JOURNAL OF RADIATION RESEARCH **10-3-4** 107-112 (Sept.-Dec. 1969)

# Radioecology of Cesium-137 and Strontium-90 in a Forest

YAMAGATA*, Noboru, MATSUDA**, Shunji and Morito CHIBA***

山県　登　　松田俊治　　千葉盛人

(Received, June 3 1969)

ABSTRACT

Quantitative distribution pattern of cesium-137 and strontium-90 was determined in a forest area after preliminary studies in different sites. Both radionuclides were found in the fallen leaves in the highest concentration and this fact can be reasonably explained by that the fall-out rates were the highest three years before this observation. About 80 and 63% of the total deposition respectively of cesium-137 and strontium -90 were found in the upper 5 cm layer of soil, 18 and 23% in the vegetation, of which 11.4 and 10.7% in the fallen leaves. Root absorption of strontium-90 by pine tree and shrub was considered at least two times higher than that of cesium-137.

## INTORODUCTION

Deposition and translocation of fall-out cesium-137 and strontium-90 have been studied extensively by many researchers in areas of agricultural interest, of plains and waters. Forest or mountainous area which covers more than 80% of the total land area of Japan has scarcely been studied in regard to the fall-out problem. This should be because of the insignificant direct contribution of the forest produces to the principal food chain of humans. However, indirect role of the forest area can not be neglected when the fate and distribution of deposited fall-out is under consideration.

## PRELIMINARY STUDY FOR CESIUM-137

A preliminary study for the distribution of cesium-137 in a pine tree (*Pinus*

* Department of Radiological Health, Institute of Public Health, Minato-ku, Tokyo.
** Kiriu College of Technology, Gunma University, Kiriu, Gunma Pref.
*** Japan Analytical Chemistry Research Institute, Itabashi-ku, Tokyo.

*densiflora*) was made at Agricultural Experiment Station, Niigata University, Muramatsu, Niigata Prefecture in July 1966.

The trunk of a pine tree was cut into pieces every ten centimeters and numbered from the base to the top. For example, No. 7 means the disk cut at 60 cm and 70 cm from the base. Three of the disks thus obtained, No. 7, 20 and 25, were divided into four concentric parts, respectively: the bark, outer, inner and center part of the wood. Twelve samples altogether were analyzed for cesium-137 content. There was found no significant differences of the potassium and cesium-137 contents due to the position along the height as well as the concentric division with only an exception of the bark. Therefore, the total content of cesium-137 in the trunk was calculated from the mean value for the nine analytical results by assuming the trunk as a cone geometrically. Other parts of the tree, *i. e.*, branch, leaves and root were respectively assumed homogenous in the distribution of potassium and cesium-137 and random sampling was made.

The result summarized in Table 1 shows that the highest concentration of cesium-137 is in the bark, about fourty times higher than in the wood (trunk). The concentration is similarly very low in the wood and in the root, intermediate in the branch and leaves. Of the total cesium-137 incorporated in a pine tree, 42% was in the bark, 30% in the branch, 19% in the leaves and only 5.7% and 3.9% was in the trunk and the root, respectively.

Interpretation of the incorporation of cesium-137 in plant has been well established, one of the two principal routes of incorporation being the root absorption and the other the aerial deposition on the plant surface.

The analytical data for potassium and cesium-137 shown in Table 2 can afford some knowledge on the fate of cesium-137 in a tree. Main part of the potassium in a tree should be supplied through the root absorption, while the main part of cesium-137 through the aerial deposition; this is because the root absorption of cesium is very small. Thus, the ratio of cesium-137 in picocuries to potassium in grams would show a variety of values according to the position of the tree.

Similar values of this ratio are observed in the root and different positions in the wood (trunk). The highest rotios are found in the bark, and still more cesium-137 is concentrated in the fallen leaves with respect to the potassium, the ratio being 16,500. The concentration of potassium in the fallen leaves is less than one tenth of that in fresh leaves in contrast to more than twice the concentration of cesium-137. This implies the cesium-137 in fallen leaves cannot be easily leached out as compared with the potassium. Fig. 1 visualizes the

**Table 1.** Distribution of $^{137}Cs$ in a pine tree (Niigata Pref., July 1966)

| Part | Weight kg | $^{137}Cs$ nCi | Concentration of $^{137}Cs$ nCi/kg |
|---|---|---|---|
| Bark | 2.1 | 14.1 | 6.73 |
| Trunk | 12.1 | 1.9 | 0.16 |
| Branch | 5.9 | 9.9 | 1.68 |
| Leaves | 3.3 | 6.3 | 1.91 |
| Root | 5.8 | 1.3 | 0.22 |
| Total | 29.2 | 33.5 | 1.15 |

**Table 2.** Different distribution of potassium and $^{137}Cs$ in a pine tree and its fallen leaves

| Part | K mg/kg fresh | $^{137}Cs$ pCi/kg fresh | $^{137}Cs$: K pCi/g |
|---|---|---|---|
| Root | 839 | 220 | 263 |
| Trunk (No. 7 a) | 252 | 89 | 353 |
| 〃 (No. 20 a) | 420 | 120 | 286 |
| 〃 (No. 20 b) | 358 | 103 | 280 |
| 〃 (No. 25 a) | 314 | 84 | 268 |
| Bark (No. 7) | 922 | 2730 | 2960 |
| 〃 (No. 20) | 1040 | 2630 | 2530 |
| 〃 (No. 25) | 1110 | 7880 | 7110 |
| Branch | 1850 | 1690 | 914 |
| Leaves | 3810 | 1860 | 489 |
| Fallen leaves | 246 | 4060 | 16500 |

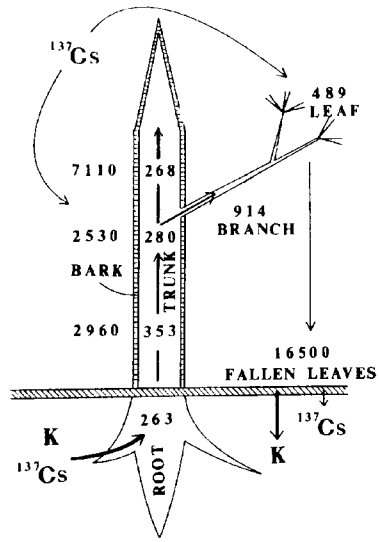


**Fig. 1.** Cycling of potassium and cesium-137 in a pine tree (Figures indicate pCi $^{137}Cs$/gK)

cycling of potassium and cesium-137 in a pine tree.

The enrichment of cesium-137 in the fallen leaves and probably in humus which is the decomposition product of the former might suggest a greater retention of fall-out cesium-137 in a forest soil than in cultivated or mineral soils.

Vertical distribution of cesium-137 was examined by use of a $\gamma$-spectrometric technique on a forest soil collected in Mt. Zaō which locates in the northern part of this country. The results are shown in Table 3. About 86% of the total deposition of cesium-137 to the depth of 20 cm located in the upper 5 cm layer which consited of half-decomposed and fresh fallen leaves. Comparison of the concentration of cesium-137 in the upper soil layer (fallen leaves) and fresh leaves taken from a several kinds of plant is shown in Table 4. The values are presented on different basis, but the aerial deposition on vegetation and the enrichment in the upper layer are clearly shown.

**Table 3.** Vertical distribution of $^{137}Cs$ in a forest soil
(Mt. Zaō, Miyagi Pref., Aug. 1966)

| Soil depth cm | $^{137}Cs$ nCi/m² | Percent of total | |
|---|---|---|---|
| 0—2* | 426 | 59.1 | 85.5 |
| 2—5* | 190 | 26.4 | |
| 5—10 | 59 | 8.2 | |
| 10—15 | 19 | 2.6 | |
| 15—20 | 27 | 3.7 | |
| Total | 721 | 100.0 | |

* Fallen leaves

## STANDING CROP IN A FOREST

Quantitative determination of the distribution of cesium-137 and strontium-90 in a forest was then performed. The sampling site was on half-way up the Mt. Akagi, Gunma Pref. and the vegetation was consisted of pine tree (*Pinus densi-*

**Table 4.** Comparison of the concentration of cesium-137 in the fallen leaves, underlying soil and vegetation (Mt. Zao, Miyagi Pref., Aug. 1966)

| Material | Concentration of $^{137}Cs$ nCi/kg* |
|---|---|
| Fallen leaves | |
| 0–2 cm | 86.3 |
| 2–5 cm | 22.4 |
| Soil | |
| 5–10 cm | 2.32 |
| 10–15 cm | 0.59 |
| 15–20 cm | 0.51 |
| Leaves | |
| *Abies Mariesii* | 6.85 |
| *Sasa sp.* | 2.12 |
| *Rhododendron* sp. | 1.62 |
| Bark (*Abies*) | 1.54 |
| Wood ( 〃 ) | 0.21 |

* Air-dry basis for fallen leaves and soil, fresh basis for vegetation

portions were treated for further analyses.

*flora*) with shrub and weeds. The total area of the site was 1200 m² in which 59 pine trees were grown. A pine tree of medium size was chosen, the height of which being 7.8 m and the diameter at the base 22 cm. Sampling of the trunk and bark (25 cm in length) was made at the position 2.4 m above the ground level, as the previous study showed no significant variation due to the vertical position.

Standing crop was made in 5 m × 5 m area close to the pine tree to collect all of the miscellaneous shrub, weeds, fallen leaves and soil. The area of 25 m² was thought reasonable by taking into consideration that the average area per one pine tree was about 20 m². These samples were weighed, mixed, and proper

## DISTRIBUTION OF CESIUM-137

Table 5 summarizes the distribution pattern quantitatively. Pine trees occupy about 80% by weight of the total vegetation and this is in striking contrast with that two thirds of the cesium-137 is found in the fallen leaves, most of which being pine needles.

Again the cesium-137 is concentrated mostly in the fallen leaves as found in other sites of observation.

The vertical distribution of cesium in soil was examined on four layers with the depth of 5 cm each. The lower two layers contained quantities less than the limit of determination.

## DISTRIBUTION OF STRONTIUM-90

An aliquot of every sample was used for the determination of strontium-90 also. The conventional standard method was used on all samples except the soils, to which the NaOH-HCl leach method[1] was applied.

The result of analyses is shown in Table 6. Of the total strontium-90 in vegetation, a little less than a half is present in the fallen leaves, but the concentration is not so remarkably high as in the case of cesium-137.

The vertical distribution in soil indicates less remarkable rate of decrease with

**Table 5.** Distribution of $^{137}Cs$ in a forest (Mt. Akagi, Gunma Pref., Oct. 1966)

| Part | Fresh weight kg/m² | $^{137}Cs$ nCi/kg | $^{137}Cs$ nCi/m² |
|---|---|---|---|
| Pine tree | 0.58 | 1.57 | 0.91 |
| Trunk | 3.58 | 0.12 | 0.43 |
| Branch | 1.37 | 0.82 | 1.12 |
| Leaves | 1.23 | 0.13 | 0.16 |
| Root | 1.65 | 0.23 | 0.38 |
| Total | 8.41 | | 3.00 |
| Fallen leaves | 1.45 | 5.72 | 8.30 |
| Shrub | 0.51 | 0.97 | 0.49 |
| Weeds | 0.0351* | — | 1.26 |
| Total of vegetation | | | 13.05 |
| Soil (0–5 cm) | | | 58.0 |
| 〃 (5–10 cm) | | | 1.4 |
| 〃 (10–15 cm) | | | <0.7 |
| 〃 (15–20 cm) | | | <0.7 |
| Total of soil | | | ~60 |

* weight of ash

**Table 6.** Distribution of $^{90}Sr$ in a forest and comparison with that of $^{137}Cs$ (Mt. Akagi)

| Part | $^{90}Sr$ nCi/kg | $^{90}Sr$ nCi/m² | $^{137}Cs/^{90}Sr$ |
|---|---|---|---|
| Pine tree Bark | 2.04 | 1.18 | 0.77 |
| Trunk | 0.20 | 0.73 | 0.59 |
| Branch | 0.40 | 0.55 | 2.04 |
| Leaves | 0.40 | 0.49 | 0.33 |
| Root | 0.25 | 0.42 | 0.90 |
| Total | | 3.37 | 1.12 |
| Fallen leaves | 3.20 | 4.60 | 1.80 |
| Shrub | 2.27 | 1.15 | 0.43 |
| Weeds | — | 0.68 | 1.85 |
| Total of vegetation | | 9.80 | 1.33 |
| Soil (0–5 cm) | | 26.9 | 2.16 |
| 〃 (5–10 cm) | | 4.0 | 0.35 |
| 〃 (10–15 cm) | | 1.6 | <0.4 |
| 〃 (15–20 cm) | | 0.5 | <1.4 |
| Total of soil | | 33 | ~1.8 |

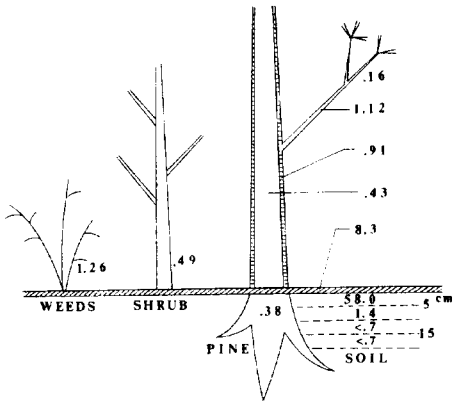


**Fig. 2.** Distribution of cesium-137 in a forest site (Figures indicate nCi $^{137}Cs/m^2$)

increasing depth.

## COMPARISON OF THE DISTRIBUTION PATTERN OF CESIUM-137 AND STRONTIUM-90

The ratios $^{137}Cs$ : $^{90}Sr$ in different part of the vegetation and soil are shown on the last column in Table 6. Over-all ratio, namely, the total cesium-137 existed in the site of observation (approximately 73 nCi/m²) divided by that of strontium-90 (42.8 nCi/m²) is 1.7.

The deviation of the figures shown on the last column in Table 6 from the ratio 1.7 would suggest different way in the translocation of these two radionuclides. A figure less than 1.7 would indicate a less tendency of cesium-137 in translocation to this phase of material and *vice versa*. Thus, the vegetation as a whole contains less amount of cesium-137 than strontium-90, but the branch of pine tree, fallen leaves and weeds are enhanced with the

former radionuclide in comparison with the latter.

The uppermost layer of soil (0–5 cm) is remarkabley enriched with cesium-137 and this would suggest less leaching of this radionuclide than the other.

Table 7 shows the percentage distribution of strontium-90 and cesium-137. Of the total deposition, 18% and 23% respectively of cesium-137 and strontium-90 were present in the vegetation. In a pine tree, about a double percentage of strontium-90 was present in both aerial part and root.

It should be mentioned here that this observation was made in October 1966 when the fall-out rates were very low, 0.04 and 0.09 mCi/km$^2$ per month, for strontium-90 and cesium-137 respectively in Tokyo[2]; the values are in contrast with the highest rates ever observed, for example, in June 1963, 4.47 and 14.3 mCi/km$^2$ [3] respectively.

**Table 7.** Percentage distribution of $^{90}$Sr and $^{137}$Cs in a forest

| Part | $^{90}$Sr Per cent of total | $^{137}$Cs deposition |
|---|---|---|
| Vegetation | 22.9 | 17.9 |
| Pine tree | 7.9 | 4.1 |
| Aerial part | 6.9 | 3.6 |
| Root | 1.0 | 0.5 |
| Fallen leaves | 10.7 | 11.4 |
| Shrub | 2.7 | 0.7 |
| Weeds | 1.6 | 1.7 |
| Soil | 76.8 | ~82 |
| 0–5 cm | 62.6 | 79.5 |
| 5–10 | 9.3 | 1.9 |
| 10–15 | 3.7 | <1 |
| 15–20 | 1.2 | <1 |

Pine needles and aerial part of other vegetation should have been much contaminated three years before the sampling time. Pine needles are believed to be renewed every three years, therefore, all leaves which had been heavily contaminated with air-borne radioactivity in 1963 should have been defoliated in 1966. This is naturally the case in deciduous trees and annual plants, but is not the case in twigs, branches and bark of trees. Thus, the reason of high concentrations of the radionuclides, especially the cesium-137, in these parts and fallen leaves can justifiably be accepted. Table 7 also suggests the higher root absorption of the strontium-90 than the cesium-137 by at least a factor of two, because both the aerial part and the root of pine tree and the aerial part of shrub contained 2–3 times much amount of strontium-90 as cesium-137.

## REFERENCES

1. Yamagata, N., Chiba, M. and H. Kobayashi (1969) Total ground deposition of $^{90}$Sr in Japan (1). *J. Rad. Res.*, **10**: 62–72.
2. Meteorological Research Institute, Radioactivity Survey Data in Japan. No. 17, Nov. 1967.
3. *ibid.*, No. 3, May 1964.