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EDITORIAL

Dear reader, with great pleasure we provide you with the first issue of Atom Indonesia Volume 40, No.1 (2014) on time. With a new spirit in the year 2014, we have improved the service by providing online journal with Open Journal System (OJS), so publications timeline will be carried on time. For example, all current issues can be viewed and downloaded from the Atom Indonesia website, http://aij.batan.go.id. Additionally, from the same website, Mendeley can also be downloaded to help organizing citations. Recently Atom Indonesia has been indexed by Google Scholar and DOAJ, and it is to be registered by DOI. Our plan this year is to apply for indexing by Scopus.

The Atom Indonesia Vol. 40 No. 1 (2014) contains seven articles discussing various applications of nuclear science and technology in the fields of material science, health, food, environment, and production of radioisotopes. Three articles were written by authors and co-authors from various Universities and Institutions in Australia, Thailand and Saudi Arabia. M. F. Md Din *et al.* from the University of Wollongong, Australia, have written the article entitled "Magnetic Properties and Magnetocaloric Effect in Layered $NdMn_{1.9}Ti_{0.1}Si_2$." The structural and magnetic properties of this compound were studied by high-intensity x-ray and high-resolution neutron powder diffraction. The Curie temperature and Néel temperature of layered $NdMn_{1.9}Ti_{0.1}Si_2$ are indicated as $T_C \sim 22$ K and $T_N \sim 374$ K respectively. The first order magnetic transition from antiferromagnetic [AF*il*-type] to ferromagnetic [F(Nd)+F*mc*] around T_C is found in layered $NdMn_{1.9}Ti_{0.1}Si_2$ and is associated with large magnetocaloric effect. This behavior has been confirmed as a contribution of the magnetostructural coupling by using neutron and x-ray powder diffraction.

"Radiation-induced DNA Double Strand Breaks and Their Modulations by Treatments with *Moringa oleifera* Lam. Leaf Extracts: A Cancer Cell Culture Model" was written by K. Boonsirichai and S. Jetawattana from the Thailand Institute of Nuclear Technology. Gamma radiation brings deleterious effects upon human cells by inducing oxidative stress and DNA damages. Antioxidants have been shown to confer protective effects on irradiated normal cells. *Moringa oleifera* Lam. is a widely used nutritional supplement with antioxidant activities. This report showed that antioxidant-containing supplements, in addition to protecting normal cells, could protect cancer cells against genotoxic effects of gamma radiation. γ-H2AX immunofluorescent foci were utilized as an indicator of radiation-induced DNA double strand breaks.

R.D. Haryuni *et al.*, from the University of Indonesia, have investigated "Fragmentation of Nimotuzumab for Preparation of ^{125}I-F(ab')$_2$-Nimotuzumab as a Precursor for Preparing ^{125}I-F(ab')$_2$-Nimotuzumab-NLS Radiopharmaceutical for Cancer Therapy". This work studied the characteristics of the F(ab')$_2$ fragment of nimotuzumab by labeling both intact nimotuzumab and its F(ab')$_2$ fragment with ^{125}I, and comparing their characteristics. The radiochemical purity are 98.27 % and 93.24 %, respectively. Stability test results show that both of ^{125}I-nimotuzumab and ^{125}I-F(ab')$_2$-nimotuzumab are more stable at 4 °C than at room temperature storage and 37 °C.

The article entitled "Synthesis of Sulochrin-^{125}I and Its Binding Affinity as α-Glucosidase Inhibitor using Radioligand Binding Assay (RBA) Method" has been written by W. Lestari *et al.* from the National Nuclear Energy Agency, Indonesia. This study was carried out to obtain the data of sulochrin binding with α-glucosidase enzyme as α-glucosidase inhibitor using Radioligand Binding Assay (RBA) method. From the RBA method, dissociation constant (K_d) and maximum binding (B_{max}) were obtained as 26.316 nM and 9.302 nM respectively. This low K_d indicates that sulochrin is able to bind to α-glucosidase.

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Another interesting topic titled "Natural Radioactivity in Some Food Crops from Bangka-Belitung Islands, Indonesia" has been explored by Syarbaini *et al.* from the National Nuclear Energy Agency, Indonesia. The study was carried out to evaluate the natural radioactivity concentration in some food crops grown in thhe Bangka-Belitung Islands. The annual internal dose resulting from ingestion of radionuclides in food was 0.205 mSv/year which is much lower than annual dose limit of 1 mSv for general public. The radionuclides with the highest consumption is ^{40}K, followed by ^{232}Th and ^{226}Ra.

H. Syaeful *et al.* have explored "Radiometric Mapping for Naturally Occurring Radioactive Materials (NORM) Assessment in Mamuju, West Sulawesi." Mamuju has been known to exhibit a high radiation dose rate which arises from NORM in rock and soil, which is a major concern is due to its location which is near inhabitant settlement area. The purposes of this research were twofold, namely: First, to delineate the location and distribution of thorium and uranium anomaly in Mamuju; and second, to provide adequate information regarding the anomaly and high dose rate area to decision makers and stakeholders in both local and central governments. The method applied is radiometric mapping using the RS-125 spectrometer with NaI(Tl) detector in the area of interest, namely the Adang Volcanic Geological Formation, which is more than 800 km^2 in size. The mapping has successfully delineated the area of NORM or the area with thorium and uranium anomaly. Thorium and uranium anomaly identified are related to multi-geological-processes which result in the increase of grade into several fold from its original state.

"Analysis of ^{99}Mo Production Capacity in Uranyl Nitrate Aqueous Homogeneous Reactor using ORIGEN and MCNP" has been written by A. Isnaeni *et al.* from the King Abdulaziz University, the Kingdom of Saudi Arabia. ^{99m}Tc is a very useful radioisotope in medical diagnostic procedure. ^{99m}Tc is produced from ^{99}Mo decay. Currently, most of ^{99}Mo is produced by irradiating ^{235}U in the nuclear reactor. ^{99}Mo mostly results from the fission reaction of ^{235}U targets with a fission yield about 6.1%. A small additional amount is created from ^{98}Mo neutron activation. Actually ^{99}Mo is also created in the reactor fuel, but usually we do not extract it. A simulation of the extraction process was performed while reactor was in operation (without reactor shutdown). With an extraction flow rate of 3.6 L/h, after 43 hours of reactor operation the production of ^{99}Mo becomes relatively constant at about 98.6 curie/hour.

The quality of Atom Indonesia has improved significantly and it follows international standards of publications. The presence of Atom Indonesia has also been recognized both nationally and internationally. This is shown by the increasing number of submitted articles in the recent years and just half of those articles passed the reviewing process. The diversity of the authors has also increased significantly. These achievements are due to the involvement of international professional editors and reviewers.

Editor in Chief

Atom Indonesia Vol. 40 No. 1 (2014) 29 - 34

Natural Radioactivity in Some Food Crops from Bangka-Belitung Islands, Indonesia

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ABSTRACT

Natural radioactivities of food crops are the main sources of internal radiation exposure in humans. Bangka-Belitung islands of Indonesia has a higher natural background radioactivity than typical areas because of tin mining activities.The study was carried out to evaluate the natural radioactivity concentration in several food crops grown in Bangka and Belitung Islands. Food samples collected from Bangka and Belitung Islands were analyzed by means of a gamma spectroscopy for natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K. The annual intake of the food was estimated on the basis of their average annual consumption. Calculations were also made to determine the effective dose to an individual consuming such diets. The intakes of these radionuclides were calculated using the concentrations in Bangka-Belitung foods and annual consumption rates of these food. Annual intakes of these radionuclides were as follows: ^{226}Ra = 190.00; ^{232}Th = 633.79 and ^{40}K = 2065.10 Bq/year. The annual internal dose resulting from ingestion of radionuclides in food was 0.205 mSv/year which is much lower than annual dose limit of 1 mSv for general public. The radionuclides with highest consumption is ^{40}K followed by ^{232}Th and ^{226}Ra.

INTRODUCTION

Bangka-Belitung is one of Indonesia provinces. It includes two large islands, Bangka and Belitung, and several smaller ones, and is located east of Sumatra, northeast of South Sumatra province. Bangka-Belitung islands province is the 31st Province in Indonesia, one of the newest provinces [1]. The Bangka and Belitung Islands is known to have the geological potential of mineral resources, especially tin, with accessory minerals consisting of monazite, zircon, xenotim, ilmenite, magnetite and pyrite spread in almost all regions. Additionally, there are some others minerals resources such as quartz sand, building construction sand, kaolin, granite, clay and mountain stone [2].

Tin mining is the most significant activity in Bangka-Belitung islands. Indonesia is the world's second largest tin producer after China. Most of Indonesia's tin production comes from the Bangka-Belitung islands. Tin mining and processing constitute a source of pollution to the environment. Environmental damages which occur in the province of Bangka-Belitung islands are very severe. These damages does not occur only on land but also at sea. The land in Bangka-Belitung is heavily damaged, with huge holes filled with standing turbid water everywhere. Bangka-Belitung coastal areas are suffering from abrasion due to the number of holes at the bottom of the sea set off by coastal mining. The rapidly increasing number of illegal mines is becoming as a large contributor to the destruction of the Bangka-Belitung environment [3]. Heavy mineral processing from the tin mining exploration on earth's crust has contributed a number of natural radioactive substances to the environment. The mining, milling and processing of minerals lead to enhanced radiation exposures, not only to the workers but also to the inhabitants of the mining and processing sites [4-7].

The analysis of radioactive minerals in foodstuffs is an important part of environmental monitoring programs. The major pathways for the transfer of radionuclides to human beings is food crops. Therefore, the natural radionuclides are the largest contributor of the radiation doses received by the population who live around the tin mining activities area. Natural radionuclides are transferred and cycled through natural processes and between the various environmental compartments by entering into ecosystems and human food chains. Studies on radiation levels and radionuclide distribution in the environment provide vital baseline radiological information. Such information

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is essential in understanding human exposure from natural and human-made sources of radiation and necessary in establishing rules and regulation relating to radiation protection.

Radiation doses obtained due to the intake of food can be calculated from the amount of radionuclide deposited on foodstuffs, the activity concentration of particular radionuclide in food per unit deposition, the consumption rate of the food products, and the dose per unit activity ingested [8-10]. Measurements of concentrations of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the food collected from Bangka and Belitung islands enable one to assess the radiation doses received by the population. With the tin mining exploration activities, the level of radiation exposure to the environment and people living in Bangka-Belitung may increase. Generally, tin leaves some natural radionuclides which easily migrate from the mining location to its surrounding environment which goes up to the land surface or is absorbed down into the water table.

Since waste from tin mining has become a serious issue in Bangka-Belitung, the knowledge of the natural radioactivity levels in food crops due to tin mining activity is important for the assessment of overall human exposure to natural radiation associated with ^{226}Ra, ^{232}Th and ^{40}K. The objectives of this work are to investigate the natural radioactivity levels (^{226}Ra, ^{40}K and ^{232}Th) in some selected major food crops from Bangka-Belitung islands and to evaluate their implications on population radiation ingestion dose. This study provides a database of natural radionuclides activity concentrations in major food crops samples from the environment of the Bangka-Belitung islands. This database is useful for further usage and research such as for estimation of transfer factors of certain radionuclides to food crops and risk assessment to human life. The data produced from this study not only becomes an asset to the Bangka-Belitung province, as it will serve as a reference level against future nuclear activities in the region, but also contributes to the Indonesia Radioactivity Database. The data produced from this study will serve as reference levels and will be a useful guide against any radioactive contamination from future nuclear activities in Bangka-Belitung province.

EXPERIMENTAL METHODS

Sample collection

The collected samples are several food crops grown and commonly consumed by the people of the Bangka-Belitung islands. The vegetable, fruit, and tuber samples were collected from local farmers and from vegetable gardens. Those samples are grown in the farms of the Bangka-Belitung area and also available in local markets. Each sample was placed in a plastic bag and labeled with a permanent marker. All the samples were packed in a rigid plastic container and then transported to the environmental laboratory of the Center for Radiation Safety Technology and Metrology for further treatments and measurement.

The fish samples were collected from local fishermen and local fish markets. The samples were cleaned to separate sand, weeds, and gravel, and was then washed with water. Fish samples were generally gutted by the fishermen. All fish samples were then frozen and dispatched to the aforementioned laboratory.

Sample preparation

In the laboratory, the vegetable, fruit, and tuber samples were carefully washed under running water and then in distilled water to remove all attached sand and dust particles. Those samples were then cut to pieces with a knife and were allowed to dry to a constant weight at room temperature. The samples were then weighed and ashed at 450 °C to remove organic matters [11].

Fish samples were allowed to thaw out naturally. Samples were rinsed under cold running tap to remove fish scales and any extraneous particulate materials. Flesh and muscle parts were removed from bones, mixed in the chopper, and prepared as samples. They were then filleted. The fillets were again rinsed to remove extraneous materials, minced, and dried to a constant weight. The fish samples were then weighed and dried in an oven at about 100 °C and reduced to ashes in a muffle furnace at 350 – 400 °C for about 24 h [12].

Radioactivity measurements

Each of the prepared samples was transferred to an airtight cylindrical plastic screw-cap vial. The vials were sealed and allowed to stand for at least 4 weeks for secular equilibrium to be established between the long-lived parent nuclides of ^{226}Ra and ^{232}Th and their short-lived daughters. The measurement of the radionuclides in the prepared samples were carried out by using ORTEC P-type coaxial high purity Germanium (HPGe) detector with a relative efficiency of 60% and a resolution of 1.95 keV (full width at half maximum) for the peak of 1.33 keV. The detector was coupled to a computer-based multichannel analyzer. The gamma ray spectrum was recorded using a PC-based 4096-channel analyzer and processed using ORTEC GammaVision-32 Gamma spectrum analysis computer software. The detector is located inside a cylindrical lead shield with a thickness of 10.1 cm, an internal diameter of 28 cm, and a height of 40 cm. The lead shield is lined with several layers of tin and copper, each of 0.5 and 1.6 mm thicknesses respectively.

The detection efficiency calibration of the system for the determination of radionuclides in the prepared samples was carried out using a certified standard source (^{152}Eu) and International Atomic Energy Agency (IAEA) reference materials prepared in geometrical shape and composition to simulate the samples' matrix. The measurements were carried out in the counting room located in the basement of the laboratory building. The measurement time for samples and background was 17 hours. The background counts were used to correct the net peak areas of gamma rays of measured isotopes. Quality assurance was additionally guaranteed by regular participations in national and international intercomparison exercises.

The gamma energy peaks 352 keV of ^{214}Pb and 609.31 keV of ^{214}Bi were used to determine ^{226}Ra. The gamma energy peaks of 238.6 keV from ^{212}Pb, 911.2 and 969 keV gamma energy peak from ^{228}Ac and 583 keV gamma energy peak from ^{208}Tl were used to determine the ^{232}Th, and that of ^{40}K was determined from the gamma energy peak of 1460.83 keV.

The activity concentrations (A) of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} for the samples were determined using the following expression [13,14] :

$$A = \frac{N_e}{\varepsilon_f P_\gamma t_c M} \tag{1}$$

where; N_e = net counts of a peak at energy E, ε_f = the counting efficiency of the detector system at energy E, P_γ = the gamma ray emission probability (gamma yield) at energy E, t_c = sample counting time, and M = mass of sample (kg). If there is more than one peak in the energy analysis range for a radionuclide, then an attempt to average the peak activities is made. The results is the weighted average radionuclide activity.

Calculation of effective dose

In order to assess the ingestion dose of radionuclides, it is necessary to determine the annual activity intake per inhabitant for each ingested radionuclide. The intake of radionuclides by ingestion is well described by the ICRP Human Alimentary Tract Model [15,16]. To derive ingested dose, the ingested annual activity of each radionuclide is multiplied by its dose conversion coefficient [17-19]. Finally, the total ingestion dose is obtained by summing the contributions of all radionuclides.

The annual intakes (Q) for ^{226}Ra, ^{232}Th and ^{40}K from foodstuffs in the present work were determined by using the activity concentrations (A) in foods and the annual food consumption rates (F) by the Bangka-Belitung islands population based on the National Socio-Economic Survey of 2012 [20]. The estimated annual internal effective dose (H) was calculated by using the following equations [17-19] :

$$H = A \times F \times IDCF \tag{2}$$

where H is the annual effective dose (Sv y^{-1}) due to ingestion of radionuclides from the consumption of foodstuffs, A is the concentration of radionuclides in the ingested foodstuffs (Bq kg^{-1}), F is the annual intake of foodstuff (kg y^{-1}), and IDCF is the ingested dose conversion factor for radionuclides (Sv Bq^{-1}). The IDCF values used for ^{226}Ra, ^{232}Th and ^{40}K are 0.28, 0.22 and 6.2 x 10^{-3} μSv Bq^{-1}, respectively.

RESULTS AND DISCUSSION

Radionuclides concentrations in major foods from Bangka Belitung

The results of the activity concentration measurements in the vegetables, fruits and tuber collected from the Bangka-Belitung province are presented in Table 1. Among the all food crops types collected and analyzed, the activity concentration of ^{226}Ra varies between 2.69 ± 0.51 Bq/kg (swamp cabbage) and 12.18 ± 2.63 Bq/kg (cassava leaf). The ^{232}Th activity in food crops varies between 8.20 ± 1.09 Bq/kg (swamp cabbage) and 46.00 ± 3.53 Bq/kg (jackfruit). The activity concentration of ^{40}K ranged from 40.12 ± 3.81 Bq/kg (cucumber) to 125.23 ± 11.80 Bq/kg (swamp cabbage). The concentration of ^{40}K was found to be very high compared to ^{226}Ra and ^{232}Th. It may be attributed to poor migration characteristics of radium and thorium from the soil to the vegetables in the concerned environment [10]. Potassium is a macronutrient, so the concentration may be high. It may be expected that the soil characteristics favor the mobilization of potassium and its subsequent migration into the plant.

The level of ^{40}K in jackfruits was 65.83 ± 3.93 Bq/kg, while in bananas it was 85.27 ± 8.04 Bq/k and in cassavas 40.40 ± 5.79 Bq/kg. The activity concentration of ^{40}K was higher in vegetables and fruits than in tubers (cassava).

Table 1. Activity concentration of natural radionuclides in vegetables, fruits and tuber.

Type of sample	Activity concentration (Bq/kg fresh-weight)		
	^{226}Ra	^{232}Th	^{40}K
Vegetables			
Spinach	7.47 ± 0.50	19.91 ± 2.72	69.80 ± 6.59
Swamp cabbage	2.69 ± 0.51	8.20 ± 1.09	125.23 ± 11.80
Mustard greens	2.77 ± 0.65	8.82 ± 1.18	110.56 ± 10.42
String beans	11.35 ± 1.62	26.37 ± 3.96	64.31 ± 6.12
Cucumber	9.55 ± 1.20	18.95 ± 2.15	40.12 ± 3.81
Cassava leaf	12.18 ± 2.63	39.19 ± 1.31	42.81 ± 10.19
Fruits			
Jackfruit	10.85 ± 1.18	46.00 ± 3.53	65.83 ± 3.93
Banana	5.45 ± 1.48	18.60 ± 3.29	85.27 ± 8.04
Tuber			
Cassava	3.68 ± 0.80	22.10 ± 2.70	40.40 ± 5.79

Nine types of fish samples were investigated for ^{226}Ra, ^{232}Th and ^{40}K and the results are listed in Table 2. It was found that the maximum level of ^{226}Ra was 11.11 ± 1.44 Bq/kg detected in Mozambique tilapias, while the minimum level of < 0.01 was detected in milkfish. ^{232}Th was detected in all fish samples with the maximum level of 44.62 ± 4.41 Bq/kg being detected in Mozambique tilapias, while the minimum level of 0.23 ± 0.05 Bq/kg was detected in red snappers. The levels of ^{40}K in fish samples were distributed from the lowest level to the highest level. The highest concentration was 90.84 ± 8.61 Bq/kg, recorded in mud crabs, followed by milkfish and shrimps with values of 64.58 ± 6.20 Bq/kg and 57.60 ± 5.57 Bq/kg respectively. The lowest concentrations were 15.02 ± 1.45 Bq/kg and 20.97 ± 2.01 Bq/kg, detected in cockles and catfish, respectively. The Mozambique tilapia was found as the dominant type of fish in absorbtion of ^{226}Ra, ^{232}Th and ^{40}K. This is due to the fact that the Mozambique tilapia is the freshwater fish species collected from the river. Most tin-mining areas have rich monazite and xenotime. These two minerals have rich natural radionuclides, particularly uranium, and thorium series and potassium such as ^{226}Ra, ^{232}Th and ^{40}K. Therefore, rivers passing through these areas would carry in their load traces of these radionuclides. Then the radionuclides could enter the food chain in the aquatic system which involves the phytoplankton (algae), zooplankton (microorganisms), and other aquatic life such as the Mozambique tilapia [21].

Table 2. Activity concentration of natural radionuclides in fish.

Type of sample	Activity concentration (Bq/kg fresh-weight)		
	^{226}Ra	^{232}Th	^{40}K
Yellow tail	0.80 ± 0.11	0.46 ± 0.10	38.83 ±3.89
Mackerel	0.36 ± 0.01	0.74 ± 0.14	45.24 ± 12.10
Milkfish	< 0.01	17.81± 4.21	64.58 ± 6.20
Mozambique tilapia	11.11 ± 1.44	44.62 ± 4.41	36.48 ±3.51
Catfish	3.81 ± 0.71	2.81 ± 0.64	20.97 ±2.01
Red snapper	0.12 ± 0.01	0.23 ± 0.05	47.60 ±5.57
Shrimp	4.27 ± 1.04	18.36 ± 2.32	57.60 ±5.57
Mud crab	0.17 ± 0.05	8.06 ±1.54	90.84 ±8.61
Cockle	0.10 ± 0.01	2.50 ± 0.74	15.02 ± 1.45

Annual radioisotopes intakes from Bangka and Belitung islands foods

Using the results of activities concentration of vegetables, fruits, tuber and fish presented in Tables 1 and 2 and the data on food consumption rate reported the Indonesia Agency of Statistics [20], the intake of radionuclides by the population of Bangka-Belitung province was estimated. The results are presented in Table 3 and 4. The corresponding food consumption rate used to evaluate the intake of radionuclides are also given in the tables. It can be seen from the tables that the radionuclides with the highest annual intake was ^{40}K (2065.10 Bq) followed by ^{232}Th (633.79 Bq) and ^{226}Ra (190.00 Bq). The foodstuff with the highest amount of intake of radionuclides is vegetables, followed by tubers, fruits and fish. The results show that vegetables predominantly absorb ^{40}K, ^{232}Th and ^{226}Ra radionuclides. This is due to the fact that vegetables have the capability to absorb elemental isotopic through root uptake and from the leaves as a result of atmospheric deposit. Among the all vegetable types analyzed, the highest amount of intake is exhibited by the swamp cabbage, followed by the spinach and the string bean, while the aquatic animal with the highest intake is the shrimp, followed by the Mozambique tilapia and the milkfish.

Table 3. The annual radionuclide intake for ^{226}Ra, ^{232}Th and ^{40}K from vegetables, fruits and tuber.

Type of food	Consumption rate$^{(a)}$ (kg y^{-1})	Activity concentration (Bq)		
		^{226}Ra	^{232}Th	^{40}K
Vegetables				
Spinach	3.80	28.39	75.66	265.24
Swamp cabbage	4.47	12.02	36.65	559.78
Mustard greens	1.46	4.04	12.88	161.42
String beans	2.76	31.33	72.78	177.50
Cucumber	1.56	14.90	29.56	62.59
Cassava leaf	2.65	32.28	103.85	113.45
Fruits				
Jackfruit	1.20	13.02	55.20	79.00
Banana	1.61	8.77	29.95	137.28
Tuber				
Cassava	3.48	12.81	76.91	140.59
Total intake (Bq)		157.56	493.44	1696.84

(a) according to a survey conducted by the Indonesia Agency of Statistics for Bangka-Belitung province.

Table 4. The annual radionuclide intake for ^{226}Ra, ^{232}Th and ^{40}K from fish.

Type of food	Consumption rate (kg y^{-1})	Activity concentration (Bq)		
		^{226}Ra	^{232}Th	^{40}K
Yellow tail	0.36	0.29	0.17	13.98
Mackerel	0.16	0.06	0.12	7.24
Milkfish	1.14	-	20.30	73.62
Mozambique tilapia	1.25	13.89	55.78	45.60
Catfish	1.09	4.15	3.06	22.86
Red snapper	0.21	0.03	0.05	10.00
Shrimp	3.28	14.01	60.22	188.93
Mud crab	0.05	0.01	0.40	4.54
Cockle	0.10	0.01	0.25	1.50
Total intake (Bq)		32.44	140.35	368.26

Annual internal dose

Using the activity intake results presented in Table 3 and 4, the annual effective internal dose due to the ingestion of ^{226}Ra, ^{232}Th and ^{40}K radionuclides are calculated. The results are given in Table 5 and 6. The recommended dose conversion coefficient for ^{226}Ra, ^{232}Th, ^{40}K are 0.28, 0.22 and 0.0062 μSv/Bq, respectively [17-19]. The total internal dose of ^{226}Ra, ^{232}Th, ^{40}K in Bangka Belitung foods were estimated to be 0.053, 0.139 and 0.013 mSv/year. The total annual internal dose from ingestion of food samples in this study was 0.205 mSv/year. It can be seen that this dose is lower than annual dose limit of 1 mSv for general public [19].

Table 5. The estimated annual internal dose for ^{226}Ra, ^{232}Th and ^{40}K from vegetables, fruits and tuber.

Type of food	Activity concentration (μSv)		
	^{226}Ra	^{232}Th	^{40}K
Spinach	7.948	16.645	1.644
Swamp cabbage	3.367	8.064	3.471
Mustard greens	1.132	2.833	1.001
String beans	8.771	16.012	1.100
Cucumber	4.171	6.504	0.388
Cassava leaf	9.038	22.848	0.703
Jackfruit	3.646	12.144	0.490
Banana	2.457	6.588	0.851
Cassava	3.586	16.920	0.872
Total	44.116	108.557	10.520

Tabel 6. The estimated annual internal dose for ^{226}Ra, ^{232}Th and ^{40}K from fish.

Type of food	Activity concentration (μSv)		
	^{226}Ra	^{232}Th	^{40}K
Yellow tail	0.081	0.036	0.087
Mackerel	0.016	0.026	0.045
Milkfish	-	4.467	0.456
Mozambique tilapia	3.889	12.271	0.283
Catfish	1.163	0.674	0.142
Red snapper	0.007	0.011	0.062
Shrimp	3.922	13.249	1.171
Mud crab	0.002	0.089	0.028
Cockle	0.003	0.055	0.009
Total	9.082	30.876	2.283

CONCLUSION

The study on the activity concentrations of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in several food crops which are regularly consumed by the population of Bangka Belitung province show that the highest value of concentration occurred vegetable, followed by fruits and fish. Among the all vegetables samples, the highest activity concentration of radionuclides was exhibited by swamp cabbages and mustrad greens, followed by string beans, spinach and cassava leaves. According to this study, fruits have maximum radionuclides concentration compared to tubers (cassava). Among aquatic animal samples, the highest activity concentration of radionuclides was exhibited by Mozambique tilapia and mud crab, followed by the shrimp.

Based on the activity concentration of radionuclides and the data on food consumption rate, the annual intakes of these radionuclides were estimated higher in swamp cabbages, spinach, string beans, cassava leaves, cassavas, shrimps and Mozambique tilapias. For spinach, string beans, and cassava leaves, the high radionuclides intake values were not only due to high radionuclides concentrations but also due to the high consumption rate. Meanwhile, for the estimation of annual effective internal dose received by the members of the public from consumption of these food crops, the main contributors to the intake internal dose were cassava leaves, spinach, and string beans, followed by shrimps and Mozambique tilapias.

The annual internal dose received by general public living in Bangka-Belitung islands area due to the consumption of the common vegetables, fruits, tuber and fish is 0.205 mSv/year. This dose is lower than annual dose limit of 1 mSv for general public.

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