienna International Atomic Energy Agency

[10] Gregory A O and Agbalagba E O 2014 Assessment of natural radioactivity, associated radiological health hazards indices and soil-to-crop transfer factors in cultivated area around a fertilizer factory in Onne, Nigeria Environ. Earth. Sci. 71 1541–9

[11] Aswood M Sh, Jaafar M S and Bauk S 2013 Assessment of radionuclide transfer from soil to vegetables in farms Cemeron Highlands and Penang, (Malaysia) using neutron activation analysis Appl. Phys. Res. 5(5) 85–92

[12] International Atomic Energy Agency 1994 Handbook of parameter values for prediction of radionuclide transfer in temperate environments (IAEA Technical report series No. 364) Vienna International Atomic Energy Agency

[13] Mitchell N1, Pérez-Sánchez D and Thorne M C 2013 A review of the behaviour of U-238 series radionuclides in soils and plants J. Radiol. Prot. 33 R17-R48

[14] James J P, Dileep B N, Ravi P M, Joshi R M, Ajith T L, Hegde A G and Sarkar P K 2011 Soil to leaf transfer factor for the radionuclides $^{226}$Ra, $^{40}$K, $^{137}$Cs and $^{90}$Sr at Kaiga region, India J. Environ. Radioact. 102(12) 1070–7

[15] Chen S B, Zhu Y G and Hu Q H 2005 Soil to plant transfer of $^{238}$U, $^{226}$Ra and $^{232}$Th on uranium mining-impacted soil from southeastern China J. Environ. Radioact. 82 223–36

[16] Ravindran P N, Beverages T G, Pillai G S and Balachandram I 2012 Galangal Handbook of Herbs and Spices vol 2 ed K V Peter (Cambridge: Woodhead Publishing) chapter 15 pp 313–8

[17] Chandrashekara K and Somashekarappa H M 2016 Estimation of radionuclides concentration and average annual committed effective dose due to ingestion for some selected medicinal plants of South India J. Rad. Res. Appl. Sci. 9 68–77

[18] Kritsananuwat R, Arae H, Fukushi M, Sahoo S K and Chanyotha S 2015 Natural radioactivity survey on soils originated from southern part of Thailand as potential sites for nuclear power plants from radiological viewpoint and risk assessment J. Radioanal. Nucl. Chem. 305 487–99

[19] Kritsananuwat R, Arae H, Sahoo S K, Fukushi M, Pangza K and Chanyotha S 2015 Radiological risk assessment of $^{238}$U, $^{232}$Th and $^{40}$K in Thailand coastal sediments at selected areas proposed for nuclear power plant sites J. Radioanal. Nucl. Chem. 303 325–34