中文摘要:

轉移因子(TF)是評估放射性核種從土壤傳輸到植物各組成的一種方法。本研究選擇台灣的 11 個稻田，通過加馬射線光譜法成功地測定了水稻種植前、後灌溉水，水稻不同組成(根、莖、葉和未去殼稻穀)以及相應土壤樣品的 ^{226}Ra、^{232}Th、^{40}K 和 ^{137}Cs 的放射性核種活性。灌溉水的活度僅檢測到 ^{40}K，範圍為 0.34 – 6.62 Bq/L，平均值為 3.34±1.66 Bq/L。總共檢測 66 個土壤樣品，其中 ^{40}K、^{232}Th 和 ^{226}Ra 的活度濃度分別為 591±134、45.4±10.2 和 30.9±6.6 Bq/kg。^{40}K 的活度高於世界平均水平 420 Bq/kg，但 ^{232}Th 和 ^{226}Ra 的活度分別與世界平均水平 45 和 32 Bq/kg 相似。在 2 個地點，檢測 6 個樣品的 ^{137}Cs，其活性濃度為 5.57±1.29 Bq/kg，其活性濃度與未污染的地點相當。水稻種植前後各土壤放射性核種的活度濃度差異不顯著。此外，在耕作前後，^{40}K、^{232}Th 和 ^{226}Ra 彼此呈正相關，這表明短期的農業操作不會改變土壤核種的活性。水稻根，莖，葉和未脫稻殼的 ^{40}K 活度分別為 238±59、368±226、404±1996、99±12 Bq/kg。^{232}Th 活度分別為 12.6±3.9、0.79±0.23、3.83±2.91、0.43±0.12 Bq/kg，而 ^{226}Ra 活度分別為 10.7±2.9、0.94±0.60、4.43±4.22、0.49±0.09 Bq / kg。^{137}Cs 根，莖和未脫稻殼的活性分別為 1.67-1.86、0.072-0.128、0.10-0.31 Bq/kg。^{226}Ra、^{232}Th 和 ^{137}Cs 的總活性中有 76-86％主要集中在根部，而稻殼分佈只有 1.1-10.0％。水稻植株的 ^{40}K 根，莖，葉和未去殼稻穀的活度分佈分別為 23％，32％，35％和 10％。水稻土壤-穀物的 TFs 在 ^{40}K 範圍為(1.21-2.86)x10^{-1}，232Th 範圍為(0.07-0.11)x10^{-1}，^{226}Ra 範圍為(0.11-0.29)x10^{-1}。^{137}Cs 為(0.16-0.61)x10^{-1}。結果顯示水稻中選定的放射性核種分佈取決於水稻組成類型和放射性核種。^{40}K 和 ^{226}Ra 的 TF 值分別與土壤 ^{40}K 和 ^{226}Ra 的活性顯著負相關(^{40}K $r = 0.92$，$p <0.001$，$n = 11$; ^{226}Ra $r = 0.976$，$p = 0.024$，$n = 4$)。這項研究還調查了台灣市售稻米消耗的天然伽馬發射放射性核種 ^{40}K，^{232}Th 和 ^{226}Ra。從當地市場收集了 30 個市售稻米樣品，包括 24 個台灣生產市售稻米和 6 個進口大米。^{40}K，^{232}Th 和 ^{226}Ra 稻米樣品的放射性核種活度分別為 24.05 ±10.21、1.00±0.28 和 1.15±0.25 Bq/kg。本地和進口樣品，每種放射性核種的活性差異均不顯著($p = 0.20$-0.93)。估計稻米年度有效劑量為 ^{40}K，^{232}Th 和 ^{226}Ra 分別為 6.80±2.89、10.53±2.97 和 14.74±3.14 μSv/y，放射性核種的總有效劑量為 17.82±11.56 μSv/y。總有效劑量比自然源攝入的 290 μSv/y 世界平均值低一個數量級。由食用檢測到的稻米 ^{40}K，^{232}Th 和 ^{226}Ra 而導致的終身終生癌症風險(ELCR)分別為為(5.21±2.21)x10^{-5}，(0.91±0.26)x10^{-5} 和(4.06±0.87)x10^{-5}。總 ELCR 為(7.65±3.35)x10^{-5}，比準則限值 10^{-3} 小一個數量級。結果表明，台灣的市售稻米消費對於所調查的放射性核素在放射學上是安全的。

關鍵詞:
天然放射性核種 ^{40}K、^{232}Th 和 ^{226}Ra、人工放射性核種 ^{137}Cs、水稻田土壤放射性核種活度、水稻根、莖、葉、與稻穀放射性核種活度、傳輸因素。

英文摘要:

Transfer factor (TF) is a method to assess radionuclides transport from soil to plant compartments. In this study, 11 sites were selected from paddy fields in Taiwan. The radionuclide activities of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs were successfully measured via gamma-ray spectrometry on irrigation water, rice plant compartments (root, stem, leaf, and un-hulled grain) and on corresponding soil samples before and after rice plantation. The activity of irrigation water only detected ^{40}K that ranged from 0.34 – 6.62 Bq/L with mean 3.34±1.66 Bq/L. In total, 66 soil samples were detected and the activity concentrations were 591±134, 45.4±10.2, and 30.9±6.6 Bq/kg for ^{40}K, ^{232}Th, and ^{226}Ra, respectively. Activity of ^{40}K was higher than world average activity 420 Bq/kg, but activities of ^{232}Th and ^{226}Ra were similar to world average 45 and 32 Bq/kg, respectively. In 2 sites 6 samples was detected ^{137}Cs with activity concentration 5.57±1.29 Bq/kg and the activity concentration was comparable to uncontaminated sites. The activity concentration of each soil radionuclide was insignificantly different before and after rice planation. In addition, ^{40}K, ^{232}Th, and ^{226}Ra had positive correlation each other for before and after planation that suggested short term farm operation did not altered soil nuclide activity. In rice plant, the ^{40}K activities were 238±59, 368±226, 404±1996, 99±12 Bq/kg for root, stem, leaf, and un-hulled grain, respectively. While ^{232}Th activities were 12.6±3.9, 0.79±0.23, 3.83±2.91, 0.43±0.12 Bq/kg, ^{226}Ra activities were 10.7±2.9, 0.94±0.60, 4.43±4.22, 0.49±0.09 Bq/kg, respectively. The activities for ^{137}Cs were 1.67-1.86, 0.072-0.128, 0.10-0.31 Bq/kg for root, stem, and grain, respectively. A major fraction, 76-86% of the total ^{226}Ra, ^{232}Th, and ^{137}Cs activities were concentrated in the roots, whereas only 1.1 to 10.0% were distributed in the grain. ^{40}K activity distributions in rice plant were 23%, 32%, 35%, and 10% for root, stem, leaf, and un-hulled grain, respectively. Rice soil–to-grain TFs were observed in the ranges of (1.21-2.86)×10^{-1} for ^{40}K, (0.07–0.11)×10^{-1} for ^{232}Th, (0.11–0.29)×10^{-1} for ^{226}Ra, and (0.16-0.61)×10^{-1} for ^{137}Cs. Results showed that the selected radionuclide distributions in rice are dependent on rice compartment type and radionuclides species. TF values for ^{40}K and ^{226}Ra had significantly negative correlation with soil ^{40}K and ^{226}Ra activities, respectively (^{40}K r=0.92, $p<0.001$, n=11; ^{226}Ra r=0.976, p=0.024, n=4). This study also investigated natural gamma emitting radionuclides ^{40}K, ^{232}Th, and ^{226}Ra of rice consumption in Taiwan. Thirty rice samples were collected from local markets including 24 local rice and 6 imported rice. Radionuclide activities were 24.05±10.21, 1.00±0.28, and 1.15±0.25 Bq/kg for ^{40}K, ^{232}Th, and ^{226}Ra for the total rice samples. Activity of each radionuclide was insignificantly different for local and imported samples (p=0.20-0.93). Annual effective doses from rice consumption were estimated to be 6.80±2.89, 10.53±2.97, and 14.74±3.14 μSv/y for ^{40}K, ^{232}Th, and ^{226}Ra, respectively, and total effective dose was 17.82±11.56 μSv/y for the selected radionuclides. These values were one order of magnitude less than the 290 μSv/year world average of the ingestion exposure from natural sources. The excess lifetime cancer risk (ELCR) due to the consumption of detected rice was (5.21±2.21) x 10^{-5}, (0.91±0.26) x 10^{-5}, and (4.06±0.87) x 10^{-5} for ^{40}K, ^{232}Th, and ^{226}Ra, respectively. The total ELCR was (7.65±3.35) x 10^{-5}, which was one order of magnitude less than the guideline limit 10^{-3}. The results suggested rice consumption in Taiwan is radiologically safe for the investigated radionuclides.

Key words: Natural radionuclides ^{40}K, ^{232}Th and ^{226}Ra, artificial radionuclide ^{137}Cs, paddy field soil radionuclide activity, rice root, stem, leaf, and rice radionuclide activity, Transfer factor (TF).