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Transfer values of Th and U in a controlled study using a hydroponic system

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1. Introduction

The toxic effects impact on public health and the natural environment have raised several questions regarding the entire range of operational activities related to uranium mining and the entire nuclear fuel cycle[1]. Due to their high sensitivity characteristics, plants have been used as natural monitors in different studies and environmental monitoring programs[2]. In general, plants can uptake radionuclides and elements present in the soil that hosts them, through the roots, translocate and accumulate many of these radionuclides in different parts of their anatomy[3]. The measurements in a biotic organism may be interpreted in the light of experiments under controlled conditions in laboratory or greenhouse, where the 'dose *vs* response' relationship is evaluated. However, it is important to emphasize that controlled conditions may not extrapolate environmental conditions, as the effect of a pollutant on an organism varies enormously depending on the elements naturally present in it, which may trigger some synergistic, additive or antagonistic effects unexpected[3].

This study evaluated the transfer values (uptake) of Th and U in the species *Epipremnum pinatum* in a controlled condition using the technique of cultivation in hydroponics or cultivation in nutrient solution, adding different standard dosages (maximum, medium and minimum) of the elements of interest. In addition, to evaluate the translocate and accumulate these radionuclides of the roots to aerial parts, using the transfer factor (*TF*). This mechanism is very important for tracking radionuclides in the food chain[4]. The activity concentrations were obtained using the nuclear technique, Neutron Activation Analysis (NAA), k_0-method[5]. A non-destructive multi-element technique, capable of providing results with high precision and accuracy for elements in a wide concentration range, from trace to percentage levels[5]. The results are expressed in Bq kg^{-1} for ^{232}Th and ^{238}U.

2. Methodology

Sampling and sample preparation procedures

The species chosen for the study, *Epipremnum pimnatum*, was sampled whole (root and aerial part) in the monitored areas of the CDTN. This specimen, born directly from the soil, were named as matrix or first-generation plants. It has a previous stage of cleaning the roots, immersed in deionized water for 24 hours, washed three times in tap water and deionized water and after placed in pots with 2.5 L of nutrient solution for a period of 2 months.

After sixty days, the seedlings (first-generation) had their adult leaves, stems and roots, removed. Thus, only the young leaves, stems and roots, born in nutrient solution, continued to be cultivated, starting to be named the seedlings of second-generation, that were cultivated for more 30 days, only in the nutrient solution, until they reached a medium size.

Experimental procedures

The experiment was carried out in a greenhouse using a cultivation technique in nutrient solution (hydroponic technique), where the salts diluted and prepared individually in deionized water to form the reagents that will compose the substrate in 2.5 L pots[6].

To enable the methodology for evaluating the transfer of radionuclides, the second generation seedlings were cultivated for 60 days in a nutrient solution added with standards of the elements of interest (Th + U), applying three different dosages of the respective standards: 1) Maximum dose (~2000 mg kg $^{-1}$); 2) Medium dose (~1,000 mg kg $^{-1}$); and 3) Minimum dose (~500 mg kg $^{-1}$).

Sample preparation for analysis

After a period of two months, the plant was sampled from the hydroponic pots, left to soak for 24 hours and washed in deionized water (repeating the process 3 times), segmented and had their biomass measured on a precision scale to obtain the wet weight. The drying process of the segmented samples occurred naturally for approximately two weeks, crushed and then calcined in a muffle. The biomass of the samples in ash was placed in polyethylene bottles, identified and measured on a precision scale (weight in ash).

Analytical Technique and Quality Control

The samples were prepared and submitted to irradiation in the TRIGA MARK I IPR-R1 research reactor, applying the nuclear technique Neutron Activation Analysis, k_0-method[5]. The plant samples were analyzed together with their respective reference material – GBW 0805, Tea Leaves[7] and neutron monitors, to determine the respective mass fractions of the radionuclides of interest[8]. The k_0-method is applied in three complementary steps: 1) Pre-Irradiation (previous preparation of set samples); 2) Irradiation (event of radionuclides activation present in samples); and 3) Post-Irradiation (acquisition of gamma spectra, deconvolution of spectra and calculation of mass fractions)[9].

The technique performance is regularly carried out in intercomparing projects, analyzing the reference material using the normalized error parameter, E_n-*score*[10] of the certified/recommended values of mass fraction, accompanied by its expanded uncertainty U (k = 2), represented by *equation 1*.

$$E_n = \frac{x_{\text{lab}} - x_{\text{cert}}}{\sqrt{U^2{}_{\text{lab}} + U^2{}_{\text{cert}}}} \qquad (1)$$

In which:

x_{lab} is the value obtained by laboratory; x_{cert} is the certified value
U_{lab} is the expanded uncertainty of the value obtained by laboratory (k = 1)
U_{cert} is the expanded uncertainty of the certified value (k = 2)

Obs.: $|E_n| \leq 1$, satisfactory result, indicating that the result obtained has a 95% probability of being within the range of the certified value. $|E_n| > 1$, unsatisfactory result.

3. Results and Discussion

Table I shows the recommended values for and experimental results for GBW 0805. It is possible to observe that E_n-*score* for Th is < 1, pointing out the performance of the method was satisfactory.

Table I: Recommended values and experimental results for GBW 0805 and E_n-*score*

GBW0805 (Tea leaves)			
El.	Experimental Results [k = 1] (mg kg^{-1})	Recommended values [k = 2] (mg kg^{-1})	E_n-*score*
Th	0.111 ± 0.003	0.105 ± 0.013	0.45
U	< 2	NR	-

El., Element; NR, Not Reported

The values of activity concentrations per dose – Minimum (500 mg kg $^{-1}$), Medium (1,000 mg kg $^{-1}$) and Maximum (2,000 mg kg $^{-1}$) – added in the cultivation of *Epipremnum pinatum* in nutrient solution were obtained and are presented in the Table II.

Table II: Activity concentrations for ^{232}Th and ^{238}U in the species evaluated (*Epipremnum pinatum*) for three doses (maximum, medium and minimum) in different plant organs (aerial part and root).

Org. Plant	MAXIMUM (~2,000)		MEDIUM (~1,000)		MINIMUM (~500)	
	^{232}Th	^{238}U	^{232}Th	^{238}U	^{232}Th	^{238}U
	Bq kg^{1}					
AP	81.5±0.4	247±1	131±18	659±15	50.5±0.5	236±1
R	468±16	6,856±136	191±3	1,130±372	289±1	337±3
AP	204±1	679±2	141±1	132±5	102±1	142±1
R	1,189±49	1,691±679	373±3	206±125	126±14	230±1
AP	77.4±0.4	605±3	48.4±0.3	299±3	546±0.3	151.9±0.2
R	546±37	5,460±124	344±1	7,360±37	102±4	256±3

AP, Aerial Part (steam and leaves); R, Root.

It was observed that for the plant organ, the root had a higher average value than the aerial part, with a significant difference for both radionuclides – ^{232}Th ($p = 0.039$) and ^{238}U ($p = 0.007$). The average values for dosages of standard of the elements of interest, added in the nutrient solution, showed an uptake capacity with a decreasing trend – 2,000 > 1,000 > 500. However, there are not differences in the measurements of the mechanisms of uptake of radionuclides in nutrient solution by plants, since the elements are always easily bioavailable in the nutrient solution, unlike what happens in the soil[11].

Transfer Factor

The measurement of the transfer factor (*TF*) means the ratio between ^{232}Th and ^{238}U activity concentrations in the aerial part plants in relation to its concentrations in the respective root plants (Table II and Figure 1). This measure points out the translocation and was calculated by *equation 2*:

$$TF = \frac{[Aerial\ Part]}{[Root]} \tag{2}$$

Figure 1 is the graphical representation of the values obtained from the activity concentrations, by dose – Minimum (500 mg kg $^{-1}$), Medium (1,000 mg kg $^{-1}$) and Maximum (2,000 mg kg $^{-1}$) – of the standards of the elements of interest added to the cultivation of *Epipremnum pinatum* in nutrient solution.

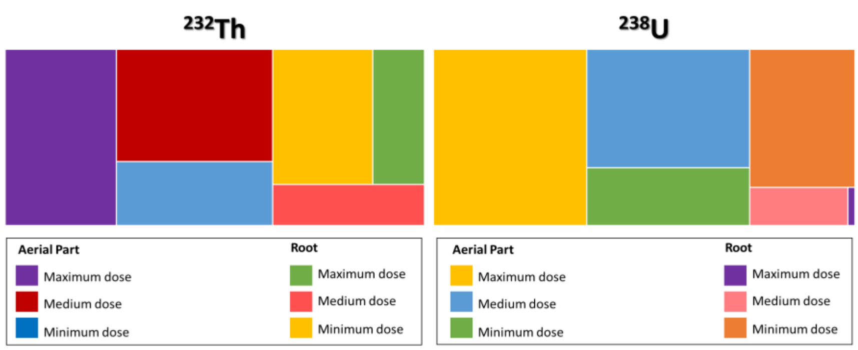

Figure 1: ^{232}Th and ^{238}U activity concentration in evaluated species (*Epipremnum pinatum*) for three dosages (maximum, medium and minimum).

The figure shows that in relation to the *TF* values for ^{232}Th and ^{238}U, the activity concentrations show a tendency to translocate a higher amount of these radionuclides than to retain them in the roots, contrary to what is observed in studies of plants grown in natural soil where the low translocation to the aerial part may be considers the possible mechanisms by which the root system can impose on the elements against the plant's tolerance and/or need to them[12].

4. Conclusions

This controlled study allowed to verify a high transfer capacity (uptake) of the radionuclides from the environment to the plant. Even under low dosage conditions, the studied species (*Epipremnum pinatum*) showed an unusual ability to translocate these radionuclides from their roots to the aerial parts. The *TF* demonstrated that the higher bioavailability of a radionuclide in the environment that hosts the plant, is higher the possibility of translocation and accumulation the radionuclides in different parts of the plant tissue, especially in the edible parts.

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