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Evaluation of radionuclides transfer from soil-to-edible flora and estimation of radiological dose to the Malaysian populace

Mayeen Uddin Khandaker [a, *], Noor Liyana Mohd Nasir [a], Kh Asaduzzaman [a], Michael Adekunle Olatunji [a], Yusoff Mohd Amin [a], Hasan Abu Kassim [a], D.A. Bradley [b], P.J. Jojo [c], Tareq Alrefae [d]

[a] Department of Physics, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Physics, University of Surrey, Guildford, GU2 7XH, United Kingdom
[c] Centre for Advanced Research, Department of Physics, Fatima Mata National College, Kollam 691001, Kerala, India
[d] Department of Physics, Faculty of Science, Kuwait University, Khaldia, Kuwait

HIGHLIGHTS

- Assessment of radionuclides transfer from soil-to-edible flora in Malaysia.
- The estimated TFs for ^{226,228}Ra show greater values than the literature data for vegetables.
- The Highland farms present greater concentrations than the ground farms.
- Committed effective dose and life-time cancer risk found below the permissible limit by UNSCEAR.

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ABSTRACT

Malaysia, a rapidly growing industrial country, is susceptible to pollution via large-scale industrial engagements and associated human activities. One particular concern is the potential impact upon the quality of locally resourced vegetables, foodstuffs that contain important nutrients necessary for good health, forming an essential part of the Malaysian diet. As a part of this, it is of importance for there to be accurate knowledge of radioactive material uptake in these vegetables, not least in respect of any public health detriment. Herein, using HPGe γ-ray spectrometry, quantification has been performed of naturally occurring radionuclides in common edible vegetables and their associated soils. From samples analyses, the soil activity concentration ranges (in units of Bq/kg) for ^{226}Ra, ^{232}Th and ^{40}K were respectively 1.33–30.90, 0.48–26.80, 7.99–136.5 while in vegetable samples the ranges were 0.64–3.80, 0.21–6.91, 85.53–463.8. Using the corresponding activities, the transfer factors (TFs) from soil-to-vegetables were estimated, the transfers being greatest for ^{40}K, an expected outcome given the essentiality of this element in support of vigorous growth. The TFs of ^{226}Ra and ^{232}Th were found to be in accord with available literature data, the values indicating the mobility of these radionuclides to be low in the studied soils. Committed effective dose and the associated life-time cancer risk was estimated, being found to be below the permissible limit proposed by UNSCEAR. Results for the studied media show that the prevalent activities and mobilities pose no significant threat to human health, the edible vegetables being safe for consumption.

1. Introduction

Our radiation environment is contributed to by two component source types: natural and anthropogenic. Natural sources comprise the radiation from cosmogenic and terrestrial activity, while artificial sources derive from reactor and accelerator-driven processes. ^{238}U, ^{232}Th and ^{40}K are the three predominant long-lived naturally occurring radionuclides that are present in the earths' crust, with activity appearing in soil, in water and/or in the earth-born material such as dust, also giving rise to radon in the air. The discharge of

* Corresponding author.
E-mail address: mu_khandaker@yahoo.com (M.U. Khandaker).

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various radionuclides into the ecosystem arise from human activities such as mining and associated minerals beneficiation, oil and gas production, in use of radionuclides in medical procedures, coal combustion and nuclear fuel cycle involvements such as fuel rods reprocessing, cement production, phosphate fertilizers production/utilization and in waste disposal (Nollet and Pöschl, 2007). To these can be added the residual environmental legacy of the testing of nuclear weapons and accidental releases from nuclear facilities (eg Windscale, Three Mile Island, Chernobly and Fukushima), contributing *trans*-nationally to the radionuclide balance in the environment. Somewhat unknowingly, we ingest these radionuclides via daily food and water intake and also through inhalation, the soil-plant-human pathway being a primary route for the transfer of radionuclides to humans (IAEA, 1982). The migration and mobilization of radionuclides into and intra environment are influenced by many factors, including those that are physiological, biological and geochemical, with soil, air, water and flora property modifications, and specific interactions of radionuclides with vegetation and other organisms within which they accumulate (Černe et al., 2010).

Radionuclides in soil are taken in by plant tissue in the uptake of minerals, directly transferred via the roots system, subsequently appearing in the food chain through the consumption of the meat of ruminants (ovine, bovine, etc) or through the consumption of vegetables common to the human diet. Edible plant/flora represent an important component of the daily diet such that plant uptake of radionuclides into the human food chain represents one of the main vectors used in calculating exposure rates and performing risk assessment (Rosén et al., 1995). Under normal environmental conditions, some 90% of ^{226}Ra (one of the major progeny of ^{238}U) enters into the human body via the food chain (Tettey-Larbi et al., 2013). Once radionuclides enter the human system, through ingestion, inhalation or external irradiation, concentration is possible in various parts of the body, hence the long biological half-lives of many radionuclides making them a potential threat to human health. Analysis of radionuclides uptake from soils by plants is important not only for analyzing the viability of arable soils, but also in evaluating the decontamination of soils by plants.

The soil-to-plant transfer factors (TF), the ratio of the concentration of radioactivity in the crop to the radioactivity per unit mass of the soil, is a value widely used for calculating radiological human dose via the ingestion pathway. It is regarded as one of the most important parameters used in evaluation studies on the impact of releases of radionuclides in the environment and/or environmental safety assessment (IAEA, 1994). This parameter is necessary for environmental transfer models, useful in the prediction of radionuclide concentration in agricultural crops for estimating dose impact to humans (Absalom et al., 1999; Antonopoulos-Domis et al., 1990; Frissel, 1994; Mayall, 1995; Thorne and Coughtrey, 1983). Transfer factor values in excess of unity imply active bioaccumulation of radioactivity. Conversely, values of less than unity either imply strong binding of radioactivity to the soil or that the plant life is not accumulating that material. For most of Europe and the USA, the TFs for most important agricultural products are known. For other areas and especially rapidly developing countries, Malaysia being a prime example of one in which the peaceful applications of nuclear technology are expanding at a pace, the TFs are not so readily available (IAEA, 1994, 2000). Thus, a local database is required for validation of existing models (e.g., the Absalom et al. (1999) model) or development of new models to predict the impact of deposited radionuclides that are based on local parameters derived for tropical environments.

The health benefits of vegetable consumption are clearly documented in the literature. Block et al. (1992) documented that the health benefits include reduction in the incidence of various forms of cancer as well as other ailments such as stroke, heart disease, and obesity. Being a tropical country, Malaysia produces a wide variety of vegetables. Malaysians relying on vegetables as a main source of fiber, minerals and vitamins. Per capita consumption of vegetables in Malaysia reveals there to be an increasing trend of these in the diet, from 27.25 kg in 1982 to 40.58 kg in 2001 and 45.9 kg in 2005 (FAMA, 1993; Ministry of Agriculture and Agro-based Industry). Being an important source of nutrients, determination of radioactivity in edible vegetables is of particular significance.

Herein measurement is made of the activity concentrations of naturally occurring and anthropogenic radionuclides available in the soil, their presence in plants, and soil-to-plant TFs. The measurements involve some common edible vegetables (see below for details) collected from the Peninsular Malaysia. The data obtained are suggested to be useful for radiological assessment to the local population and also as input to epidemiological studies, the procedures also being important as a guide to those wishing to follow the present system in obtaining the associated radiological profiles. The results are also expected to serve as reference data, assisting in ascertaining possible changes in environmental radioactivity due to nuclear, industrial, and other human activities.

2. Materials and methods

2.1. Selection of sampling location

Malaysia, located between 1° and 7° north of the Equator has specific ecological conditions with an average temperature of 27°–32 °C throughout the year. The humidity is high (80–85%) and rainfall is fairly evenly distributed. Originally, vegetables were grown in small holdings worked by a largely rural community, subsequently to be used for their own consumption; the bulk of urban needs were served by imports. However, urbanization and rapid industrial development stimulated demand for fresh greens in urban centers. Consequently, land to the outskirts of town centers were converted into vegetable farms, with larger farms being concentrated in specialized highlands areas for the production of temperate vegetables; peat regions in other areas are similarly being worked for edible vegetables production. A total of five such locations (See Fig. 1) were selected to collect the samples: Langkawi

Fig. 1. The sampling locations (red solid circles) around peninsular Malaysia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)