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Study on the ^{137}Cs and ^{60}Co Transfer Factors from Soil to Several Tropical Vegetables

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It is necessary to accurately assess the deposition of fallout radionuclides on plants to ascertain the degree of risk and deleterious effects on public health. Therefore, a study of ^{137}Cs and ^{60}Co transfer factors (TF) from soil to eight tropical vegetables has been conducted by using a pot treatment system in the Green House of the Center. The research aims to determine the transfer factor of ^{137}Cs and ^{60}Co from soil to tropical vegetables such as spinach, swamp cabbages, chilli, tomato, bitter melon, mustard green, eggplant and cassava. This experiment was carried out by using the complete random design to evaluate two treatments, consisting of the soil contaminated with ^{137}Cs and ^{60}Co and without both radionuclides (^{137}Cs and ^{60}Co). The number of experiments for each vegetable was 12 pots and the control plant also was 12 pots. After being harvested, the weight of dried tropical vegetables and soil was measured. Transfer factor was determined according to the accumulation of ^{137}Cs and ^{60}Co concentrations in these tropical vegetables and soil by counting them using a gamma spectrometer. The transfer factors of ^{137}Cs and ^{60}Co from dry soil to dry tropical vegetable was found between 0.0153–0.5688 and 0.0024–0.2688, respectively. The lowest and highest TF were found in tomato and bitter melon, respectively for ^{137}Cs and ^{60}Co radionuclides.

Key words: transfer factor, ^{137}Cs, ^{60}Co, soil, tropical vegetable

1. Introduction

Both routine and nuclear accidental releases of nuclear wastes result in radionuclides shipping into the environment and ground. Radionuclides in the ground especially soil are frequently transferred to various plant tissues by direct transfer through the root system, or by fallout of radionuclides and resuspension of contaminated soil followed by deposition on plant leaves[1)]. The uptake in plants varies, resulting in different public dose rates. This is characterized by the transfer factor, which represents the ratio of radionuclide concentration in the plant to soil per unit mass. This ratio describes the amount of element expected to enter a plant from its substrate under equilibrium conditions[2)].

The transfers of radionuclides through the food chain have been studied for over fifty years, in keeping with nuclear and civilian nuclear experiments. The transfer

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factor is the absorption of radionuclides from soil to plant. Transfer from soil to plant increases due to several factors namely chemical characteristics of radionuclide, fallout or waste, time after fallout, soil characteristics, plant species, and soil cultivation[3]. This data of transfer factors is required as one of the parameters in the calculation of the internal radiation dose assessment due to the ingress of radionuclides into the human body through soil pathways - plant - human associated with radionuclide releases from nuclear installations[4].

During the nuclear disaster such as the Fukushima Daiichi power plant in 2011 and other nuclear accidents before that accident, mostly ^{137}Cs were released. ^{137}Cs radionuclide emits radiation at the energy of 661.66 keV with yield $P\gamma$ = 0.85 and has a half-life of about 30 years. ^{137}Cs in the atmosphere can get into the soil which can then also reach the plants. ^{137}Cs tend to be tied up by soil so that very little is absorbed by plant roots. ^{137}Cs can enter the human body directly when humans consume food from contaminated plants. In the human body, ^{137}Cs can settle on almost all the soft tissues of the body, because they have the same characteristics as the stable potassium (K)[2, 5]. This highly radioactive substance is transformed very quickly, with a high number of disintegrations per second and a short half-life. On the other hand, small amounts of cobalt are naturally found in most rocks, soil, water, plants, and animals. Radioactive cobalt, as ^{60}Co and is the most important radioisotope of cobalt, has been found in nuclear power plant (NPP) sites. ^{60}Co radionuclide emits γ radiation with E = 1173.24 keV and 1332.50 keV with yield $P\gamma$= 0.99 and has a half-life of 5.27 years. ^{60}Co is known to have very low solution concentrations due to low solubility.

There are many soil types including Alluvial, Latosol, red-yellow podzolic, Mediterranean, Grumosol/Vertisol and Andosol. The soil's appropriate degree of acidity (pH) ranges from 4.5 to 8.0 with an ideal pH of 5.8[6–8]. Latosol is found in tropical rainforests with a relatively high content of iron and aluminium oxides. They are typically classified as oxisols (USDA soil taxonomy) or ferralsols according to the World Reference Base for Soil Resources[9]. Latosols are tropical soils, but the reverse is not true because many soils in the tropics are not latosolic. Latosols are red or yellowish-red in colour throughout and they do not have distinct horizons like a podsol. The soil generally contains a thin but very fertile layer of humus dropped from plants and animals in the forest, followed by an infertile second layer due to rapid leaching in the high rainfall. The third level, weathered bedrock, is common to almost all soil types. The latosol is completely reliant on the rainforest to maintain fertility, as all nutrients leach away quickly when the forest is felled and the layer of humus is no longer being replaced[10].

Regarding the incomplete data transfer factor from soil to vegetable crops in tropical vegetables, it is necessary to research the transfer factors from various types of soil to various plant types in Indonesia. The data will be used as input material for the IAEA if any revised the handbook of the transfer factor. The objective of this investigation is to study the soil-to-plant transfer factor of radionuclides to selected plant samples from soil to tropical vegetable crops.

2. Materials and methods

2.1. Soil samples

The soil used as media in this experiment is taken from surface soil with a depth of up to 20 cm. The soil was dried and filtered with a 2 mm sieve filter and was used for preliminary analysis that included pH, organic matter, texture, concentration of P, K, Al, H, and cation exchange rates conducted in the Research Center for Soil and Agroclimate in Bogor. In addition, there were also measurements of ^{137}Cs and ^{60}Co in dry soil before pot experiments.

2.2 Experimental pot

The experiment was carried out in a completely randomized design, which tested 2 treatments, namely by treating the soil with and without ^{137}Cs and ^{60}Co radionuclides with 12 replicates, respectively. Each pot is filled with soil that has been air dried, pulverized and filtered by using a 2 mm sieved filter sieve and then stirred evenly and weighed between 5 - 20 kg of weight. The activity concentration of ^{137}Cs and ^{60}Co radionuclides under study was about 5 kBq/kg soil each. After the soil sample was contaminated with these radionuclides, it was allowed to stand for 1 month to reach equilibrium. Eight types of vegetables (green mustard, spinach, eggplant, swamp cabbage, chilli, bitter melon, tomato, and cassava leaf, either as seeds or trunks) were then planted in these pots. N, P and K fertilizers were given to keep nutrient balance in the soil. Watering was done every day. Pest control was done by using pesticide spraying to avoid pest attacks.

2.3. Analysis and measurement

Tropical vegetable crops were cut into small pieces, weighed their wet weight in poliethylene vials and closed, and was measured the ^{137}Cs and ^{60}Co radioactivity contents with a gamma spectrometer. Furthermore, tropical vegetables are dried in an oven at 105°C for 16 hours. Dry tropical vegetables were weighed and then measured the contents of ^{137}Cs and ^{60}Co with a gamma spectrometer. The ground after being harvested was also dried, then weighed and put into vials, and measurements of the activity of ^{137}Cs and ^{60}Co were performed by a high-resolution gamma spectroscopic system employing a

Table 1. Transfer factor of radionuclides ^{137}Cs and ^{60}Co in several tropical vegetable plants

Name of Plant	Type / Family of Plants	Soil type	Soil pH	Transfer Factor	
				^{137}Cs	^{60}Co
Spinach (*Amaranthus sp*)	Shrub / *Amaranthaceae*	Latosol	5.7	0.2517 ± 0.8717	0.0305 ± 0.1056
Swamp cabbage (*Ipomea Reptans poir*)	*Convolvulaceae*	Latosol	5.7	0.0800 ± 0.2229	0.2086 ± 0.5510
Chilli (*Capsicum annuum L.*)	Shrubs / *Solanaceae*	Latosol	5.7	0.0746 ± 0.1300	-
Tomato (*Solanum lycopersicum*)	Shrubs /*Solanaceae*	Latosol	6.0	0.0153 ± 0.0795	0.0024 ± 0.0023
Bitter Melon (*Momorica charantia L*)	Herba / *Cucurbitaceae* (squash type)	Latosol	4.6	0.5688 ± 0.5800	0.2688 ± 0.5100
Mustard greens (*Brassica juncea*)	Cruciferae (*Brassicaceae*)	Clay	7.3	0.0298 ± 0.1032	0.0067 ± 0.0232
Eggplant (*solanum melongena*)	Shabby /*Solanaceae* (eggplant type)	Dusty clay	7.5	0.0115 ± 0.0354 (w)* 0.2060 ± 0.1789(*d*)**	
Cassava leaf (*Manihot esculenta*)	*Euphorbiaceae*	Dusty clay	5.9	0.5041+ 1,6815	-

Note: * (*w*) = *wet*
**(*d*) = *dry*

high-purity germanium (HPGe) detector coupled with a multichannel analyzer.

2.4. Calculation

The concentrations of ^{137}Cs and ^{60}Co in tropical vegetables and soils are determined by the following equation:

$$A = \frac{C_c - C_b}{E.Y.W}, \quad (1)$$

with: A = Radionuclide concentrations in the sample (Bq/g), C_c = sample count rates (cps), C_b = background count rates (cps), E = calibration efficiency (%), Y = gamma energy abundance of the radionuclides, and W = sample weight (g). Radionuclide specific activities were obtained from a quantitative analysis of γ-ray spectra using the γ lines at 661.6 keV for ^{137}Cs, 1173.2 keV and 1332.5 keV for ^{60}Co.

The radionuclide transfer factor is determined using the following equation:

$$TF = \frac{A_v}{A_s}, \quad (2)$$

With TF = radionuclide transfer factor, A_v = radionuclide concentration in dry vegetable sample (Bq/g), and A_s = radionuclide concentration in dry soil (Bq/g).

3. Results and discussion

Table 1 shows the research results. The values of the ^{137}Cs transfer factors (TF) from soil to several tropical vegetables vary between 0.0153 and 0.5688, with the lowest TF found in tomato, whereas the highest was found in bitter melon. The values of the ^{60}Co transfer factors from soil to several tropical vegetables vary between 0.0024 and 0.2688, and similar to the TF of ^{137}Cs, the lowest and highest TF of ^{60}Co was found in tomato and bitter melon, respectively. These transfer factor values are still within the transfer factor of IAEA in Technical Reports Series No.472, where the transfer factors of ^{137}Cs in the leafy vegetables are between 0.0003 – 0.9800 and in the non-leafy vegetables are between 0.0007 – 0.7300. The transfer factor of ^{60}Co in the leafy vegetables was between 0.0130 -1.0000 and in the non-leafy vegetables was between 0.0570 – 0.2300. These results showed a considerable difference in their distribution among the plants assessed.

The value of the transfer factor is influenced by the type of soil, type of plant, type of radionuclide and soil pH. In the type of soil "clay", dusty clay planted with shrubs (*Solanaceae*) and *Euphorbiaceae* obtained a higher transfer factor ^{137}Cs of 0.2046 in the eggplant (*Solanaceae*) and 0.5041 in the cassava plant (*Euphorbiaceae*), when compared to the soil type of "Latosol" with Tomato and Chilli (*Solanaceae*) plant species are 0.0153 and 0.0746.

Different types of plants planted in the same type of soil that is latosol showed different ^{137}Cs transfer factors, this was found higher in spinach (*Amaranthaceae*) was 0.2517 and swamp cabbage (*Convolvulaceae*) was 0.0800. Inorganic materials including essential elements are absorbed from the soil and passed up through the stem, moving up usually in the xylem[11]. The results obtained are lower when compared to the results obtained at the transfer factor of ^{137}Cs from latosol soil to spinach plants, namely 0.1701, this is probably due to the type of plant where mustard is a grass plant where the stems are relatively barely visible. present or short, this allows the transfer of ^{137}Cs absorbed from the soil and transmitted upwards through the stems relatively less while spinach

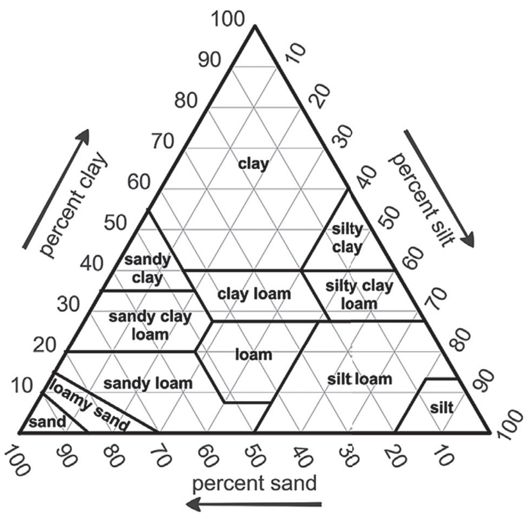

Fig. 1. Soil texture triangle from NRCS, USDA[13].

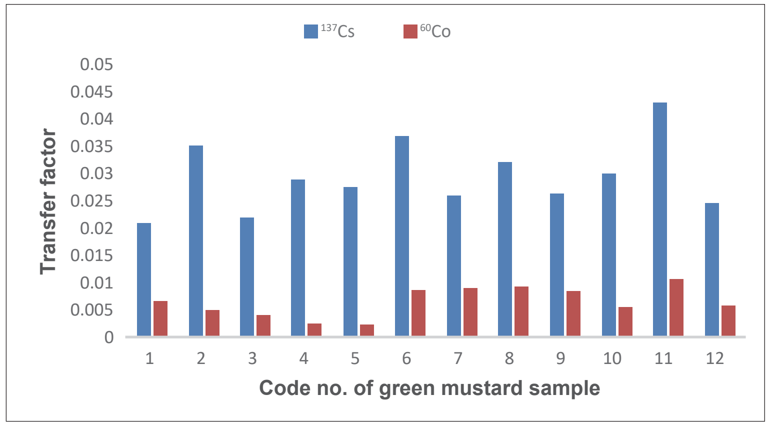

Fig. 2. Transfer factor of ^{137}Cs and ^{60}Co from soil to mustard greens.

is a shrub plant where in the stem there is a network of vessels formed which may be able to transfer more ^{137}Cs than mustard plants[12].

In the same type of soil that is the same soil of Latosol and the same pH of 5.7 and type of radionuclide shows a different ^{60}Co transfer factor which is higher in the swamp cabbage (*Convolvulaceae*) was 0.2086, while in the spinach (*Amaranthaceae*) was 0.0305. Differences type of radionuclides in the same plant species show different transfer factors which in spinach (*Amaranthaceae*) ^{137}Cs transfer factor was 0.2526 and higher than that of the ^{60}Co transfer factor (0.0305).

From the soil analysis, it was known that the soil texture contains sand 24%, ash 22% and clay 54%. This shows that soil is "clay" soil same as Figure 1 Soil Texture Triangle from the Natural Resources Conservation Service, USDA[13]. Clay texture soil has a large area of the big until the soil's ability to retain water and tie nutrients highly, this shows in the green mustard (*Brassica juncea*). From the soil analysis result, the soil chemical contains soil with a pH is 5.9, this value is not much different from the ideal pH value for the growth of the cassava[9], which affects the ^{137}Cs transfer that is high enough to cassava leaf. The soil type is Grumosol/Vertisol. Therefore, the results showed that soil type influences the transfer factors.

The value of the ^{137}Cs transfer factor from soil to tropical vegetables is higher than the TF value of ^{60}Co. Perhaps this is due to the chemical characteristic of caesium which is similar to the potassium element (in the same periodic system). Potassium is a macronutrient used in the growth of tropical vegetables.

The tropical climate of Indonesia gives a big chance to cultivate many vegetable crops throughout the year due to the availability of sufficient sunlight. Vegetables are food derived from plants with high water and fibre content. It contains a lot of vitamins and minerals needed by the body. In this experiment, we used 8 types of tropical vegetables as the objectives of the research on this paper that is mustard greens, spinach, eggplant, swamp cabbage, chilli, bitter melon, tomato, and cassava leaf.

Mustard Greens (*Brassica rapa convar*) is a kind of vegetable which is quite popular. This vegetable is also known as caisim, caisin, or meatballs mustard[12]. The suitable soil for planting mustard greens is loose soil which contains lots of humus, is fertile and has good drainage. The optimum acidity (pH) of the soil for growth is between pH 6 to 7. Figure 2 shows the experimental results for the transfer factor of radionuclide ^{137}Cs and ^{60}Co from soil to mustard greens.

Spinach (*Amaranthus sp.*), included in the *Amaranthaceae* family, is a crop of a year or more and a shrub. Spinach can grow throughout the year, both in lowland and highlands (mountains). The degree of soil acidity (soil pH) that is good for growth is between 6-7[13]. Figure 3 shows the experimental results for transfer factor of radionuclide ^{137}Cs and ^{60}Co from Soil to Spinach.

Eggplant (*Solanum melongena*) is a perennial plant of shrubs that can grow up to 60-90 cm, fruit-producing plants used as vegetables. Eggplant can grow in low to highland about 1200 m asl, air temperature 22-30°C, sandy, fertile, rich in organic materials, aeration and good drainage and pH between 6.8 - 7.3, and sufficient

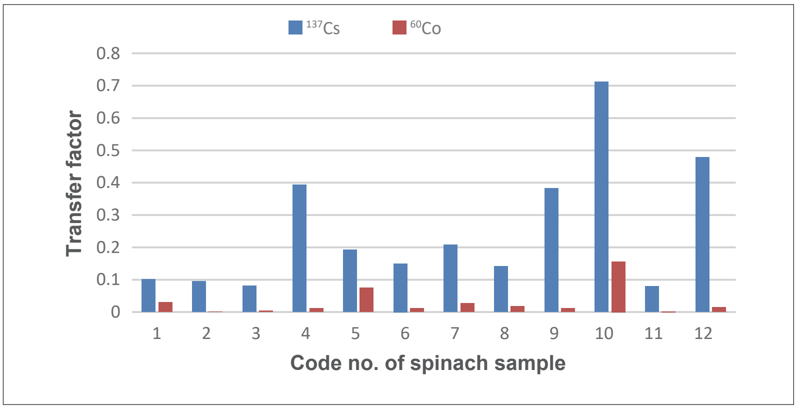

Fig. 3. Transfer factor of ^{137}Cs and ^{60}Co from soil to spinach.

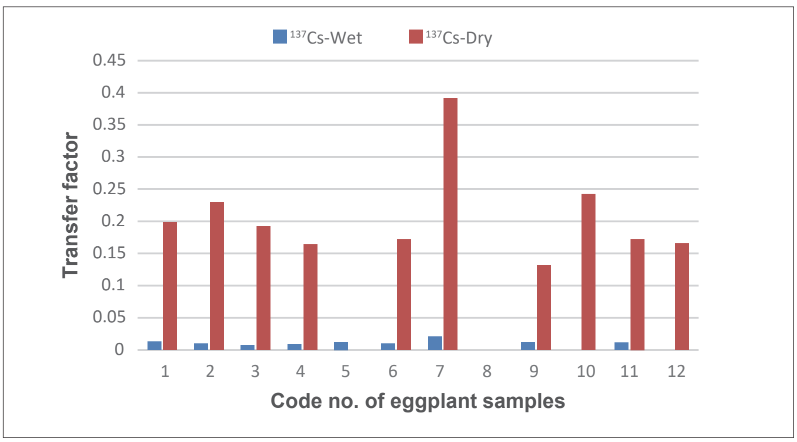

Fig. 4. Transfer factor of ^{137}Cs from soil to eggplant in dry samples and wet samples.

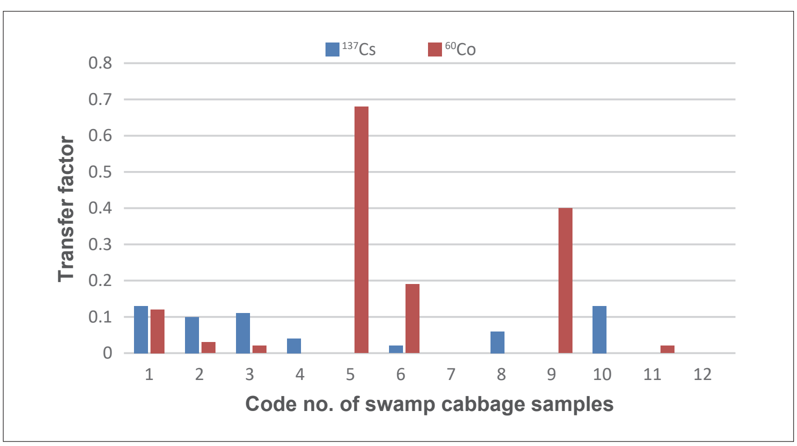

Fig. 5. Transfer factor of ^{137}Cs and ^{60}Co from soil to swamp cabbage.

sunlight[14]. Figure 4 the experimental results for transfer factor of radionuclide ^{137}Cs from soil to eggplant with measurement condition for dry samples and wet samples.

Swamp Cabbage (*Ipomoea reptans poir*) is a grass-shaped plant that is crawling (twisted). Having a root tire system and its root branch spread in all directions, can penetrate the soil to a depth of 60-100 cm and extend horizontally at a radius of 100-150 cm or more[15]. Figure 5 shows the experimental results for transfer factor of radionuclide ^{137}Cs and ^{60}Co from soil to swamp cabbage.

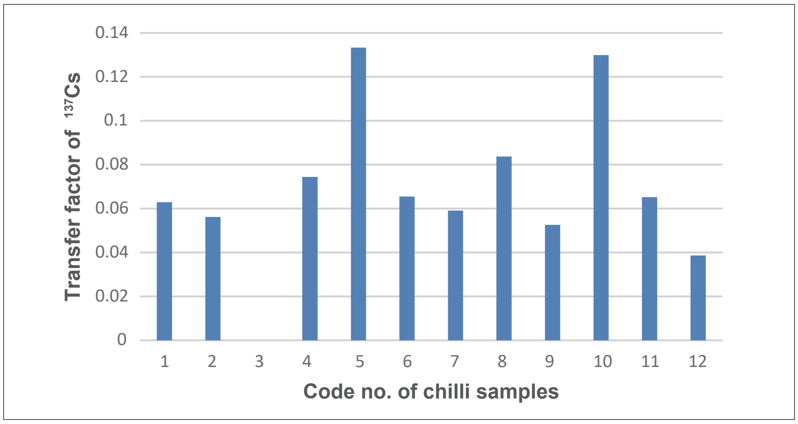

Fig. 6. Transfer factor of ^{137}Cs from soil to chilli.

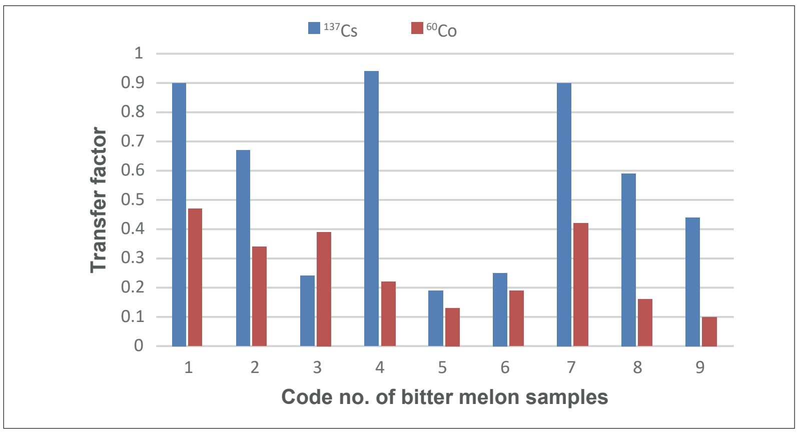

Fig. 7. Transfer factor of ^{137}Cs and ^{60}Co from soil to bitter melon.

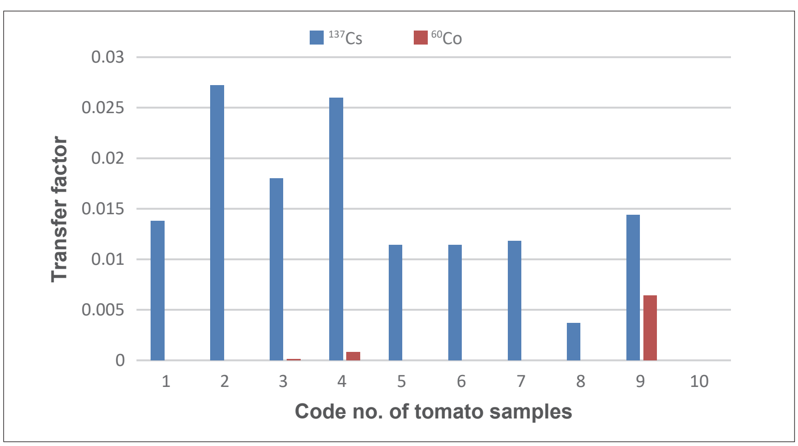

Fig. 8. Transfer factor of ^{137}Cs and ^{60}Co from soil to tomato.

Large chilli (*Capsicum annum L.*) is a seasonal crop of shrubs or half shrubs that have a somewhat diffuse rooting system; The main stem grows upright and the base is woody. Leaves grow singly with varied shapes, namely taper to ovate and pointed ends. Chilli fruit contains a lot of carotenes, vitamin A, and vitamin C. Ideal soil for pepper plants is the type of soil andosol, latosol and regosol. The optimum pH is 5.5-6.8 where above or below this acidity will result in low production[16]. Figure 6 shows the experimental results for transfer factor of

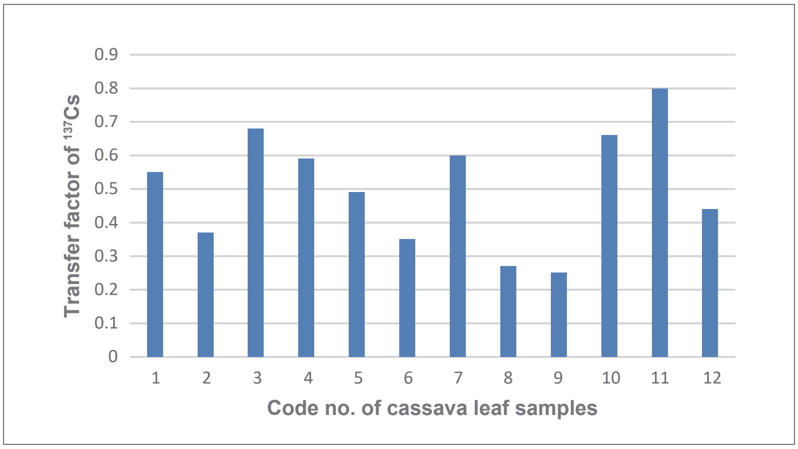

Fig. 9. Transfer factor of ^{137}Cs from soil to cassava leaf.

radionuclide ^{137}Cs from soil to chilli.

Bitter melon plants are herbaceous plants one year old or older that grow to creep and creep. Plants that are fruit vegetables have leaves that are shaped like fingers with yellow flowers[17]. Figure 7 shows the experimental results for transfer factor of radionuclide ^{137}Cs and ^{60}Co from soil to bitter melon.

Tomato is one type of vegetable that many people favour because it tastes good and fresh as well as a source of vitamins[18]. Including the type of plants in the form of shrubs or shrubs with a length that can reach 2 meters. The surface of the stem is covered with many fine hairs, especially the green parts. Among the hairs are usually hair glands. Figure 8 shows the experimental results for transfer factor of radionuclide ^{137}Cs and ^{60}Co from soil to Tomato.

Cassava leaf (*Manihot esculenta*) is a kind of plant that leaves cooked vegetables containing the amino acid methionine[19]. Cassava leaves have 5 to 9 sheets of leaves. The stem has a distinctive branching pattern, which varies depending on the cultivar. Cassava is a tropical and subtropical annual tree of the *Euphorbiaceae* family. Cassava plants grow well in rainfall between 1,500-2,500 mm/year. The air temperature is at least about 10°C. Temperatures below 10°C cause plant growth slightly hampered, it becomes dwarfed due to flower growth that is less than perfect. Optimum humidity between 60-65%. Soil with a crumb structure has a good air system, nutrients are more easily available and are easy to process. For better cassava plant growth, soils must be fertile and rich in organic materials both macro and micro elements. Figure 9 shows the experimental results for transfer factor of radionuclide ^{137}Cs from soil to cassava leaf.

Currently, there is a new and increasing concern for the environment stemming from various evidence that the environment is being seriously affected by the activities of human beings. If the level of activity concentrations of natural radionuclides in the soils were higher than the range of the world average, it might pose a radiation hazard to the population. Continuous intake of radionuclides through the food chain may have some serious health effects on individuals in the long term. Therefore, it is important to assess the internal doses to humans from ingestion of radionuclides present in agricultural products and it is necessary to know the main processes which determine the transport of radionuclides in the environment[20].

Much research has been done to study the transport of radionuclides, especially ^{137}Cs and ^{60}Co as the fission product of uranium. These two radionuclides are more representative of discharges from nuclear facilities and are of interest for radiological protection because of their great mobility in the biosphere and affinity with biological systems.

Khadra *et al.*[20] studied the TF of ^{137}Cs in wheat plants from the sandy loam soil and found that the TF was 0.81 and from clayey soil was 0.24, showing that soil type influences the transfer factors. They also revealed that TF in roots were higher than those for leaves for all soils only for ^{137}Cs. Quinto *et al.*[21] studied ^{137}Cs and ^{60}Co uptake by lettuce plants in field conditions and found that the TF of both radionuclides ranged from 0.05 to 0.1 in mature vegetables. Choi *et al.*[22] found the TF of ^{137}Cs for seeds of soybeans is in the range of 3.0×10^{-5}–2.7×10^{-4} and for leaves is in the range of 9.2×10^{-5}–1.9×10^{-4}. These TF were decreased to 34% in the fourth year. A very old experiment by Boikat *et al.*[23] found that TF combined from all experiments appeared lognormally distributed with median values of 0.22 on podzolic and 0.09 on marshy soils. Whereas a study by Mollah and Begum from Bangladesh[24] found the TFs of ^{60}Co for rice, bean, peanuts, pineapple, cabbage, tomato, spinach and grass were found to be 0.09, 0.15, 0.12, 0.67, 0.28, 0.79, 1.03 and 0.34, respectively, and much more studies about TF of a large number of radionuclides to many types of plants are being conducted.

Here we studied the transfer factor from several types of soil and vegetables. The transfer factor depends sensitively on chemical, physiological and ecological conditions. Radionuclides absorbed are transferred to the plant organs and their quantities are determined based on the kind of contamination source and of biological and environmental processes. Some other factors that affect this factor are the type of radionuclide, plant species, soil type, soil physical properties (soil texture), soil chemical properties (soil pH, soil organic matter content, and soil cation exchange capacity) and stable element concentration[4, 19-21]. Whereas minor factors are differences in crop varieties, differences in agricultural management (fertilization) and the weather.

4. Conclusion

a. The transfer factors of radionuclide ^{137}Cs from soil to 8 tropical vegetable plants that are mustard greens, spinach, eggplant, swamp cabbage, chilli, bitter melon, tomato, and cassava leaf are 0.0298, 0.2517, 0.2061, 0.0800, 0.0746, 0.5688, 0.0153 and 0.5041, respectively.
b. The transfer factors of radionuclide ^{60}Co from soil to 5 tropical vegetable plants that are mustard greens, spinach, swamp cabbage, bitter melon, and tomato is 0.0067, 0.0305, 0.2086, 0.2688, and 0.0024, respectively.
c. In general, the transfer factor of ^{137}Cs was higher than the ^{60}Co. The lowest and highest transfer factor were found in tomato and bitter melon, respectively for ^{137}Cs and ^{60}Co radionuclides.
d. It is suggested that research on transfer factors in other types of soils and other crops should be conducted.

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