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# Transfer factors of $^{90}$Sr and $^{137}$Cs from soil to the sweet potato collected in Taiwan

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## Abstract

The activity concentrations of $^{90}$Sr and $^{137}$Cs in sweet potatoes collected at eight locations in Taiwan were measured using radiochemical analysis and $\gamma$-ray spectrometry. $^{90}$Sr is found to be more concentrated in leaves than in storage roots (the mean activity ratio of storage roots to leaves is 0.55), while $^{137}$Cs distributes homogeneously in both storage roots and leaves (the corresponding ratio for $^{137}$Cs is 0.94). The mean transfer factors of $^{90}$Sr and $^{137}$Cs from soil-to-storage roots are determined to be 0.55 and 0.095, respectively, while the mean transfer factors of $^{90}$Sr and $^{137}$Cs from soil to leaves are 1.38 and 0.105, respectively. The effective dose equivalent values due to the dietary intake of $^{90}$Sr and $^{137}$Cs through sweet potato for the Taiwanese are estimated to be $9.38 \times 10^{-8}$ and $2.37 \times 10^{-8}$ Sv yr$^{-1}$, respectively. © 1999 Elsevier Science Ltd. All rights reserved.

*Keywords:* Sweet potato; Transfer factor; Strontium-90; Caesium-137

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## 1. Introduction

Radionuclides produced by nuclear explosions and nuclear facilities are released into the environment. These nuclides are parts of the fallout which is deposited on the ground and reach humans via the food-chain (Eisenbud, 1973). There are two long-lived radionuclides with half-lives of 28.8 yr for $^{90}$Sr and 30 yr for $^{137}$Cs. Owing to the similar chemical properties to Ca and K, which are important elements in the human

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body, $^{90}$Sr and $^{137}$Cs are the two important contributors to the internal radiation dose.

Sweet potato (*Ipomoea batatas* L. (Lam.)) feeds a large population and is distributed over high quality cultivated land in tropical and subtropical area worldwide. The popularity is largely attributed to its features that are adapted to hot, humid conditions, fast growth, resistance to stress of drought or extremes of heavy rainfall, and ability to grow even in poor or degraded soil. Sweet potato leaves are also served as a major leafy vegetable in many Asian countries. For instance, it is usually the only one in Taiwan markets after a typhoon. In contrast to the situation as one of the most staple food crops in the world, very few research activities have been conducted on sweet potatoes (Woolfe, 1992), particularly related to contamination by radionuclides and assessment of public health or the impact on the environment in these subtropical and tropical areas.

For this reason, the studies on the distribution and the translocation of these radionuclides in the sweet potato are helpful to understand the absorption and transfer behaviors between soil and sweet potato. It can also serve as a reference for dose assessment for people who consume the sweet potato in Taiwan and nearby regions.

## 2. Materials and methods

### 2.1. Sampling and pretreatment

Storage roots and leaves of sweet potato and soil samples were collected at eight locations in Taiwan in 1984. The sampling sites are shown in Fig. 1. Climatic conditions and soil properties at each sampling location are shown in Table 1. As sweet potato is well adapted in drought and degraded soil, it is widely distributed from wet (3232 mm precipitation) to dry (1013 mm precipitation) places with a range of soil pH from 3.9 to 7.1. The soils are varied in texture.

All the sweet potatoes and their leaves and the soil samples (20 cm depth) were collected directly from the local farmers. Sweet potatoes, which were not peeled, and leaf samples were completely washed free of soil, then ashed below 450°C for 24 h. The soil samples were dried in a drying oven at 110°C for 24 h. Activity concentrations of $^{90}$Sr, $^{137}$Cs and $^{40}$K in these samples were determined by either radiochemical analysis or $\gamma$-ray spectrometry.

### 2.2. Radiochemical analysis of $^{90}$Sr and $^{137}$Cs

The radioactivity concentrations of $^{90}$Sr in storage roots, leaves and soil samples and those of $^{137}$Cs in plant samples were determined using the radiochemical methods (STA, 1976, 1983).

Small quantities of $HNO_3$ were added to 5 g of ashed plant samples or 100 g of soil samples after the addition of a given quantity of carrier solution ($Sr^{2+}$ : 50 mg, $Cs^{+}$ : 25 mg), and then evaporated to dryness. A small quantity of HCl was added to

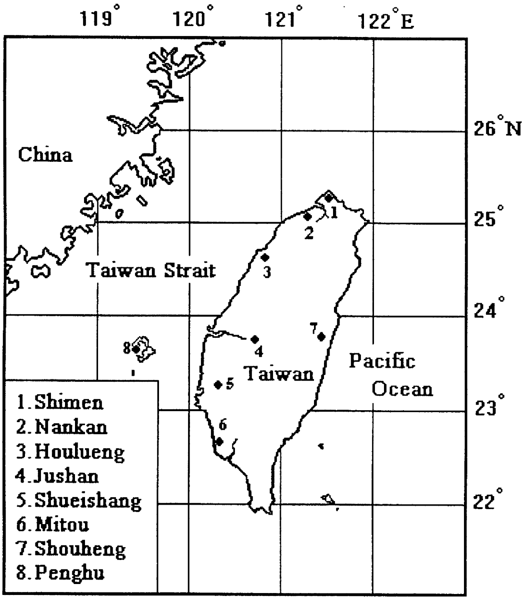

Fig. 1 Sampling sites.

the dried sample and heated to boiling. The solution was filtered and the residual was discarded. By adding 20 g of $Na_2CO_3$, $SrCO_3$ was precipitated at pH = 10–11 for $^{90}Sr$ determination. The supernatant solution was treated with ammonium molybrophosphate (AMP) to precipitate Cs for $^{137}Cs$ determination.

### *2.2.1. Analytical procedure for $^{90}Sr$*

$SrCO_3$ was dissolved in HCl and diluted to about 700 ml with water. 10 g of oxalic acid and then 6 M $NH_4OH$ were added to the solution until the pH was 4.2. The supernatant was decanted and the oxalate precipitate was dissolved in $HNO_3$. A volume of fuming $HNO_3$ (s.g. 1.52) equal to 3 times that of the solution was added. The system was cooled by ice-water for 4–5 h. The precipitate was filtered and dissolved in water. Any radioactive impurity was eliminated by scavenging on $BaCrO_4$ and $Fe(OH)_3$. After scavenging, $(NH_4)_2CO_3$ solution was added. $SrCO_3$ precipitate was filtered using a filter paper and dried at 50°C. The recovery of Sr was estimated by weighing $SrCO_3$. The $SrCO_3$ precipitate was then let to stand for 2 weeks to establish radioactive equilibrium between $^{90}Sr$ and $^{90}Y$. Then, the precipitate was dissolved in HCl, and $Fe^{3+}$ carrier, $NH_4Cl$ and $NH_4OH$ were added to coprecipitate $^{90}Y$ on $Fe(OH)_3$. The precipitate on filter paper was dried and subjected to $\beta$-counting using a low-background gas-flow-type proportional counter (CANBERRA Model 2404). The counting efficiency was 42%. The minimum detectable activities of $^{90}Sr$ are calculated to be 0.07 Bq $kg^{-1}$ fresh and 0.2 Bq $kg^{-1}$ dry for plant samples and soil samples, respectively.

Table 1
Soil properties and climatic conditions

| Site | Location | pH | Exchangeable cations ($\mathrm{cmol\,kg^{-1}}$ dried soil) | | | Organic matter (%) | Clay (%) | Texture | Soil type | Annual precipitation (mm) | Mean temperature (°C) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | K | Ca | CEC | | | | | | |
| 1 | Shimen | 3.9 | 0.48 | 0.13 | 22.1 | 10.09 | 47.6 | CL | Inceptisol | 3232 | 21.9 |
| 2 | Nankan | 4.1 | 0.27 | 0.82 | 10.7 | 4.39 | 39.5 | SiCL | Inceptisol | 1840 | 22.0 |
| 3 | Houlueng | 4.9 | 0.35 | 0.83 | 5.3 | 2.15 | 11.5 | LS | Inceptisol | 1717 | 22.0 |
| 4 | Jushan | 5.0 | 0.43 | 1.31 | 6.5 | 2.19 | 14.2 | SL | Inceptisol | 2094 | 24.1 |
| 5 | Shueishang | 4.7 | 0.29 | 2.08 | 9.6 | 2.41 | 22.8 | L | Inceptisol | 1779 | 22.6 |
| 6 | Mituo | 5.8 | 0.36 | 2.18 | 7.4 | 1.71 | 15.5 | SL | Alfisol | 1732 | 24.3 |
| 7 | Shouheng | 5.3 | 0.51 | 3.20 | 16.7 | 2.90 | 24.2 | L | Inceptisol | 2059 | 22.7 |
| 8 | Penghu | 7.1 | 0.14 | 5.33 | 8.5 | 1.35 | 9.8 | LS | Alfisol | 1013 | 22.9 |

### 2.2.2. Analytical procedure for $^{137}$Cs

The precipitate of molybrophosphate was dissolved with NaOH and the pH was adjusted to 8.2 by adding HCl in the presence of 10 ml of EDTA-4Na solution (50 w/v%). The solution was passed through an ion exchange resin column (Muromac C-3, 100–200 mesh), and then rinsed with 100 ml water and 1500 ml HCl (3 + 197). The adsorbed Cs was then stripped out with 300 ml HCl (1 + 5). Finally, the precipitate of $^{137}$Cs formed by adding $H_2(PtCl_6)$ solution was filtered. The recovery of Cs was calculated by weighing the dried $Cs_2(PtCl_6)$. The precipitate on the filter paper was then subjected to $\beta$-ray activity measurement using a low-background gas-flow proportional counter (CANBERRA Model 2404). The counting efficiency was 30% The minimum detectable activity of $^{137}$Cs is calculated to be 0.1 Bq $kg^{-1}$ fresh for plant samples.

## 2.3. Gamma spectroscopy

The activity concentrations of $^{137}$Cs and $^{40}$K in soil samples and those of $^{40}$K in plant samples were determined by $\gamma$-ray spectrometry (STA, 1979).

The $\gamma$-ray spectrometry system was based on a pure Ge detector (CANBERRA GC-4020, FWHM 1.82 keV at 1.33 MeV) coupled to a computerized data acquisition system (CANBERRA Series 95, 4096-channel pulse height analyzer). About 1.5 kg of soil sample and about 50 g of ashed plant samples (3 kg fresh weight) were measured in a cylindrical acrylic container (130 mm$\phi$, 90 mmH) that was placed directly on the detector. The counting time was 80,000 s. The efficiency calibration was carried out using a standard multi-$\gamma$-ray source mixed in agar. The minimum detectable activity of $^{137}$Cs is calculated to be 0.33 Bq $kg^{-1}$ dry for soil samples.

## 2.4. General chemical analyses

Soil pH was measured in 1:2 of soil/water ratio with a glass electrode pH meter. The organic matter content of soil was estimated from the ignition loss at 430°C for 24 h (Davies, 1974). Evaluation of cation exchange capacity (CEC) and exchangeable bases of soil was determined by the method of Schollenberger and Simon (1945). For elemental analysis, soil samples were digested with concentrated $HNO_3$ and HF in Teflon vessels (Lim & Jackson, 1982) with the aid of Parr microwave digestion bombs. An aliquot was determined for Na and K with a flame photometer (Corning 410). Ca and Mg were determined with an atomic absorption spectrophotometer (Perkin-Elmer 2380).

# 3. Results

The activity concentrations of $^{90}$Sr and $^{137}$Cs in soil, storage roots and the leaves of sweet potatoes are shown in Table 2. The transfer factors (TFs) for storage roots and

Table 2
The activities and transfer factors of $^{90}$Sr and $^{137}$Cs from soil to storage roots or leaves of sweet potato

| Site | Location | Activity of $^{90}$Sr | | | | | TR |
|---|---|---|---|---|---|---|---|
| | | Soil (Bq kg$^{-1}$ dry) | Storage root | | Leaf | | |
| | | | (Bq kg$^{-1}$ fresh) | TF | (Bq kg$^{-1}$ fresh) | TF | |
| 1 | Shimen | 2.63 | 2.76 | 1.05 | 6.96 | 2.65 | 0.40 |
| 2 | Nankan | 0.39 | 0.17 | 0.44 | 1.39 | 3.56 | 0.12 |
| 3 | Houlueng | 0.96 | 0.61 | 0.64 | 0.69 | 0.72 | 0.88 |
| 4 | Jushan | 0.23 | 0.14 | 0.61 | 0.43 | 1.87 | 0.33 |
| 5 | Shueishang | 0.74 | 0.07 | 0.09 | 0.13 | 0.18 | 0.54 |
| 6 | Mituo | 0.20 | 0.07 | 0.35 | 0.20 | 1.00 | 0.35 |
| 7 | Shouheng | 0.37 | 0.39 | 1.05 | 0.27 | 0.73 | 1.44 |
| 8 | Penghu | 0.39 | 0.05 | 0.13 | 0.14 | 0.36 | 0.36 |
| | Mean | | | 0.55 ± 0.37 | | 1.38 ± 1.20 | 0.55 ± 0.39 |

| Site | Location | Activity of $^{137}$Cs | | | | | TR |
|---|---|---|---|---|---|---|---|
| | | Soil (Bq kg$^{-1}$ dry) | Storage root | | Leaf | | |
| | | | (Bq kg$^{-1}$ fresh) | TF | (Bq kg$^{-1}$ fresh) | TF | |
| 1 | Shimen | 39.60 | 1.32 | 0.033 | 1.17 | 0.030 | 1.13 |
| 2 | Nankan | 4.02 | 0.24 | 0.060 | 0.32 | 0.080 | 0.75 |
| 3 | Houlueng | 2.93 | 0.12 | 0.041 | 0.18 | 0.061 | 0.67 |
| 4 | Jushan | 2.62 | 0.24 | 0.092 | 0.26 | 0.099 | 0.92 |
| 5 | Shueishang | 2.36 | 0.07 | 0.030 | 0.10 | 0.042 | 0.70 |
| 6 | Mituo | 1.02 | 0.37 | 0.363 | 0.42 | 0.412 | 0.88 |
| 7 | Shouheng | 4.11 | 0.33 | 0.080 | 0.27 | 0.066 | 1.22 |
| 8 | Penghu | 2.52 | 0.15 | 0.060 | 0.12 | 0.048 | 1.25 |
| | Mean | | | 0.095 ± 0.111 | | 0.105 ± 0.126 | 0.94 ± 0.23 |

leaves in Table 2 are calculated according to the following formula:

$$\mathrm{TF} = \frac{\text{Activity concentration in plant } (\mathrm{Bq\,kg^{-1}} \text{ fresh})}{\text{Activity concentration in soil } (\mathrm{Bq\,kg^{-1}} \text{ dry})} \tag{1}$$

The mean TFs of $^{90}$Sr and $^{137}$Cs from soil to storage root are 0.55 and 0.095, respectively, and the mean TFs of $^{90}$Sr and $^{137}$Cs from soil to leaves are 1.38 and 0.105, respectively.

Table 3 shows the concentrations of $^{40}$K and Ca together with TFs. For $^{40}$K, TFs were calculated by Eq. (1), and for Ca, by the following formula:

$$\mathrm{TF(Ca)} = \frac{\text{Concentration in plant } (\mathrm{g\,kg^{-1}} \text{ fresh})}{\text{Concentration in soil } (\mathrm{g\,kg^{-1}} \text{ dry})} \tag{2}$$

The mean TFs of Ca and the primordial radionuclide $^{40}$K from soil to storage root are 0.25 and 0.25, respectively, while those from soil to leaves are 1.93 and 0.26, respectively.

For comparison of the distribution of radionuclides in sweet potato, the translocation ratios (TRs), which are defined as Eq. (3)

$$\mathrm{TR} = \frac{\text{TF for soil to storage root}}{\text{TF for soil to leaf}} \tag{3}$$

are also listed in Tables 2 and 3.

It is evident that $^{90}$Sr is more concentrated in the leaves than in the storage root, and the mean value of the activity ratio (storage root/leaf) of $^{90}$Sr is 0.55. The uptake and translocation of Ca in sweet potato seem similar to $^{90}$Sr, giving the value of 0.21 (Table 3). On the contrary, $^{137}$Cs and $^{40}$K distribute more homogenously in both storage roots and leaves, giving mean values of TR for $^{137}$Cs and $^{40}$K of 0.94 and 1.00, respectively.

In contrast to the large fluctuation in activity concentrations of $^{90}$Sr and $^{137}$Cs, the level of $^{40}$K seems to fluctuate within a narrow range, and the activity concentration of $^{40}$K is generally much higher than those of the artificial radionuclides, $^{90}$Sr and $^{137}$Cs, in storage roots and leaves.

## 4. Discussion

### 4.1. Translocation of radionuclides in the plant

Cs has been reported to show a high degree of mobility in plants (Van der Borght, Kirchmann, van Puymbroek & Fagniart, 1967). Some evidence indicates that absorbed $^{137}$Cs can be redistributed throughout the plant to reproductive structures and storage organs (Koranda & Robison, 1978). Coughtrey and Thorne (1983) summarized that the TR of root crops is approximately for 0.67. The value is very close to our results for sweet potato, ranging from 0.67 to 1.25, in Table 2.

Table 3
Concentrations and transfer factors of K and Ca from soil to storage roots and leaves of sweet potato

| Site | Location | Concentration of Ca | | | | | TR |
|---|---|---|---|---|---|---|---|
| | | Soil (g kg$^{-1}$ dry) | Storage root | | Leaf | | |
| | | | (g kg$^{-1}$ fresh) | TF | (g kg$^{-1}$ fresh) | TF | |
| 1 | Shimen | 1.88 | 0.12 | 0.06 | 1.14 | 0.61 | 0.11 |
| 2 | Nankan | 0.39 | 0.10 | 0.26 | 1.66 | 4.23 | 0.06 |
| 3 | Houlueng | 1.00 | 0.16 | 0.16 | 2.13 | 2.13 | 0.08 |
| 4 | Jushan | 0.62 | 0.12 | 0.19 | 1.67 | 2.68 | 0.07 |
| 5 | Shueishang | 0.93 | 0.18 | 0.19 | 2.99 | 3.21 | 0.06 |
| 6 | Mituo | 1.09 | 0.44 | 0.40 | 1.16 | 1.06 | 0.38 |
| 7 | Shouheng | 2.21 | 1.43 | 0.65 | 1.83 | 0.83 | 0.78 |
| 8 | Penghu | 4.89 | 0.49 | 0.10 | 3.46 | 0.71 | 0.14 |
| | Mean | | | 0.25 ± 0.19 | | 1.93 ± 1.35 | 0.21 ± 0.25 |
| Site | Location | Activity of $^{40}$K | | | | | TR |
| | | Soil (Bq kg$^{-1}$ dry) | Storage root | | Leaf | | |
| | | | (Bq kg$^{-1}$ fresh) | TF | (Bq kg$^{-1}$ fresh) | TF | |
| 1 | Shimen | 488 | 75 | 0.15 | 123 | 0.25 | 0.61 |
| 2 | Nankan | 305 | 88 | 0.29 | 93 | 0.30 | 0.95 |
| 3 | Houlueng | 301 | 104 | 0.35 | 82 | 0.27 | 1.27 |
| 4 | Jushan | 405 | 70 | 0.17 | 108 | 0.27 | 0.65 |
| 5 | Shueishang | 464 | 137 | 0.30 | 188 | 0.41 | 0.73 |
| 6 | Mituo | 485 | 50 | 0.10 | 56 | 0.12 | 0.89 |
| 7 | Shouheng | 449 | 130 | 0.29 | 80 | 0.18 | 1.63 |
| 8 | Penghu | 414 | 138 | 0.33 | 105 | 0.25 | 1.31 |
| | Mean | | | 0.25 ± 0.09 | | 0.26 ± 0.09 | 1.00 ± 0.36 |

The content of Ca was found to be significantly greater in the tips and older leaves than in the stem petioles (Pace, Dull & Phills, 1985). Woolfe (1992) indicates that sweet potato tops are potentially much richer sources of Ca than the roots, and than other non-leafy vegetables. Translocation of Ca in sweet potato could explain the lower content of $^{90}$Sr, which has the chemical similarity with Ca, in root than that in leaf.

Compared with the well-documented studies on potatoes, very few studies have been concerned with the uptake and translocation of radionuclides in sweet potatoes. In root vegetables (excluding potatoes), root/shoot ratios of $^{90}$Sr are generally less than unity, and a value of 0.3 may be considered representative. Very small amounts of Sr enter potato tubers and the tuber/foliage ratio is as low as 0.02–0.04 (Coughtrey & Thorne, 1983). The potato is taxonomically and anatomically different from the sweet potato. It appears also that there is a discrepancy in nutritional characteristics between these two crops. The root/leaf ratios of sweet potato in Table 2 ranged at 0.12–1.44, which is similar to those for the above-mentioned root vegetables rather than for potatoes.

### 4.2. *Effect of environmental factors on the uptake of radionuclides*

The activities of $^{90}$Sr and $^{137}$Cs in the soils showed highest values in the north than in other places (Table 2). In agreement with our other investigation in the forest ecosystem (Chiu, Lai, Lin & Chiang, 1999a, Chiu, Lai, Wang & Lin, 1999b), this effect would be attributed to the site receiving the highest precipitation particularly in the winter monsoon from the Asian continent which brought with it the nuclear fallout of the 1960s more than to other areas. The results in Table 2 showed that the higher values of radioactivity of the soil contribute, but not always to higher plant uptake. Some inconsistency in the activity between the soil and plant uptake could be due to soil factors.

Soil moisture associated with the mass flow of the elements has been reported to be an important factor controlling the bioavailability of radionuclides (Coughtrey & Thorne, 1983). Soil moisture would play a key factor in the mass flow and the subsequent uptake of $^{90}$Sr by sweet potato because its production is seldom irrigated. Lack of irrigation was considered as a major motivation for growing sweet potato in Taiwan (Calkins, Huang & Hang, 1977). This is the reason for the highest uptake of $^{90}$Sr by sweet potato at the wettest site 1 and the lowest at the driest site 8. However, some discrepancies of uptake of $^{90}$Sr by the plant could be due to leaching — a reciprocal effect of the rainfall on the retention and accumulation of $^{90}$Sr in the soil. Leaching depletes the availability of $^{90}$Sr and results in the low TF of $^{90}$Sr from soil to the plant.

Sr uptake by plants is closely related to Ca availability in soil (Abbazov, Dergunov & Mikulin, 1978). Hence the uptake of Sr decreases as exchangeable Ca increases as a result of competition between those two cations. It supports the low TF of $^{90}$Sr at sites 5, 6 and 8 where soil has relatively high amounts of exchangeable Ca. Particularly, Sr availability is reduced at site 8 with its high soil pH.

On the other hand, the uptake of Sr by plants from soils is influenced by the degree and form of the organic matter content in soil (Abbazov et al., 1978). The TF of $^{90}$Sr in Table 2 is basically related to the factors of soil organic matter and the above-mentioned climate conditions. A high uptake and associated high TFs of $^{90}$Sr in the storage root and leaf were found at sites 1 and 2 where the organic matter contents are high. Similarly, it is apparent that the compositions of clay and organic matter in soils as well as their total contents have a complex effect on $^{137}$Cs availability and subsequent uptake by plants. The TFs of $^{137}$Cs showed an independence of organic matter and climate conditions. An extraordinary high value was found at site 6. The high availability of $^{137}$Cs is probably due to its sandy texture containing little clay to fix $^{137}$Cs in the soil.

Soil pH has little effect on plant $Cs^+$ uptake (Bergeijk, Noordijk, Lembrechts & Frissel, 1992). It is well accepted that the presence of elevated $K^+$ concentration in soils can result in markedly lower levels of uptake (Coughtrey & Thorne, 1983). On the contrary, the $^{137}$Cs uptake could be accounted for by K deficiency in the soil, particularly in the place where the soil K is depleted either naturally or by continuous cropping. Under such conditions, the uptake of Cs will be greater than in K-rich soils (Coughtrey & Thorne, 1983). However, due to the intensive cropping system, there is generally excessive use of fertilizer, including K in Taiwan (Calkins et al., 1977). The abundance of K in such soils would result in the reductions of $^{137}$Cs uptake and the subsequent TF away from the simple pattern of environmental factors which control the Cs uptake.

The TFs for Ca and K are inconsistent with those for $^{90}$Sr and $^{137}$Cs, respectively. This would be due to the competition between those cations, which results from their concentration and/or the soil factors controlling availability in the soil.

Nevertheless, the TFs for Ca and $^{90}$Sr seem to be similar, compared with the TFs between K and $^{137}$Cs. The TF for K is two orders higher than that for $^{137}$Cs. The discrepancy might be attributed to the incidental characteristics rather than the interaction caused by other elements.

Table 4
The TFs of sweet potato, potato, leafy vegetable and crops published by various organizations

| Organizations | Crops | $^{90}$Sr | $^{137}$Cs |
|---|---|---|---|
| Taiwan RMC (This study) | Storage root (sweet potato) | $9 \times 10^{-2}$–1.05 | $2.97 \times 10^{-2}$–$3.63 \times 10^{-1}$ |
| | Leaves (sweet potato) | $1.8 \times 10^{-1}$–3.56 | $2.95 \times 10^{-2}$–$4.12 \times 10^{-1}$ |
| Japan RWMC (1994)[a] | Tubers (potato) | $1.2 \times 10^{-2}$–$2.6 \times 10^{-2}$ | $1.3 \times 10^{-3}$–$6.9 \times 10^{-3}$ |
| | (white potato) | | $4.0 \times 10^{-3}$–$6.1 \times 10^{-2}$ |
| | (sweet potato) | | $6.3 \times 10^{-3}$–$6.4 \times 10^{-2}$ |
| | (taro) | | $2.0 \times 10^{-3}$–$2.1 \times 10^{-2}$ |
| IAEA (1994) | Tubers (potato) | $4.2 \times 10^{-3}$–$5.5 \times 10^{-2}$ | $1.5 \times 10^{-2}$–$5.7 \times 10^{-2}$ |
| IUR (1984–1992) | Tubers (potato) | $2.0 \times 10^{-2}$–$3.3 \times 10^{-1}$ | $6.0 \times 10^{-3}$–$8.3 \times 10^{-2}$ |
| CEC (1979) | Root vegetables | $6 \times 10^{-2}$ | $5 \times 10^{-3}$ |
| | Leafy vegetables | $7 \times 10^{-1}$ | $2 \times 10^{-2}$ |
| NCRP (1984) | Edible parts of crops | $1.6 \times 10^{-3}$–1.7 | $1.5 \times 10^{-5}$–$2.9 \times 10^{-1}$ |
| IAEA (1987) | Edible parts of crops | $3.0 \times 10^{-1}$ | $3.0 \times 10^{-2}$ |
| U.S. DOE (1984) | Vegetables, fruits | $2.9 \times 10^{-1}$ | $1.1 \times 10^{-2}$ |

[a] The values in this publication are compiled from two published papers, Stoutjesdijk, Desmet, Pennders, Sibbel, Sinnaeve and van Ginkel (1983) and Okajima, Shimasaki and Kubo (1990).

Certain clay minerals are known to adsorb monovalent cations and the adsorption of K is much smaller than Cs (Brouwer, Baeyers & Maes, 1983). The higher adsorption strength of Cs reduces the availability of Cs for uptake by plant and thus the TF values.

On the other hand, the cultivar may play a minor part in affecting concentrations of such minerals compared with external factors. Villareal, Tsou, Lin and Chiu (1979) have reported that no significant difference in Ca content was noted for 10 cultivars grown under the same conditions in one Taiwanese location.

In short, the results indicate that no single factor can cover all sampling sites with any specific criterion. The environmental factors might have a complex effect on the bioavailability and the subsequent uptake by sweet potato.

For the purpose of comparison, the transfer factors of tubers, leafy vegetables and crops published by various organizations are listed in Table 4 together with those obtained in this work. Sweet potato in Taiwan has larger transfer factors for both $^{90}$Sr and $^{137}$Cs than sweet potato, tubers (potato) in Japan (Japan RWMC, 1994; IUR, 1992; IAEA, 1994) and other root vegetables (CEC, 1979). We suppose that the differences might come from the complex effect of environmental factors as mentioned above. However, the transfer factors of sweet potato for both $^{90}$Sr and $^{137}$Cs are still in good agreement with those of vegetables, fruits, grains (U.S. DOE, 1984), and edible parts of crops (NCRP, 1984; IAEA, 1987).

### *4.3. Annual effective dose equivalent*

For the purpose of assessing the effective dose equivalent due to the dietary intake of $^{90}$Sr and $^{137}$Cs through sweet potato in Taiwan, the mean activity concentrations of $^{90}$Sr and $^{137}$Cs in sweet potato and the annual consumption per capita in Taiwan are listed in Table 5. As the mean activity concentrations of $^{90}$Sr and $^{137}$Cs in sweet potato calculated from Table 2 are 0.53 and 0.36 $\mathrm{Bq\,kg^{-1}}$, and the annual consumption of sweet potato in Taiwan is 5.06 $\mathrm{kg\,yr^{-1}}$, the annual intakes of $^{90}$Sr and $^{137}$Cs from ingestion of sweet potato per capita in Taiwan are calculated to be 2.68 and 1.82 $\mathrm{Bq\,yr^{-1}}$, which are about 20.6 and 3.03% of the annual intake of $^{90}$Sr (13 $\mathrm{Bq\,yr^{-1}}$) and $^{137}$Cs (60 $\mathrm{Bq\,yr^{-1}}$) from the main foodstuffs in Taiwan (Wang, Lai, Huang & Lin, 1996), respectively. Therefore, the effective dose equivalents received by individuals from the ingestion of sweet potato containing $^{90}$Sr and $^{137}$Cs are calculated to be only $9.38\times10^{-8}$ and $2.37\times10^{-8}$ $\mathrm{Sv\,yr^{-1}}$ using the dose conversion factor of $3.5\times10^{-8}$ and $1.3\times10^{-8}$ $\mathrm{Sv\,Bq^{-1}}$ for $^{90}$Sr and $^{137}$Cs, respectively (ICRP, 1989). For comparison with nearby regions, the effective dose equivalent received by Taiwanese ($9.38\times10^{-8}$ $\mathrm{Sv\,yr^{-1}}$) from the ingestion of $^{90}$Sr in sweet potato is larger than that received by Japanese ($6.65\times10^{-9}$ $\mathrm{Sv\,yr^{-1}}$), but is less than that received by Jiangxians in mainland China ($7.25\times10^{-7}$ $\mathrm{Sv\,yr^{-1}}$) from the ingestion of red potato. Besides, in Table 5, we can also find that the effective dose equivalent received by Taiwanese ($2.37\times10^{-8}$ $\mathrm{Sv\,yr^{-1}}$) from the ingestion of $^{137}$Cs in sweet potato is also larger than that received by Japanese ($4.29\times10^{-9}$ $\mathrm{Sv\,yr^{-1}}$) from the ingestion of sweet potato.

Because no information on the annual yield of sweet potato leaves is available in Taiwan, the effective dose equivalents of $^{90}$Sr and $^{137}$Cs through the intake of sweet

Table 5
Annual intakes of sweet potato by Taiwanese and Japanese and of red potato by Jiangxians (Mainland China), respectively

| | $^{90}$Sr | $^{137}$Cs |
|---|---|---|
| Taiwanese (sweet potato) | | |
| Mean activity (Bq kg$^{-1}$) | 0.53 | 0.36 |
| Consumption (kg yr$^{-1}$)[a] | 5.06 | 5.06 |
| Annual intake (Bq yr$^{-1}$) | 2.68 | 1.82 |
| Dose equivalent (Sv yr$^{-1}$) | $9.38 \times 10^{-8}$ | $2.37 \times 10^{-8}$ |
| Japanese (sweet potato)[b] | | |
| Radioactivity (Bq kg$^{-1}$) | 0.053 | 0.093 |
| Consumption (kg yr$^{-1}$) | 3.58 | 3.58 |
| Annual intake (Bq yr$^{-1}$) | 0.19 | 0.33 |
| Dose equivalent (Sv yr$^{-1}$) | $6.65 \times 10^{-9}$ | $4.29 \times 10^{-9}$ |
| Jiangxians (red potato)[c] | | |
| Mean activity (Bq kg$^{-1}$) | 1.45 | — |
| Consumption (kg yr$^{-1}$) | 14.3 | — |
| Annual intake (Bq yr$^{-1}$) | 20.7 | — |
| Dose equivalent (Sv yr$^{-1}$) | $7.25 \times 10^{-7}$ | — |

[a] Council of Agriculture, R.O.C. (1995).
[b] Abukawa et al. (1998).
[c] Radiological Health Group, Jiangxi Institute of Industrial Hygiene (1987).

potato leaves cannot be estimated in this study, although certain amounts of $^{90}$Sr and $^{137}$Cs were found in the leaves.

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