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Factors affecting uptake of ^{131}I in Chinese white cabbage (*Brassica Chinensis Linn*)

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Abstract

The factors affecting the uptake of ^{131}I in Chinese white cabbage (*Brassica Chinensis Linn*) were studied. The time required for the ratio between the activity in the vegetable (Bq kg^{-1} dry mass) and the activity in the soil (Bq kg^{-1} dry mass) to reach equilibrium was around 72 h derived from an investigation period of 145 h. The ratio was also dependent on the mass of the vegetable (increased by more than twice when the vegetable mass was decreased to around 60%), the growth period of the vegetable (almost linearly decreased from 3.0×10^{-2} to 1.1×10^{-2} when the growth period changed from 66 to 81 d) and the season of culture, while it was independent of the concentration of ^{131}I applied to the soil. The mean concentration ratio obtained for 51 samples was $(6.3 \pm 4.4) \times 10^{-2}$. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Radioiodine; ^{131}I; Uptake; Chinese white cabbage; Soil

1. Introduction

The Daya Bay nuclear reactor built near to Hong Kong has gone into operation in 1994. In spite of the very low probability of having a nuclear accident, the potential risk always exists. In the late stage of a nuclear accident, the main irradiation path is the internal irradiation caused by the transfer of radionuclides from soil to vegetation and consumption of contaminated foodstuff.

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For the terrestrial food chain model used to estimate the radiation dose received by the human body, the most readily available parameters in the literature are the concentration ratio (CR) and the soil-to-plant transfer factor. According to Till and Meyer (1983), the CR was defined as the ratio between the radionuclide activity per unit dry mass of plant and the radionuclide activity per unit mass of dried soil, while the soil-to-plant transfer factor was defined as the ratio between the radionuclide activity per unit fresh weight of plant and the radionuclide activity per unit mass of dried soil. Obviously, the two ratios were connected by the fresh-to-dry-weight ratio.

Based on the values compiled by Ng, Burton, Thompson, Tanky, Kretner and Pratt (1968), by Ng, Calsher, Quim and Thompson (1977) and by Bretthauer, Mullen and Moghisi (1972), the Nuclear Regulatory Committee published the CR values for different vegetation in the publication R.G.1.109 (USNRC, 1977). The CR values were also discussed in other publications (IAEA, 1982; NCRP, 1984). Further research (Ng, 1982) showed that, among the various transfer coefficients in the terrestrial food chain, the range for that from soil to vegetable was the widest, reaching $3 \sim 4$ orders of magnitude. The reason behind this was that the CR for a certain radionuclide was not only related to the vegetation type, but was also closely related to other parameters such as the growing stage, the soil properties and environmental factors (such as temperature and relative humidity).

Although direct deposition from the atmosphere may be more important to the plant than the root uptake process in the case of a nuclear accident, especially for the short half-life radionuclides such as ^{131}I, it is far more likely for the root uptake properties to deviate significantly from published nominal values. When the CR values provided by USNRC (1977) are used as the input parameters, the estimated dose values may be greatly overestimated or underestimated. Therefore, it is best to employ specific data for specific vegetation in a specific region to reduce the uncertainties on the dose caused by the uncertainties in the parameter values.

There are a number of different types of leafy vegetables in the local area. In the present study, *Brassica Chinensis Linn* (referred to as white cabbage in the following discussions) was chosen for investigation, which has similar characteristics in growth period ($\sim$ 2 months) and yield ($\sim$ 10 kg m^{-2}) to other local leafy vegetables, and the factors affecting its uptake of ^{131}I were studied. The time required for the ratio between the activity in the vegetable and that in the soil to reach equilibrium was first studied. The dependences of the ratio on the mass, growth period of the vegetable, concentration of ^{131}I applied to the soil and the season of culture were also investigated.

2. Methodology

Cylindrical pots containing cabbage sprouts of similar size were placed outdoors. The soil employed was krasnozem which is coarse and sandy and is common in the Daya Bay area. The volume of soil used in each pot was 4.87×10^4 cm^3 with a depth of 15 cm. The soil had a bulk density of 2.65, pH of 5.3–8.0, cation exchange capacity of 0.73 mg equivalent per 100 g, Ca concentration of 1.9–2.2 g kg^{-1}, organic matter concentration of 15.44 g kg^{-1} and total N concentration of 0.47 g kg^{-1}.

The ^{131}I solutions (500 ml in the form of NaI) were carefully poured onto the surface soil layer of the experimental groups, without wetting the portion of the vegetables above the ground. Examination of the homogeneity in distribution of the ^{131}I poured onto the soils showed that the ^{131}I concentration decreased quickly with the depth of the soil and dropped to almost zero when the depth reached around 9 cm immediately after application of ^{131}I (cf. the depth reached by the vegetable root of about 3 cm). For each experimental group, a control group with the same mass range and growth period was also grown in the same season, but without application of ^{131}I.

At harvest, the vegetables were carefully removed, and were then washed with distilled water and wiped with blotting paper. The fragmented roots were carefully removed from the soils by hand. The soils were then visually examined again for any presence of remaining fragmented roots before they were mixed to give a homogeneous sample. The soil sample was then oven-dried at 70°C until a constant weight. The dry weights of vegetable and soil samples were recorded before measurement for ^{131}I concentration, the typical weights being 4 and 20 g, respectively. Standard samples with similar geometry, density and weights prepared with known amounts of added ^{131}I were used to calibrate the counting efficiency and correct the self-absorption by the samples. The CR values corresponded to those obtained at the equilibrium conditions. We denoted the non-equilibrium values as CR(t), where t is the time elapsed after application of ^{131}I.

The radionuclide ^{131}I is a γ-ray (364 keV) emitter which has a half-life of 8.02 d. In the present study, the NaI(Tl) γ-spectroscopy system was used to determine the activity of ^{131}I. Measurements were made normally within 1 h after sampling, so no decay corrections were needed.

The time required for achieving equilibrium and thus the CR value was first established. Then, the dependence of CR on the mass of the vegetable, growth period of the vegetable, the concentration of ^{131}I applied to the soil and the season of culture were studied. Each dependent factor was studied keeping other factors constant. The experimental conditions are shown in Table 1.

3. Results

3.1. Temporal variation of CR(t)

The temporal variation of CR(t) was studied for an investigation period of 145 h. 50–75 g samples were used. The growth period of the vegetables was 50 d, the season was spring (March–April) and the ^{131}I concentration was 3.7×10^4 Bq $(500\,\text{ml})^{-1}$. The results are shown in Fig. 1. Statistical t-tests showed that the CR(t) value at the transferral time of 72 h was different from those at 7, 24, and 62.4 h at the 95% confidence level, while it did not show a difference from those at 97, 121 or 145 h even down to the 80% confidence level. This showed that the CR(t) value at 72 h was likely to have reached the equilibrium value, and was likely to be different from those before 72 h (except for the data at 2.5 h which had a large uncertainty). From the above, we were confident that the CR(t) values obtained after 72 h were good estimates of the

Table 1
Experimental conditions for studying dependent factors

Factor in consideration	Experimental conditions			
	Mass per plant (g)	Growth period (d)	Concentration of ^{131}I (3.7×10^4 Bq/500 ml)	Season
Time to reach equilibrium	50–75	50	1	Spring (Mar–Apr)
Vegetation mass per plant	A : 50–75B : 20–50	50	1	Spring (Mar–Apr)
Growth period	50–75	66–81	1	Winter (Nov–Jan)
Concentration	50–75	53–58	1–40	Summer (Apr to Jun)
Season	50–75	50–70	1–40	Winter–Summer

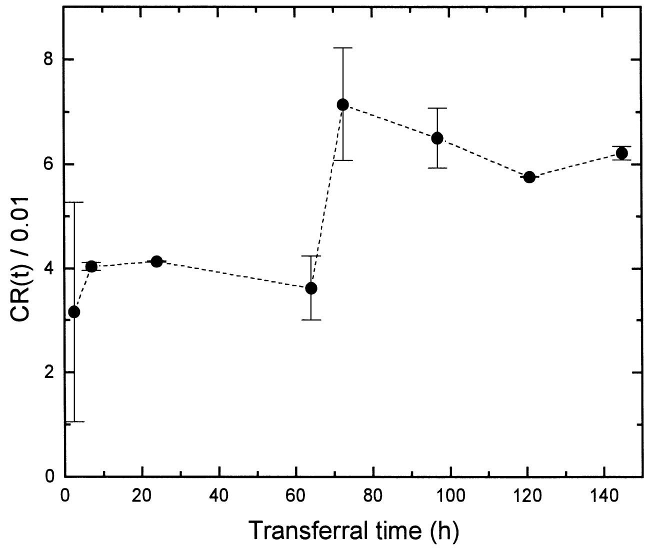

Fig. 1. Temporal variation of CR(t) for an investigation period of 145 h. Two samples were used to produce each datum point. Error bars are for 1 S.D. The data for transferral times of 24 and 121 h had error bars smaller than the symbols.

equilibrium CR values. Therefore, in all the experiments below, the sampling of the vegetables took place around and after 72 h after the application of ^{131}I to the soil.

3.2. *Effects of mass of vegetables*

The ranges and average values of the CR in the two mass ranges 20–50 and 50–75 g are given in Table 2. It can be observed that the average CR value for the smaller-mass group is higher (by more than twice). The statistical t-test showed that the average CR values for the two groups of different mass were different at the 99% confidence level. In all the experiments described below, the mass range of the vegetables was 50–75 g.

Table 2
Effects of mass of vegetables on the concentration ratio (CR). The growth period of the vegetables was 50 d; the season was spring (March to April) and the concentration of ^{131}I applied to the soil was 3.7×10^4 Bq

Mass of vegetables (g)	No. of samples	CR value (10^{-2})	
		Range	Average
50–75	8	1.66–7.90	4.78 ± 2.18
20–50	12	6.65–21.0	11.7 ± 5.05

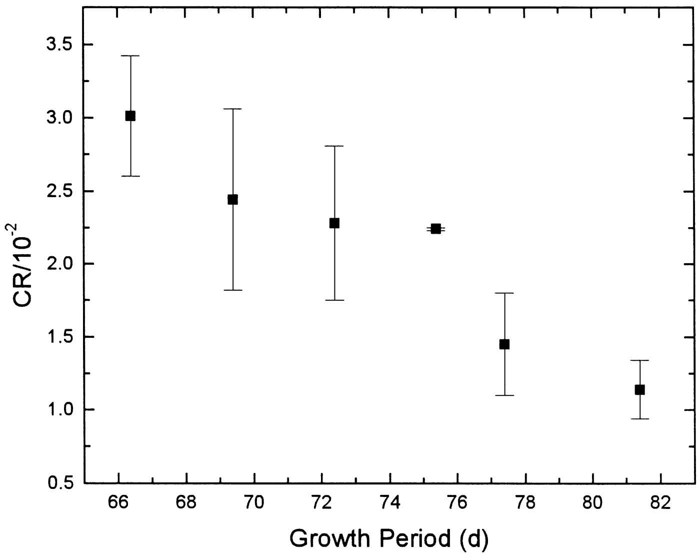

Fig. 2. CR values for vegetables of different growth periods. Two samples were used for each datum point. Error bars are for 1 S.D. The datum for a transferral time of 75.4 d had error bars smaller than the symbol.

3.3. Effects of growth period

The CR values for vegetables of different growth periods were shown in Fig. 2. It was interesting to observe that the CR value almost linearly decreased from 3.0×10^{-2} to 1.1×10^{-2} when the growth period changed from 66 to 81 d. However, since the number of samples used for one result was only 2, this observation can only be treated as tentative.

3.4. Effects of applied concentration of ^{131}I

The CR values for different concentrations of ^{131}I applied to the soil, 3.7×10^4–1.48×10^6 Bq (1–40 μCi), are shown in Fig. 3. It was observed that the CR was independent of the concentration of ^{131}I applied to the soil.

3.5. Effects of season

The dependence of the CR on the season of culture could be identified. This was made possible, despite the different concentrations of ^{131}I involved, owing to the CR being independent of the applied concentration of ^{131}I. The results are shown in Table 3, together with the mean temperature and mean relative humidity for different seasons. The average CR obtained during winter was the smallest when both the temperature and relative humidity were low, and the average CR values obtained

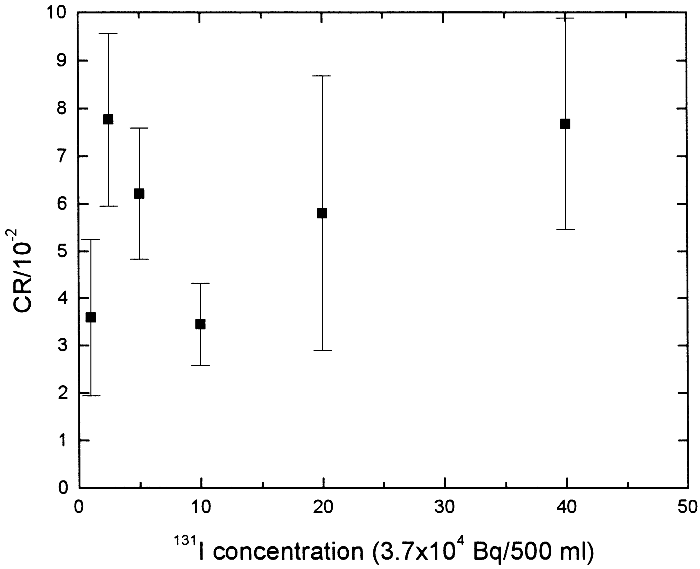

Fig. 3. CR values for vegetables for different concentrations of ^{131}I applied to the soil. Error bars are for 1 S.D. The weight of vegetables was 50–75 g, the growth period ranged from 53 to 58 d; the season was summer (April–June).

Table 3
Effects of season of culture on the concentration ratio (CR). The weight of vegetables ranged from 50 to 75 g; the growth period ranged from 50 to 70 d

Season (months)	Mean Temperature (°C)	Mean Relative Humidity (%)	Concentration of ^{131}I (10^4 Bq per 500 ml)	No. of samples	CR value (10^{-2})	
					Range	Average
Winter (Nov–Jan)	13.3	69	3.7	11	1.28–4.50	2.76 ± 0.92
Spring (Mar–Apr)	21.9	84	3.7	8	1.66–7.90	4.78 ± 2.18
Summer (Apr–Jun)	29.3	86	148	20	1.89–10.6	5.64 ± 2.60

during spring and summer were largest when both the temperature and relative humidity were high. Statistical *t*-tests showed that the average CR value for winter was different from those for spring and winter at 99% confidence level, while those for spring and summer did not show significant difference even down to the 60% confidence level. It is established that most water absorbed by roots in the vegetable is lost by transpiration from the leaves. During the dry winter season, transpiration loss is enhanced, so more water will enter the vegetable through the roots to maintain the water balance, which leads to an increase in the root uptake of ^{131}I and thus higher CR values. The air temperature may also affect the plant activity (such as the growth rate, protoplasm streaming and enzyme activity etc.) and the photosynthetic activity. However, our results might indicate that the effects of relative humidity were dominant in the considered temperature range.

4. Discussions and conclusions

Iodine is well known as an element which is volatile in the environment. The present experiments did not explicitly determine or single out the effect of direct deposition of ^{131}I volatilised from the soil. Nevertheless, at least a part of this effect is believed to have been automatically taken into account since the amount of directly deposited ^{131}I will be reflected in the final CR value.

The present investigation shows that the CR values depend on the mass of the vegetable, the growth period of the vegetable and the season of culture. These may contribute to the wide range of CR values for a certain radionuclide for a particular vegetation type as mentioned in the introduction. Furthermore, the time required for the ratio between the activities in the vegetable and soil to reach equilibrium is also important for an accurate determination of the CR value. All these conditions might have to be provided along with the determined CR values in the future to allow more meaningful comparisons. When all the data for our 51 samples were combined, the CR ranged from 1.1×10^{-2}–21×10^{-2} with a mean of $(6.3 \pm 4.4) \times 10^{-2}$, which was somewhat higher than the CR of 0.02 reported by NRC (USNRC, 1977).

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