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ARTICLE

Study on the Reference Plants for the Assessment of Radiation Impact on Non-Human Species in Southwest of China

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This paper introduces the researches on terrestrial reference plants in a area of southwest of China, including selection of candidate reference plants, the description of geometric characteristics, and the transfer factors of ^{90}Sr, ^{137}Cs, and Pu in plants. The plant species involved are 2 trees (*Firmiana simplex, Cryptomeria fourtunei*), 2 shrubs (*Nerium indicum Mill, Vitex negundo Linn*), and 1 herb (*Artemisia umbrosa*). Expected values of the soil-to-plant transfer factors are provided. Further researches on radiation protection of non-human species in China are discussed.

KEYWORDS: non-human species, reference plants, ^{90}Sr, ^{137}Cs, Pu, transfer factors

I. Introduction

The aim of ionizing radiation protection is not only to protect people and to protect non-human species as well. This change of concept has made the development of a framework for radiation protection of non-human species in urgent need.

The framework including reference organisms, an agreed set of quantities and units, a set of reference dose models, and reference dose-per-unit-intake data are discussed in ICRP Publication 91[1)]. The Commission is developing a set of reference fauna and flora, plus their relevant databases—in a manner similar to that of Reference Man[2)].

The impact assessment of radioactive effluents from nuclear facilities on ecological environment is requested in Chinese environmental codes and regulations, but the framework for assessing the impact of ionizing radiation on non-human species in China is not yet established.

The researches of reference plants are conducted in an area in southwest of China, where located a decommissioned anuclear facility. Through field investigation in the environment, the candidate reference pants are selected, the geometric characteristics of the plants are measured, the radioactivity of ^{90}Sr, ^{137}Cs and Pu are analyzed, and the transfer factors for the plants (Bv) are calculated.

II. Materials and methods

In order to select reference plant, in a area of Sichuan province, the southwest of China, plant quadrat investigations are conducted, 5 different plant species are selected as candidate reference plants. The transfer of ^{90}Sr, ^{137}Cs, and Pu from soil to plant (organs) is studied in field.

1. Selection of reference plants

The vegetation of the area is flourishing. Plant quadrat investigations are conducted to select reference plant in the area. There are 3 forest land quadrats, 2 shrub land quadrats and 1 grass land quardrat made in the area. Through plant quadrat investigation, dominant species are identified. For forest land, the dominant species are *Melia toosendan, Firmiana simplex, Quercus variabilis Bl. and Nerium indicum Mill*. For shrub land, the dominant species are *Cotoneaster horizontalis Decne, Compositae Asteraceae, Vitexnegundo L. Var. cannabifolia* and *Rosales*. For grass land, the dominant species are *Plantago asiatica L., Artemisia annua L., Filipendula palmata (Pall.) Maxim.* and *Leontopodium*.

Considering public understanding and environmental monitoring data available for the plants, a phoenix tree *(Firmiana simplex)* and a cryptomeria *(Cryptomeria fourtunei)* are selected for candidate reference plants of tree, a rosebay *(Nerium indicum Mill)* and a chaste tree *(Vitex negundo Linn)* as candidate reference plants of shrub, and a moxa *(Artemisia umbrosa)* as candidate reference plant of herb respectively. The plant and soils in root depth are sampled. The geometric characteristics of plants are measured. To obtain statistic transfer data, each plant species and paired soils are gathered in 5 different sampling points.

2. Sampling procedure and preparation of analytical methods

The samples are taken in the environment around a nuclear facility which was decommissioned some years ago. The radionuclides are from former release of the facility in the 1970s.

The plant and soil samples are collected simultaneously. Soil samples are randomly taken from root depth.

For ^{90}Sr and Pu analysis, plant samples are dried at 105℃, carbonized by electric stove, and passed ashing in muffle at 450℃, then the ash is ready for analysis. The soil samples are dried at 100℃, grind into powder and then pass through 2mm sieve, ready for analysis.

For ^{137}Cs analysis, plant samples are dried by oven at 105℃, and then grind into powder for analysis. Soil samples are air-dried naturally for 7days and then pass through 2mm sieve.

^{137}Cs is measured by S-95 γ Spectrometry (made in USA by CANBERRA Company). The relative measuring efficiency of the spectrometry is 35%. The detection limit for both plant and soil samples are 0.01Bq/kg dry weight.

^{90}Sr is measured by radio-chemical analysis followed by oxalate precipitation, HDEHP chromatograph and β count

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for plant samples(with detection limit 0.04Bq/kg dry plant), and Leaching with HCl (6.0mol/L), cation exchange, β count for soil samples (with detection limit 0.01Bg/kg dry soil).

Pu is measured by Extraction chromatography, β count for plant samples and Leaching with chlorazotic acid, cation exchange, and β count for soil samples. The detection limit is 0.015Bq/kg dry weight.

For each Bv data, 5 replica plant and soil samples are collected.

The research was conducted in a area in the suburbs of Guangyuan city, Sichuan Province, where located a decommissioned nuclear facility. The climate is sub-tropical and humid. The local soil is purplish soil. The physical and chemical parameters of the soil in the area are determined. Following parameters are considered: pH (in water), organic carbon content (%), exchangeable K in soil (cmol(+)/kg), exchangeable Ca in soil (cmol(+)/kg), CEC and etc.

The physical and chemical parameters of soil are listed in **Table 1**.

Table 1 The physical and chemical parameters of soil

Soil properties	Values
pH (in water)	7.4
CEC（cmol/kg soil）	16.4
E（K^+）（cmol/kg soil）	0.47
E（Ca^{++}）（cmol/kg soil）	5.95
Org. Carbon（%）	4.3
Density of soil（kg dry weght/m^3）	1650
Effective aerial density（kg dry weight/m^2）	168

3. Geometric characteristics of the plants

Geometric characteristics of plants are necessary for establishment of dose assessment models. Tree truck can be simplified as a cylinder. For trees, the height, diameter at chest height (the diameter measured at 1.2m's high of the tree) and the tree crown area (length × width) are measured. Tree leaf and branch samples are collected separately.

For shrubs, the height, diameter at chest height, and crown area (length × width) are measured. The leaf and branch of plants are collected as samples separately.

For herb, the height of grass is measured, and aerial parts of the plant are gathered as samples.

The geometric parameters of trees and shrubs are listed in **Table 2**.

The diameter and the crown area of *Firmiana simplex* are much higher than that of *Cryptomeria fourtunei*. But the height of the 2 trees is quite similar. For shrubs, the diameter and the height of *Nerium indicum Mill* are higher that of *Vitex negundo Linn*. The crown area of *Vitex negundo Linn* is relatively large, for this plant generally grows in large population.

The herb collected is *Artemisia umbrosa*. The average height is 0.76m, which is randomly measured from 10 plants, and the vegetation mass per unit area is about 0.05kg/m^2. The herb is typical in local area, for obtaining enough mass for sample (some 8 kg of fresh weight is needed for radioactivity analysis), each sample needs about 160 m^2 grass land area.

Table 2 Geometric characteristics of trees and shrubs

Plant	Diameter* (m)	Height (m)	Crown area (length×width, m^2)
Firmiana simplex	1.05	10.2	6.9×6.2
Cryptomeria fourtunei	0.64	9.8	3.1×3.2
Nerium indicum Mill	0.11	4.2	3.3×3.7
Vitex negundo Linn	0.07	2.5	11.4×2.4

Note："*" Diameter at chest height of 1,2 m.

III. Soil to plant transfer factors of reference plants

Ash to fresh weight conversion factors of the plants are important information for the application of transfer factors, and related data of plant samples (organs) are showed in **Table 3**.

Table 3 Ash-to-fresh weight conversion factors for plant samples

Unit: g ash weight/g fresh weight

Plant	Sampling parts	N	Ash-to-fresh weight conversion factors
Firmiana simplex	Leaves	5	3.27E-02±2.54E-03
	Branches	5	1.33E-02±1.47E-03
Cryptomeria fourtunei	Leaves	5	3.84E-02±5.67E-03
	Branches	5	1.67E-02±3.10E-03
Nerium indicum Mill	Leaves	5	2.97E-02±1.36E-03
	Branches	5	1.75E-02±1.56E-03
Vitex negundo Linn	Leaves	5	3.28E-02±1.12E-03
	Branches	5	9.90E-03±4.14E-04
Artemisia umbrosa	Aerial parts	5	2.15E-02±1.22E-03

Note:"*" Data is given as (Average ± Standard deviation).

The soil to plant transfer factor (Bv) is generally defined by International Union of Radioecologists (IUR) as the concentration of radionuclide in the plant (organs), on a dry or wet weight basis, divided by that in soil in dry weight basis. The Bv values of ^{90}Sr, ^{137}Cs, and Pu for the candidate reference plants are provided in Table 4~6, respectively.

For ^{90}Sr (see **Table 4**), the Bv of the plants are generally in the same order. The Bv of *Cryptomeria fourtunei* leaves and *Nerium indicum Mill* branches are relatively higher among the plants investigated. The Bv of *Vitex negundo Linn* branches are relatively lower. It can be seen from Table 4 that for *Cryptomeria fourtunei* and *Vitex negundo Linn*, the Bv of leaves are higher than that of its branches for the same species, and for *Firmiana simplex* and *Nerium indicum Mill*, the Bv of branches are higher than that of its leaves.

For ^{137}Cs (see **Table 5**), the Bv values of leaves are generally higher than that of branches for the plant species investigated (except for herb which is sampled as aerial parts). This tendency is quite different from the results of ^{90}Sr. It can be seen in tables 8 that Bv values of branches of *Nerium indicum Mill* and *Vitex negundo Linn* are relatively lower in comparison with other plant samples.

For Pu (see **Table 6**), the Bv of *Nerium indicum Mill* branches and *Cryptomeria fourtunei* leaves are about 1 order's higher than that of other plants. The Bv of *Vitex negundo Linn* leaves are relatively lower. For trees, there is tendency that Bv values of leaves are higher than that of branches for the same plant. But for shrubs it's various.

Table 4 Soil to plant transfer factors (Bv) of ^{90}Sr for plants

Unit：Bv:(Bq/kg fresh plant)/(Bq/kg dry soil)

Plant	Sampling parts	Expected Bv values*
Firmiana simplex	Leaves	4.11E-01±2.91E-01
	Branches	4.47E-01±5.57E-01
Cryptomeria fourtunei	Leaves	9.41E-01±1.33E+0
	Branches	4.95E-01±5.93E-01
Nerium indicum Mill	Leaves	4.13E-01±2.84E-01
	Branches	7.18E-01±1.21E+0
Vitex negundo Linn	Leaves	3.80E-01±4.82E-01
	Branches	1.96E-01±2.49E-01
Artemisia umbrosa	Aerial parts	4.33E-01±3.38E-01

Note:"*" Data is given as (Average ± Standard deviation). Sample numbers are 5 for plants.

Table 5 Soil to plant transfer factors (Bv) of ^{137}Cs for plants

Unit：Bv:(Bq/kg fresh plant)/(Bq/kg dry soil)

Plant	Sampling parts	Expected Bv values
Firmiana simplex	Leaves	7.71E-02±5.29E-02
	Branches	1.45E-02±1.12E-02
Cryptomeria fourtunei	Leaves	4.93E-02±3.87E-02
	Branches	2.09E-02±9.68E-03
Nerium indicum Mill	Leaves	3.45E-02±3.55E-02
	Branches	6.53E-03±5.34E-03
Vitex negundo Linn	Leaves	4.89E-02±7.46E-02
	Branches	5.96E-03±9.95E-03
Artemisia umbrosa	Aerial parts	1.11E-01±1.10E-01

See note of Table 4.

Table 6 Soil to plant transfer factors (Bv) of Pu for plants

Unit：Bv:(Bq/kg fresh plant)/(Bq/kg dry soil)

Plant	Organs	Expected Bv values*
Firmiana simplex	Leaves	7.25E-01±3.56E-01
	Branches	1.50E-01±1.48E-01
Cryptomeria fourtunei	Leaves	1.54E+0±1.55E+00
	Branches	3.51E-01±1.61E-01
Nerium indicum Mill	Leaves	2.32E-01±1.26E-01
	Branches	9.87E+0±1.97E+01
Vitex negundo Linn	Leaves	8.92E-01±7.41E-01
	Branches	9.05E-02±7.41E-02
Artemisia umbrosa	Aerial parts	3.32E-01±2.15E-01

See note of Table 4.

Ⅳ. Discussions and conclusion

1. Comparison with the data in literature

The soil to plant transfer factors (Bv values) of ^{90}Sr, ^{137}Cs and Pu in the literature are mostly drawn from field investigation, green house or growth chamber experiments in European countries contaminated by Chernobyl nuclear accident[3)~9)].

For ^{90}Sr, Bv values of natural plants in field conditions obtained in Sweden are in the range of 2.1E-03~22.9[3)], which are varied a lot depending on plant species. The Bv from herbs in forest land around Chernobyl in Russia are in 0.03~0.43[4)], and Bv of leaves are higher than that of branches for the same species. The Bv of Eucalyptus trees are in 3~43 in field conditions in Spain[5)]. The Bv of *Pinus picea* in Chernobyl contaminated area, French, are in 0.3~3[6)], which is similar to that of *Cryptomeria fourtunei* (Leaves: 0.06~3.24, branches: 0.06~1.39) of this research.

For ^{137}Cs, the Bv of wild plants in two different ecosystems from Belarus between 0.11~0.51[7)]. The Bv from pot experiments in Chernobyl contaminated field are between 0.04~0.41[8)]. The Bv from natural plants in coral soil from Marshall Islands (UAS) are between 10~23[9)].

For Pu, the Bv of *Nerium indicum Mill* is 0.35, which is similar to that of pine branches (0.7) but much higher than that of Larch branches(0.005) from the Chernobyl contaminated areas in Russia[4)].

The Bv values of ^{90}Sr and ^{137}Cs from wild plants are in a wide range, one important reason is that the origination of Bv data are various, including different soil types, plant species, and climate conditions.

Taranenko et al considered three vegetation layers for the dose assessment of plants, including height, mass per unit area, layer density etc.[10)]. The height (meters) used in the model is 9 for tree, 0.9 for shrub and 0.1 for herb. In this research, the height is 9.8~10.2m for tree, 2.5~4.2 for shrub, and 0.76m for herb. The height of tree is quite similar, but the height for shrub and herb are much higher than that of Taranenko[10)]. It's reasonable for the geometric characteristics of plants are varied with different ecosystems.

2 Conclusion

The impact assessment of radioactive effluents from nuclear facilities on ecological environment is requested in environmental impact assessment, but there is not a system for assessing the impact of ionizing radiation on non-human species in China at present. The transfer behavior of radionuclide in non-human species (animals and plants) is important basis for the dose assessment of ionizing radiation. The transfer behavior of ^{90}Sr, ^{137}Cs and Pu in local plant species are studied in an area of southwest of China. The plant species as candidate reference plants, including 2 tree species (*Firmiana simplex, Cryptomeria fourtunei*), 2 shrubs (*Nerium indicum Mill,Vitex negundo Linn*), and one herb (*Artemisia umbrosa*) are investigated. The geometric characteristics are measured for establishment of dose assessment models. Expected Bv values for the plants are provided. The results provide a basis for further study on reference plants and calculation of external and internal exposure of the plants in Southwest of China.

The following points have been considered:

(1) Due to enormous variability of plant species and habitats, the selection of reference organism is necessary. At first we need a set of reference plants of representative sizes for the basis further detailed consideration of assessment of exposures, such as tree, shrub and herb.

(2) Proper geometric models are needed for selected terrestrial reference organisms, e.g., the trunk and crown are approximately considered as simple three dimensional phantoms, for example, cylinder and cone.

(3) To meet the need for impact assessment of ionizing radiation of nuclear facilities on non human species in China, a simple and fast tool can be developed at first, where the

construction of nuclear power plants is fast.

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