Actinides Th and U

6

Some fungi have the ability to take up thorium and uranium, but this capability differs depending on the species (Campos et al. 2009; Borovička et al. 2011, Turtiainen et al. 2013). Although thorium and uranium concentrations in fungi are usually measurable, in exceptionally low amounts (Mietelski et al, 2002; Rufyikiri et al, 2002), there have been attempts to analyze the content of these trace elements in mushroom mycelium growing *in vivo* (Thomet et al. 1999; Berthelsen et al. 1995). It is not known how natural isotopes coming from soil are taken up by mycelium and into fruiting bodies and through the food chain. The role of soil fractions such as rhizosphere and soil-root interface appears important for the understanding of elemental uptake by fungi.

Thorium and uranium contents in mushrooms seem depend on the acidity of the soil. Results of our previous study (Vinichuk, 2012c) indicate a positive correlation exists between pH and uranium (r=0.91 for mushroom mycelium; r=0.50 for fruiting bodies) and between pH and thorium content (r=0.33 mushroom mycelium; r=0.52 for fruiting bodies). Although, there are currently no available data on soil acidity effects on the uptake of thorium and uranium by ectomycorhyzal fungi, the biomass of fungi in the genus *Penicillium* absorbs most uranium at pH 3-7.5 (Galun et al. 1983). There is an inversely proportional relationship for thorium (r=-0.66) and uranium (r=-0.51) between the content of organic matter in the soils studied and concentrations of elements in the mushroom mycelium.

Thorium content in the rhizosphere fraction is slightly higher than its content in soil (Table 6.1.).

***Table 6.1** Mean concentrations of actinides (mg kg^{-1} DW) in soil fractions and fungi and bioconcentration ratios (BCR), mean values ± standard deviation. Adapted from Vinichuk, 2012c).*

Element	Bulk soil	Rhizosphere	Soil-root interface	Fungal mycelium	Fruit bodies
			Element concentrations		
Th	1.10 ±0.30[a]	1.45±0.5[a]	0.28±0.096	0.74±0.23[a]	0.0041±0.0009
U	6.85±4.02[a]	9.36±3.99[a]	5.79±2.81[a]	3.11±1.24[a]	0.026±0.016
			Bioconcentration ratios		
Th	-	0.85±0.24	0.18±0.04	0.64±0.16	0.006±0.002
U	-	1.05±0.19	0.52±0.18	0.99±0.29	0.035±0.021

The means within rows with different letters (a, b) represent a significant difference ($p < 0.01$). BCR defined as concentration of the element (mg kg^{-1} DW) in the specific fraction divided by concentration of the element (mg kg^{-1} DW) in bulk soil).

The concentration of thorium in mushroom mycelium is slightly lower than its content in the soil, whereas, the content in fruit bodies is two orders of magnitude lower than in the soil. As the soil-root interface fraction is essentially the finest plant roots with adhered soil particles, it could be argued the root system of plants (trees) takes up but does accumulate neither uranium nor thorium. The concentration of thorium in the soil-root fraction is lower than the Th content in the bulk soil. Thus, the content of these elements in plant tissue can be assumed as lower: after being absorbed, metals accumulate in the roots. Uranium and thorium concentrations in mycelium are generally lower that in bulk soil, whereas, metal concentration in fruit bodies is orders of magnitude lower than in bulk soil. Borovička et al. (2011) also report similar results for thorium and uranium content in fruit bodies of mushrooms. Uranium appears to have similar behavior to thorium. The median concentration of this element is higher in bulk soil (6.85 mg kg^{-1}) than in mycelium (3.11 mg kg^{-1}). In fruit bodies, uranium is only found in trace amounts (0.026 mg kg^{-1}), indicating low uptake rate of this element by fruit bodies and efficient exclusion of U from fungi (Table 6.1.).

The content of uranium and thorium in mushrooms appears to depend on the concentration of these isotopes in the soil and there are significant correlations between uranium concentration in bulk soil and mycelium and in bulk soil and in fruit bodies (Figure 6.1).

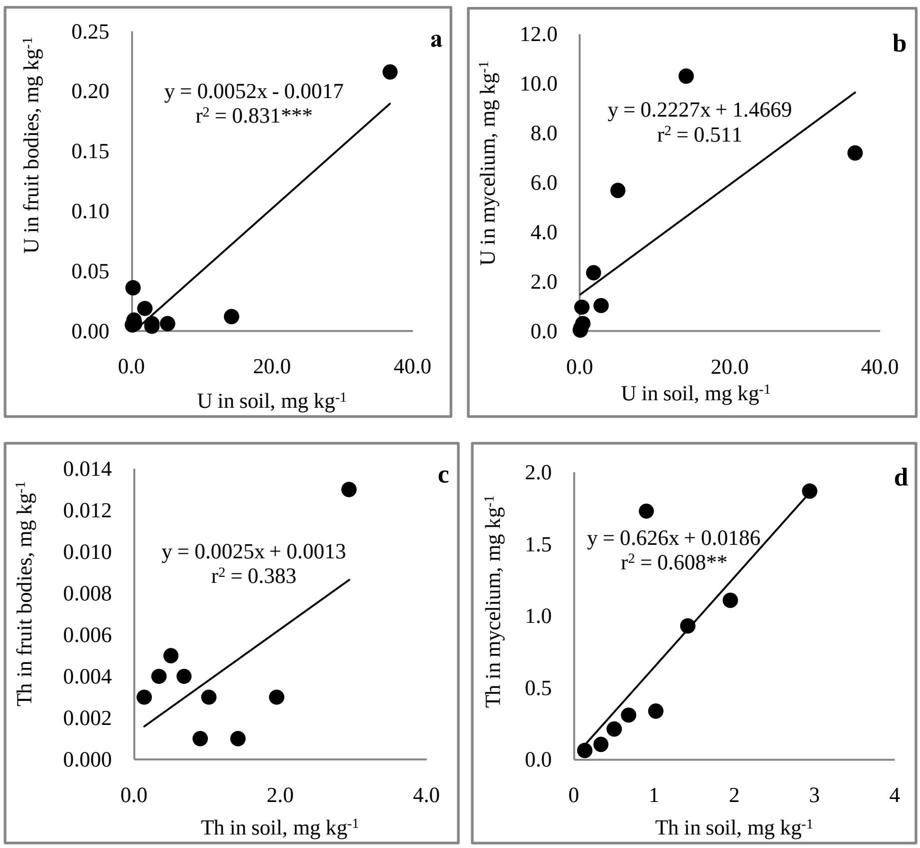

Figure 6.1 *Relationships between concentration of U (a, b) and Th (b, c) in fungal sporocarps and soil mycelium in relation to the soil in which they are growing. Adapted from Vinichuk, (2012c).*

Uptake of uranium by mycelium correlates with calcium (r=0.86) and strontium uptake (r=0.79, P<0.05). Uranium concentration in fruit bodies of fungi correlates with Ca concentration (r=0.62, P<0.01). Mietelski et al. (2002)

reported uranium in fruit bodies of mushrooms in measurable amounts; however, there was no uranium accumulation in mushroom species examined. Uranium uptake and translocation by the arbuscular mycorrhizal fungus *Glomus intraradices* under root-organ culture conditions are reported by Rufyikiri et al. (2002), although no accumulation of U was observed.

Thus, both uranium and thorium enter the fruiting bodies of fungi but they do not be accumulated. Bioconcentration ratios of uranium and thorium in the fruit bodies of fungi species studied in Sweden have a wide range of variation, but significantly less than 1 (Table 6.2).

Table 6.2 *Element bioconcentration ratios (BCR: mg kg^{-1} DW in fungi) / (mg kg^{-1} DW in bulk soil) for fungal sporocarps. Adapted from Vinichuk, (2012c).*

Sampling plots according to Vinichuk et al. (2010b)	Species	Th	U
4	*Boletus edulis*	0.0011	0.0296
6	*Cantharellus tubaeformis*	0.0029	0.0014
10	*Collybia peronata*[a]	0.0746	0.0857
7	*Cortinarius armeniacus*	0.0059	0.0149
5	*C. odorifer*	0.0100	0.0059
8	*C.* spp.	0.0119	0.2105
8-10	*Hypholoma capnoides*[a]	0.0149	0.0429
1	*Lactarius deterrimus*	0.0044	0.0012
3	*L. scrobiculatus*	0.0015	0.0103
6	*L. trivialis*	0.0029	0.0021
5-7	*Sarcodon imbricatus*	0.0020	0.0049
2	*Suillus granulatus*	0.0007	0.0008
8-10	*Tricholoma equestre*	0.0224	0.0714

[a]Saprophyte.

For most species of fungi, BCR for This ≤0.01, whereas, the BCR for U are almost an order of magnitude higher but do not exceed 0.2. The coefficient of variation of BCR for U in fruit bodies of fungi is almost 3 times higher than for Th. Similar BCR values are reported by Baeza & Guillén (2006) in the fruiting bodies of fungi in forest ecosystems in Spain (Th=0.030-0.62; U=0.043-0.49). Species of the genus *Cortinarius* absorb U at one or two orders of magnitude more intensively than other species.

The saprotroph species *Collybia peronata* has the highest BCR for Th. Mycorrhizal species, especially members of Cortinariaceae (*Gymnopilus hybridus* (Fr.) Maire are characterized by elevated levels of both of these naturally radioactive elements (Campos et al. 2009). According to Baeza & Guillén research (2006), the highest rates of thorium and uranium uptake are in a representative of Cortinariaceae, e.g. ectomycorrhyzal species *Hebeloma cylindrosporum* Romagn, which is often found on sandy forest soils low in organic matter. Due to its exceptional ability to absorb radioactive elements, this species is used as bioindicator of soil contamination.

Although metabolism in fungi occurs most intensely within their fruit bodies, the concentration of thorium and uranium in fungal mycelium is more than two orders of magnitude higher than the concentration in fruit bodies, indicating a minor role of both elements in spore formation within sporocarps.

Estimates based on uranium and thorium concentrations in bulk soil and mycelium and mycelium content in typical forest soils in Sweden indicate that the mycelium in upper forest soil layers may comprise 2.0-5.0% of the total thorium content of soil and 1.4-2.7% of the total uranium content of soil. However, the direct method used for estimating mycelium biomass may not provide complete removal of soil mycelium; especially for the upper enriched organic matter soil layers where hyphae mycelium closely intertwine with semi-decomposed organic remains. Therefore, the data on thorium and uranium contents in mushroom mycelium may be underestimated rather than overestimated.

The uptake of uranium and thorium in fungal fruit bodies do not relate: Pearson correlation of U and Th in fruit bodies of fungi is 0.050 (p=0.870).