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Original Article

An Assessment of Radioactivity Levels of ^{210}Pb and ^{40}K in Tobacco and Radiation Exposure from Smoking

Tomohiro Nagamatsu[a,b], Akihiro Sakoda[a], Takahiro Kataoka[a], Toshiro Ono[b], and Kiyonori Yamaoka[a]*

[a]*Graduate School of Health Sciences, Okayama University,*
[b]*Department of Radiation Research Shikata Laboratory, Advanced Science Research Center, Okayama University, Okayama 700-8558, Japan*

No research has been conducted on the radiation influence of tobacco on the alimentary system, although there have been some previous works on the respiratory system. In this study, the radioactive concentrations of ^{210}Pb and ^{40}K in a cigarette sample were first measured. The transfer factors of the nuclides from tobacco into smoke and solution (saliva and/or alcohol) were then examined. Moreover, the radiation doses from smoke inhalation were also evaluated. The radioactive concentrations of ^{210}Pb and ^{40}K in the cigarette tobacco were 0.01 and 0.3 Bq/cigarette. Since this ^{210}Pb activity and the ^{210}Po activity previously reported for the same sample were comparable, it can be concluded that there was a radioactive equilibrium between the 2 nuclides. The observed transfer factor of ^{210}Pb (12%) into smoke was almost the same as that of ^{40}K (15%), whereas the reported value for ^{210}Po (60%) was significantly higher. The radiation doses due to inhalation of cigarette smoke varied from organ to organ, depending on the organotropic properties of the nuclide. For example, the kidneys, respiratory tract, and spleen showed relatively high doses from ^{210}Pb and ^{210}Po. The leaching rates indicated an inconsistent tendency related to solution types. This result could suggest that alcohol drinking, which is common in smokers, does not especially enhance the leaching characteristics.

Key words: tobacco, radionuclides, smoking, intake, radiation exposure

Cigarette smoke is a complex mixture including more than 100 carcinogens [1]. Tar is mainly referred as a carcinogen, although tar, carbon monoxide, and nicotine *etc.* are all commonly present in the smoke. When a cigarette is smoked, the substances are inhaled into the respiratory system or ingested into the alimentary system. Thus, smoking is a risk factor affecting the occurrence and progression of several diseases, including lung cancer, chronic bronchitis, angina pectoris, myocardial infarction, gastric ulcer, and duodenal ulcer. The influences of chemicals in the cigarette smoke on the respiratory and alimentary systems have often been studied [2-4].

In addition to chemical substances, tobacco contains naturally occurring radioactive nuclides. However, no research has been conducted focusing on the effect of radionuclides in tobacco on the alimentary system, although some previous works have examined their effect on the respiratory system. As long as

Received October 18, 2010; accepted December 2, 2010.
*Corresponding author. Phone: +81-86-235-6852; Fax: +81-86-235-6852
E-mail: yamaoka@md.okayama-u.ac.jp (K. Yamaoka)

there is a possibility for such radionuclides to be distributed in the human body due to smoking, radiation risk should be considered throughout the body from the perspective of radiation protection. It is therefore important to assess to what extent radionuclides from smoking are distributed to major organs or tissues.

In the present study, both the inhalation of radionuclides their ingestion by means of dissolution into saliva were considered. We first measured the radioactive concentrations of ^{210}Pb and ^{40}K in a cigarette sample. ^{210}Pb and its progeny (^{210}Po) in cigarette tobacco are considered to be 2 of the most important nuclides [5, 6]. In addition, ^{40}K is quite familiar because it is significantly included in plants and living bodies. We therefore also determined how much ^{210}Pb and ^{40}K can be transferred from cigarette tobacco into smoke. Lastly, leaching tests were performed to estimate the transfer of the 2 nuclides from tobacco into saliva based on 2 scenarios: (1) normal smoking and (2) smoking with alcohol drinking.

Materials and Methods

Calculation of photon detection efficiency. Gamma-ray spectrometry was performed using a high-purity germanium (HPGe) detector for the measurement of ^{40}K and ^{210}Pb in tobacco and leaching solution. The detection efficiency of the HPGe detector used was experimentally calibrated using standard gamma-ray sources with an energy range of 88 (^{109}Cd)−1836 (^{88}Y) keV. Photon energy emitted from ^{210}Pb (46.5 keV) was out of the energy range of the calibration, although that from ^{40}K (1461 keV) was within. We therefore calculated the detection efficiency only for 46.5 keV (^{210}Pb) using a Monte Carlo simulation code, Electron Gamma Shower 5 [7]. Fig. 1 shows the detector geometry for calculation of the detection efficiency. The sample geometry (*e.g.* height, density and sample container) differed somewhat from measurement to measurement. The validity of the calculated detection efficiency is briefly described in the Discussion section.

Radioactivity measurement of tobacco. A type of cigarette distributed in Japan was prepared for this study because its radioactivity is known to be relatively high [8]. Several tens of grams of the tobacco leaves extracted from the cigarettes were enclosed in a standard plastic (U8) container. Gamma

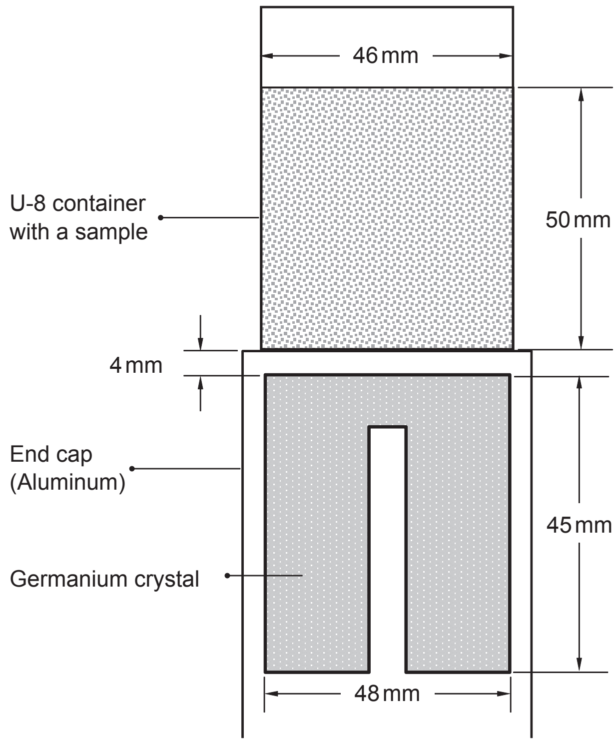

Fig. 1 Geometry of high-purity germanium detector with a sample.

rays from ^{210}Pb (46.5 keV) and ^{40}K (1461 keV) were measured using a HPGe detector (GMX-15200, SEIKO EG&G, Tokyo, Japan). The specific activity of the radionuclide (A (Bq/g)) can be expressed as

$$A = \left(\frac{S}{t} - \frac{S_b}{t_b}\right)\frac{1}{\varepsilon_\gamma \varepsilon_e W}, \quad (1)$$

where S is the area of the peak of the gamma-ray of the sample, S_b is the area of the peak of the gamma-ray of background, t is the measurement time of the samples, t_b is the measurement time of the background, ε_γ is the branching ratio of the gamma ray [9], ε_e is the detection efficiency of the detector, and W is the sample weight.

Measurement of transfer factor of radionuclides from cigarette tobacco into smoke. Tobacco samples from approximately 100 cigarettes were smoked to determine the transfer factor of ^{210}Pb and ^{40}K from the tobacco into smoke. After smoking, the cigarette ashes and butts were collected and their radioactivities were then measured with the HPGe detector. The transfer factor (T) of each radionuclide is given by

$$T = \frac{R - R_{smoked}}{R} \times 100\ (\%), \quad (2)$$

where R and R_{smoked} are the radioactivities (Bq) per the raw and smoked cigarettes, respectively.

Leaching of radionuclides from tobacco. Ethanol and/or saliva with a volume of approximately 1 L was first brought to 37℃. Several tens of grams of the tobacco leaves were then put in the solution with a volume of approximately 1 L. After shaking at 37℃ for 2 h to leach radionuclides, the leachate and tobacco were carefully separated. ^{210}Pb and ^{40}K within the leachate were measured using the HPGe detector. The leaching rate of each radionuclide is given by

$$L = \frac{R_{leached}}{R} \times 100\ (\%) \quad (3)$$

where R and $R_{leached}$ are the radioactivities (Bq) in the raw cigarettes used and the leachate, respectively.

Results and Discussion

Fig. 2 shows the ratios of the detection efficiencies between the calculation and the calibration experiment. In the energy range from 80 to 120 keV, the calculated values were somewhat higher than the measured values. However, the ratio was lowered with decreases in the photon energy. Consequently, the value of the extrapolated line at 46.5 keV (^{210}Pb) corresponds to 0.98. Thus, it can be verified that in the present work, the Monte Carlo simulation worked very well to estimate the detection efficiency of the gamma ray emitted from ^{210}Pb.

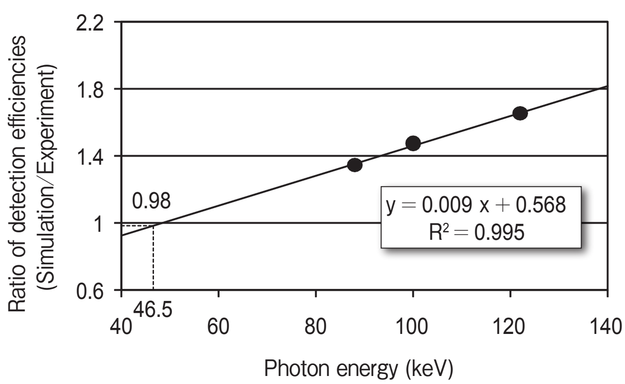

Fig. 2 Comparison of detection efficiencies between Monte Carlo simulation and calibration experiment.

The radioactive concentrations in the tobacco sample are presented in Table 1. The concentration of ^{40}K was much higher than that of ^{210}Pb. Our measured ^{210}Pb concentration was comparable to that of ^{210}Po for the same sample reported by Takizawa *et al.* [8], implying that suppression of the radionuclides in the tobacco has not occurred and that there is radioactive equilibrium between ^{210}Pb and its decay product ^{210}Po [5].

The smoking transfer factors of both ^{210}Pb and ^{40}K were very similar, as seen in Table 1. These values were lower than approximately 60% for ^{210}Po [8]. This may be because ^{210}Po has a volatilization temperature much lower than those of ^{210}Pb and ^{40}K [5]. Not only ^{210}Po but also ^{210}Pb and ^{40}K, however, can be expected to play a role in internal radiation exposure from the inhalation of cigarette smoke. We therefore assessed the annual committed effective dose from each radionuclide using inhalation dose coefficients established by the International Commission on Radiological Protection (ICRP) [9], *i.e.* 1.1 and 3.3 μSv/Bq for ^{210}Pb and ^{210}Po, respectively: the dose coefficient for ^{40}K is not given there. The effective dose (E (Sv)) was calculated as the following formula:

$$E = T \times I \times F \times C \times R \times t, \quad (4)$$

where T is the transfer factor from the tobacco to

Table 1 Radioactivities of ^{210}Pb and ^{40}K in the tobacco sample, their transfer factors into smoke and annual committed effective doses due to smoke inhalation

	Tobacco leaf		Smoking transfer factor (%)	Effective dose (μ Sv/year)
	(Bq/g)	(Bq/cigarette)		
^{210}Pb	0.018 ± 0.001	0.012 ± 0.001	11.8	5.7
^{40}K	0.483 ± 0.013	0.339 ± 0.009	15.4	–[2)]
^{210}Po[1)]	0.020 ± 0.002	0.015 ± 0.001	60.3	108.9

1)For reference, the values for ^{210}Po reported in Ref. [8] are exhibited.
2)The effective dose cannot be estimated because of no dose coefficient for ^{40}K given by ICRP [9].

smoke (−), I is the ratio of inhaled smoke to total generated smoke (=0.5), F is the inhalation dose conversion factor (Sv/Bq), C is cigarette consumption (=20 cigarettes/day), R is the radioactive concentration of ^{210}Pb or ^{210}Po (Bq/cigarette), and t is the duration of smoking (=365 days). Although the effective doses are 5.7 to 108.9 μSv/year (Table 1), the doses may change depending on the smoking habit.

Table 2 represents the annual committed equivalent doses for an individual with the above smoking habit (*i.e.* 20 cigarettes/day), which were calculated using dose coefficients by ICRP [9]. It can be confirmed that for both nuclides, the doses to kidneys, respiratory tract, and spleen are much higher. In addition, the doses to the bone surface from ^{210}Pb and liver and red marrow from ^{210}Po are also greater than the others. These trends may be due to the organotropic properties of each nuclide, although the deposition of cigarette smoke is the main cause of the high dose to the respiratory tract.

Table 2 Annual committed equivalent doses from smoking inhalation of ^{210}Pb and ^{210}Po in organs and tissues

Organs and tissues	Equivalent dose (Sv/year)	
	^{210}Pb	^{210}Po
Adrenals	3.5×10^{-7}	1.3×10^{-6}
Bladder Wall	3.5×10^{-7}	1.3×10^{-6}
Bone Surface	6.9×10^{-5}	7.7×10^{-6}
Brain	3.5×10^{-7}	1.3×10^{-6}
Breast	3.5×10^{-7}	1.3×10^{-6}
GI−Tract		
Esophagus	3.5×10^{-7}	1.3×10^{-6}
St Wall	3.5×10^{-7}	1.3×10^{-6}
SI Wall	3.5×10^{-7}	1.4×10^{-6}
ULI Wall	3.6×10^{-7}	1.5×10^{-6}
LLI Wall	3.8×10^{-7}	1.7×10^{-6}
Colon	3.7×10^{-7}	1.6×10^{-6}
Kidneys	1.5×10^{-5}	6.0×10^{-5}
Liver	7.5×10^{-6}	3.3×10^{-5}
Muscle	3.5×10^{-7}	1.3×10^{-6}
Ovaries	3.5×10^{-7}	1.3×10^{-6}
Pancreas	3.5×10^{-7}	1.3×10^{-6}
Red Marrow	8.5×10^{-6}	1.3×10^{-5}
Respiratory Tract		
ET Airways	1.5×10^{-5}	9.6×10^{-5}
Lungs	2.9×10^{-5}	7.1×10^{-4}
Skin	3.5×10^{-7}	1.3×10^{-6}
Spleen	1.2×10^{-5}	5.2×10^{-5}
Testes	3.5×10^{-7}	1.3×10^{-6}
Thymus	3.5×10^{-7}	1.3×10^{-6}
Thyroid	3.5×10^{-7}	1.3×10^{-6}
Uterus	3.5×10^{-7}	1.3×10^{-6}
Remainder	5.9×10^{-7}	2.3×10^{-6}

Note: The doses are based on the assumptions of AMAD 1 μm and absorption type M.

Table 3 Leaching rates of ^{210}Pb and ^{40}K from the tobacco leaf into ethanol, saliva, and distilled water

Solution (Mixing ratio)	Leaching rate (%)	
	^{210}Pb	^{40}K
Ethanol and Distilled water (0.95 : 0.05)	16.2	27.3
Ethanol and Distilled water (0.5 : 0.5)	26.9	18.8
Ethanol, Saliva and Distilled water (0.45 : 0.1 : 0.45)	0.0	60.6
Saliva (1.0)	28.5	56.7

The leaching rates of ^{210}Pb and ^{40}K from the tobacco into solution are listed in Table 3. The radionuclides were dissolved within the range of the leaching rates of 16.2–60.6%, except for ^{210}Pb, which was leached into ethanol, saliva, and distilled water (0.45 : 0.1 : 0.45). For both nuclides, however, the results indicated an inconsistent tendency depending on the solution type, although this inconsistency cannot be reasonably explained. In general, smokers often drink alcohol. Our results suggest that such lifestyle habits may not enhance the leaching of the radionuclides. The leaching times in the present experiment (2 h) are much longer than those in actual smoking situations (*e.g.* several seconds). Consequently, smokers may ingest radionuclides from the tobacco through the saliva and/or liquor at much lower levels, by several tens of percentages, than indicated in the present results. In the next stage, a practical experiment should be carried out to more accurately estimate the leaching rates: namely, the dissolution of cigarette particles into saliva should be attempted. Such research would be helpful to assessing the internal radiation dose from the ingestion of natural radionuclides due to smoking.

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