

Compartmentalisation of uranium and heavy metals into sediment and plant biomass in a constructed wetland filter

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Abstract: The compartmentalisation of contaminants derived from retention pond water passed through a newly commissioned constructed wetland filter (CWF) at Ranger Uranium Mine, Northern Territory, Australia was studied. The CWF is composed of 8 cells and a sump and is dominated by *Eleocharis sphacelata*. Following two dry seasons, during which time retention pond water was polished by the CWF, sediment was sampled incrementally from the 0–10 cm depth. Sediment was characterised by a moderate to slightly acid pH (4.5–6.5), very low to moderate cation exchange capacity (0.4–11.3 cmol₊/kg) and low organic C content (0.6–1.6%). Total U concentration decreased in an approximately exponential fashion with path length through the CWF and sediment depth from a maximum of 570 mg/kg in the surface sediment of Cell 1. Total U was correlated with total Mn which might imply the active sequestering of U by Mn oxide surfaces. A similarly high correlation was found between total Mn and Co which was attributed largely to native soil minerals. However the relative enrichment of surface sediment by Mn and Co, especially in the front cells, suggests the formation of Mn oxides and the sorption of Co as an active process. On average, 51% of total U was extracted by sodium bicarbonate (0.5 M; pH 8.5). It was estimated that 64–77% of the retained U load from the polishing of mine water could be accounted for in the sediment of the CWF.

The mass of U associated with *E. sphacelata* root and shoot was small compared to sediment load. At any one time during the sampling interval, U in *E. sphacelata* accounted for less than 0.2–4.9% of retained U, but over the operational time of the CWF a much larger portion of retained U will have turned over in organic matter.

1 INTRODUCTION

Ranger Uranium Mine (RUM), operated by Energy Resources of Australia Ltd (ERA), is situated 8 km east of the township of Jabiru in the Northern Territory, Australia and is located within a 78 km² project area which lies adjacent to Magela Creek, a tributary of the East Alligator River. The Ranger Project Area is surrounded by, but does not form part of, Kakadu National Park which has World Heritage listing. Commercial production began in 1981 and is currently around 4000 t U₃O₈/year. Climate is typical of the wet-dry tropics with the majority of rainfall occurring between December–March (mean annual precipitation = 1483 mm) and a pronounced dry season between June–September (mean Class A pan evaporation = 2616 mm).

The proximity of RUM to Kakadu National Park demands a very high standard of water management which has operated using a system of designating restricted release zone (RRZ) and non-RRZ waters based upon mine water origin.

This has entailed the use of retention ponds for water storage and a policy of zero release for the most contaminated waters. Irrigation to natural bushland on the mine lease during the dry season remains the principal means by which excess contaminated water is disposed but, in 1995, a constructed wetland filter (CWF) was commissioned on site to polish water before being disposed to land. The CWF comprises eight cells and a sump of 5.8 ha total surface area interconnected by spillways, a flow path of 1.08 km and total volume of 50 000 m³. Water depth varies between cells but is commonly 0.5-1.0 m. Based upon an input of 4600 m³/day, the filter has a retention time of approximately 11 days. The typical composition of RRZ water treated by the CWF is shown in Table 1 with uranium (U), manganese (Mn), sulphate (SO₄) and magnesium (Mg) the principal contaminants. Other metals such as Cu, Pb and Zn are not routinely measured because concentrations are low but total concentrations given as interquartile ranges based on historic data (1985–1999) are 2.0–9.9 µg/L, 1.0–4.0 µg/L and 7.3–21.2 µg/L respectively. During its first three years of operation, the CWF treated 450 800, 164 400 and 432 700 m³ of RRZ water over each of three dry seasons. Whilst Mg and SO₄ behave conservatively, U and Mn are polished by the CWF. For example in 1995 and 1996, U removal amounted respectively to around 55% and 73% of input load with corresponding Mn attenuation of over 90% and 78% (Klessa et al., 1998). In 1997, removal of both U and Mn was estimated to be over 90% (Energy Resources of Australia, 1998).

Although it has been demonstrated operationally, and by earlier research at Ranger (Akber et al., 1992a; Jones et al., 1995), that uranium is polished effectively by passing mine water through a CWF, little attention has been paid to the fate of U so sequestered. Over the longer term, and particularly post mining when CWFs could form an integral part of a rehabilitated landscape, an understanding of the compartmentalisation of contaminants within a wetland system is crucial to predicting the efficacy and viability of this treatment process. In this respect, Reddy & Gale (1994) have criticised the lack of attention in wetland research to biogeochemical processes which dictate the retention and release of contaminants.

2 METHODS

Sediment sampling, sample preparation and analyses

Samples were collected in February 1997 from each of the cells with the exception of Cell 6. A stainless steel piston corer (37 mm ID) was driven into the sediment from a moored boat and, on extraction of the intact cores, divided into 0–10, 10–30, 30–50 and 50–100 mm segments and bagged. Representative samples were obtained from Cells 1, 2, 3 and 5 by sampling within the flow path, near the inlet, outlet and middle of each cell, and combining to form a composite sample. Cells 4, 7 and 8, which have longer flowpaths, were sampled by obtaining separate samples from the inlet, middle and outlet regions of each of these cells. Generally, each representative sample was composed of 20 cores and

always taken within the vicinity of plant growth, principally *Eleocharis spachelata*, which dominates the CWF.

Table 1 Composition of influent to the constructed wetland filter during 1995–97

| Year | pH | EC ($\mu\text{S}/\text{cm}$) | Mg (mg/L) | SO ₄ (mg/L) | Mn ($\mu\text{g}/\text{L}$)† | U ($\mu\text{g}/\text{L}$)† |
|------|---------|--------------------------------|-----------|------------------------|--------------------------------|-------------------------------|
| 1995 | 6.6–9.2 | 860–1000 | 98–130 | 380–560 | 6–2700 | 280–1200 |
| 1996 | 6.5–8.5 | 750–930 | 79–100 | 330–450 | 28–160 | 65–790 |
| 1997 | 6.1–7.4 | 670–960 | 88–110 | 320–420 | 86–680 | 110–310 |

†Filterable (<0.45 μm) fraction

Before analysis, samples were air-dried at 35°C and then passed through a 5 mm stainless steel sieve to remove stones and coarse gravel which were discarded. The <5 mm fraction was then ground using an agate mortar and pestle to pass through a 2 mm sieve. For some analyses, representative subsamples of each sediment sample were ground to <0.15 mm.

The assays performed and the methods used are summarised in Table 2.

Table 2 Methods employed in sediment sample analyses

| Assay | Method | Reference |
|--|---|--|
| Air-dry moisture | 105°C to constant weight | 2A1 ¹ |
| PH | 1:5 soil:water suspension | 4A1 ¹ |
| Electrical conductivity (EC) | 1:5 soil:water suspension | 3A1 ¹ |
| Cation exchange capacity (CEC) | 0.01 M silver thiourea | 15F3 ¹ |
| Exchangeable bases | 0.01 M silver thiourea | 15F1 ¹ |
| Total organic carbon ² | Heanes wet oxidation | 6B1 ¹ |
| Total nitrogen ² | Kjeldahl acid digestion; indophenol blue | Cusbert et al. (1994); 7A2 ¹ |
| Extractable phosphorus | Olsen extractable, 1:20 | 9C1 ¹ |
| Total phosphorus ² | Acid persulphate digestion | After Fuller (1997) |
| Total metals ² (Cd, Co, Cu, Fe, Mn, Pb, U & Zn) | Microwave <i>aqua regia</i> digestion; ICPMS, ICPAES | EPA (1994) |
| Extractable U | Olsen extractable; 1:20; ICPMS | Extraction follows 9C1 ¹ |

¹Raymont & Higginson (1992); ²<0.015 mm sediment

Plant sampling, sample preparation and analyses

Plant samples were taken from a number of sites in the CWF and on a number of dates during the 1997 dry season. The first series, taken in early May, preceded the start of the operational period in the CWF which began on 27 May and ended on 8 October. Sampling was limited to *E. spachelata* whose shoots were taken using stainless steel secateurs by cutting approximately 5 cm above the sediment-water interface. On some occasions, separate samples of young and mature shoots were taken, arbitrarily defined by <30 cm and >30 cm heights respectively. Roots were sampled from whole plants by cutting and lifting sods with a stainless steel spade. However, the difficulty of removing intact plants is such that it is unlikely that the whole root mass of individual plants was harvested. On three occasions, fresh weight yields of *E. spachelata* shoots were

measured using a 1 m² quadrat in Cell 5 to provide an estimate of plant shoot biomass in the CWF.

Within 2 h of harvesting, plant samples were washed initially under tap water and rubbed gently without rupturing the tissue to remove adhering periphyton and plaque. This was followed by rinsing under deionised water. Samples specifically retained as ‘unwashed’ did not undergo any washing. At one sampling, the unwashed sheath was removed from mature stems and retained separately for analysis. Stems and roots were cut into approximately 1 cm lengths using stainless steel scissors and the plant material dried in a forced draught oven at 40°C. After drying, each sample was ground through a mill directly into polycarbonate containers.

Samples (0.5 g) underwent microwave digestion using nitric acid (5 ml) in teflon vessels. Digests were then analysed for Al, Ca, Cd, Co, Cu, Fe, Mg, Mn, Mo, Ni, P, Pb, S, Ti, U and Zn using ICPMS and ICPAES and the results recorded on an oven-dry basis.

3 RESULTS

General properties of the sediment

Data is summarised for each cell in Table 3 by providing results for the 0–1 and 0–10 cm depths. Over all cells and sampling depths, sediment was characterised by the virtual absence of free salt (22–266 µS/cm), a moderate to slightly acid pH (4.6–6.5), very low to moderate CEC (0.4–11.3 cmol₊/kg) and low organic C content (0.6–1.6%). Magnesium was found to dominate the exchange sites comprising an average of 78% of total exchangeable bases in the order Mg²⁺>>Ca²⁺>K⁺≥Na⁺. In addition, there was no evidence of gradients in the aforementioned parameters along the length of the CWF.

Table 3 General properties of sediment

| Variable | Depth (cm) | Cell | | | | | | |
|--------------------------------|------------|------|------|------|------|------|------|------|
| | | 1 | 2 | 3 | 4† | 5 | 7† | 8† |
| PH | 0-1 | 5.29 | 6.27 | 4.81 | 6.08 | 5.03 | 5.34 | 5.47 |
| | 0-10 | 5.96 | 6.33 | 5.79 | 5.81 | 5.47 | 5.65 | 5.69 |
| EC (uS/cm) | 0-1 | 126 | 158 | 266 | 79 | 176 | 117 | 117 |
| | 0-10 | 57 | 91 | 102 | 54 | 66 | 69 | 73 |
| CEC (cmol ₊ /kg) | 0-1 | 5.7 | 5.9 | 5.8 | 2.4 | 1.8 | 4.5 | 7.7 |
| | 0-10 | 5.4 | 2.3 | 4.3 | 2.8 | 2.4 | 4.6 | 5.2 |
| Total C (%) | 0-1 | 1.61 | 1.09 | 0.89 | 0.72 | 1.45 | 1.05 | 1.23 |
| | 0-10 | 0.59 | 0.54 | 0.46 | 0.50 | 0.71 | 0.74 | 0.78 |
| Total N (%) | 0-1 | 0.12 | 0.07 | 0.05 | 0.04 | 0.10 | 0.04 | 0.05 |
| | 0-10 | 0.03 | 0.02 | 0.01 | 0.02 | 0.03 | 0.01 | 0.02 |
| Total P (%) | 0-1 | 0.03 | 0.03 | 0.02 | 0.01 | 0.01 | 0.01 | 0.02 |
| | 0-10 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| Available P (mg/kg) | 0-1 | 1.6 | 2.5 | 1.8 | 1.6 | 2.6 | 1.5 | 1.2 |
| | 0-10 | 0.9 | 1.3 | 1.2 | 1.4 | 1.7 | 1.3 | 1.4 |

†Mean of inlet, middle and outlet sampling sites

Total cadmium, cobalt, copper, iron, manganese, lead and zinc in sediment

In general, and with the exception of Fe, metal concentrations were highest in surface (0–1 cm) sediment and declined with depth (data not given). The most well-defined concentration gradients along path length were shown by Co and Mn (Table 4) but the presence of ‘hot spots’ of Cd, Pb and Zn in Cells 5, 7 and 8 sediments may have confounded evidence of path length gradients for these metals. These ‘hot spots’ may derive from pyritic minerals present in crushed non-mineralised waste rock used as a base in the construction of spillways in the CWF.

Table 4 Total metal content of sediments

| Metal | Depth (cm) | Cell | | | | | | |
|--------|------------|------|------|------|------|-------|------|------|
| | | 1 | 2 | 3 | 4† | 5 | 7† | 8† |
| Cd | 0-1 | 0.06 | 0.04 | 0.03 | 0.02 | 6.56 | 0.20 | 0.46 |
| | 0-10 | 0.01 | 0.02 | 0.06 | 0.01 | 1.09 | 0.09 | 0.14 |
| Co | 0-1 | 14.2 | 9.2 | 5.6 | 1.7 | 2.4 | 2.8 | 3.4 |
| | 0-10 | 5.6 | 4.0 | 3.2 | 1.4 | 1.6 | 3.0 | 2.2 |
| Cu | 0-1 | 37.2 | 39.1 | 17.3 | 11.5 | 18.9 | 15.8 | 20.4 |
| | 0-10 | 17.7 | 19.0 | 12.5 | 12.2 | 10.1 | 19.9 | 17.6 |
| Fe (%) | 0-1 | 3.03 | 2.11 | 1.61 | 1.84 | 1.32 | 2.35 | 2.83 |
| | 0-10 | 1.58 | 1.95 | 2.15 | 1.85 | 1.04 | 2.95 | 2.55 |
| Mn | 0-1 | 251 | 207 | 85 | 55 | 34 | 55 | 25 |
| | 0-10 | 63 | 83 | 40 | 17 | 16 | 40 | 29 |
| Pb | 0-1 | 13.9 | 8.4 | 6.5 | 10.1 | 47.9 | 11.9 | 15.5 |
| | 0-10 | 6.9 | 8.5 | 9.2 | 9.8 | 14.0 | 12.8 | 12.9 |
| Zn | 0-1 | 47.6 | 31.2 | 19.9 | 12.2 | 735.0 | 30.0 | 65.7 |
| | 0-10 | 18.9 | 13.0 | 29.0 | 8.7 | 123.7 | 11.5 | 18.9 |

†Mean of inlet, middle and outlet sampling sites; units in mg/kg unless otherwise stated

Total and extractable U in sediment

An approximately exponential decline in U was found in the sediments of the CWF both in the direction of flow and with depth. Total U was strongly correlated ($P < 0.001$) with total Co, Mn and organic matter. When data was normalised and subjected to stepwise regression, Mn ($P < 0.001$), sediment depth ($P < 0.001$) and path length ($P < 0.01$) were found to be the best predictors of total U concentration in sediment as shown by Equation 1:

$$\log y = 0.7594 \log x_1 - 3.3260x_2 - 0.0909x_3 - 0.1566 \quad \text{Equation 1}$$

where y is total U (mmol/kg), x_1 is total Mn (mmol/kg), x_2 is path length (m), x_3 is mean sampling depth (cm), corrected $r^2 = 0.71$ ($P < 0.001$) and $\sigma_y = 0.2977$.

On average, between 42–62% of total U was extracted by 0.5 M NaHCO_3 (Table 5). The pattern to the distribution of extractable U mirrored that of total U with a decrease in concentration also being a function of path length, sediment depth and total Mn. However, while the highest concentrations of extractable U were found in surface (0–1 cm) sediment of the front three cells (Table 5),

U extractability was relatively low by comparison in Cell 1 (35%) and at a maximum in Cell 3 (88%).

Table 5 Bicarbonate-extractable U content of sediment

| | Depth (cm) | Cell | | | | | | |
|------------|------------|-------|-------|-------|------|-------|------|------|
| | | 1 | 2 | 3 | 4† | 5 | 7† | 8† |
| Mg/kg | 0-1 | 198.1 | 295.4 | 221.3 | 53.6 | 175.7 | 73.3 | 69.0 |
| | 0-10 | 63.9 | 84.4 | 41.3 | 10.0 | 32.2 | 12.0 | 17.1 |
| % of total | 0-1 | 34.8 | 67.7 | 88.3 | 59.3 | 77.9 | 63.4 | 52.3 |
| | 0-10 | 48.1 | 63.1 | 59.4 | 50.3 | 67.6 | 53.4 | 51.3 |

Composition of *E. sphacelata*

Over the sampling period, the U content of washed shoots ranged between 0.03–47 mg/kg dry matter (DM) with a mean of 3.2 mg/kg DM and a 95% confidence interval around the mean of 1.8–5.7 mg/kg DM. Based on a sampling time in the early dry season (7/5/97), young shoots were characterised by having significantly ($P<0.05$) higher concentrations of P, Cu and Mo and lower concentrations of Mg, Ca, S, Ni and Pb when compared to mature shoots. The mean U contents of mature and young shoots were 0.42 and 0.65 mg/kg DM respectively but were not significantly ($P>0.95$) different. Later samplings showed the same pattern in differences between young and mature shoots for the macronutrients (ie Mg, Ca, S and P) but not necessarily for the micronutrients (ie Ni, Cu, Mo and Pb).

Washed roots contained significantly ($P<0.05$) higher concentrations of the metals Ti, Fe, Al, Co, Mo, Pb and U compared to washed shoots and, with the exception of Fe, were around an order of magnitude greater (Table 6). In the case of Fe, concentrations were two orders of magnitude higher with a mean of 4%. In contrast, shoots contained greater ($P<0.01$) concentrations of Mg and Ca than roots.

Unwashed shoots were typified by having higher ($P<0.05$) concentrations of Al, Pb and U compared to washed shoots. This degree of surface contamination was expressed by taking the concentration ratio of unwashed: washed shoots (given in brackets) to give the following order:

Cd (0.8)<Ni (0.9)<Mg=P=S (1.0)<Ca=Cu=Zn (1.1)<Mo (1.3)<Mn (1.5)<
<Co (2.6)<Fe (4.4)<Pb (5.6)<Al (7.9)<U (8.4)<Ti (16.5)

Relationships between U and other elements in washed shoots, principally those which are possible indicators of contamination by particulates or sediment, were investigated. U was strongly ($P<0.001$) and positively correlated with Al and Fe. Further data analysis, by incorporating the results from the analysis of roots, and unwashed shoots and sheath, tested the hypothesis that the degree of contamination, as determined by relationships between indicators, and between indicators and U, held irrespective of the plant part analysed. The corollary to this was that the U content of plant samples from the CWF is determined by the degree of dilution of the internal, uncontaminated fraction by an external,

contaminated fraction which has a large influence on U concentration. Inclusion of these other results led to a marked improvement in explained variance for linear relationships between U and contamination indicators.

Table 6 Mean composition (mg/kg DM) of washed shoots and roots of *Eleocharis sphacelata*

| Element | Shoot | Root | Element | Shoot | Root |
|---------|-------|-------|---------|-------|-------|
| Mg | 3962 | 2471 | Co | 0.16 | 2.07 |
| P | 690 | 479 | Ni | 0.74 | 2.11 |
| Ca | 2190 | 546 | Cu | 3.91 | 8.30 |
| S | 7800 | 6108 | Zn | 25.2 | 83.1 |
| Mn | 438 | 279 | Mo | 0.24 | 1.30 |
| Fe | 440 | 37627 | Cd | 0.03 | 0.86 |
| Al | 244 | 1686 | Pb | 0.43 | 5.75 |
| Ti | 1.7 | 10.8 | U | 6.9 | 101.7 |

4 DISCUSSION

The mechanisms by which uranium is removed from mine water by the CWF are unclear but have been postulated to involve adsorption to sediment surfaces and to suspended matter such as oxyhydroxides and organic matter, coprecipitation with oxyhydroxides, and biological uptake (leGras & Klessa, 1997). Results from sediment analysis suggest that the majority of retained uranium is accounted for in sediment with around half present in a potentially labile form.

During 1995 and 1996, a total load of 250 kg U was polished and retained by the CWF. To derive the recovery of retained sediment U in the absence of a control, an estimate was made of the depth of sediment into which U, derived from the treated mine water, was dissipated and conserved, and of the background U concentration in sediment. Studies have shown that following irrigation of mine water at Ranger over 6 years, uranium was conserved within the surface 5 cm of soil (Noller & Zhou, 1992; Akber & Marten, 1992b). Sediment in the CWF is made up of subsoil and a typical background total U concentration for non-mineralised subsoil in the area is around 5-10 mg/kg U. This in turn implies a recovery within the 0-5 cm depth of sediment of approximately 64-77% (159-192 kg U) of the retained U load.

It is likely that adsorption and coprecipitation of U by colloids as well as sorption by sediment surfaces determine the removal of U from solution in the CWF. Based on the examination of rate loss equations of particulate and soluble U, Fe and Mn, previous findings suggested that U removal is more influenced by Fe rich particulates than by colloidal Mn (leGras & Klessa, 1997). In the weathered regolith, Fe oxyhydroxides act as scavengers of U (Koons et al., 1980) and U can also become associated with Mn oxides especially on the surface of fissures and remnant schistosity which typify well-oxidised zones (Koppi et al., 1996).

In the work described here, there was a significant ($P < 0.001$) correlation between Mn and U in the sediments of the CWF with around 71% of the

variation in total U explained by total Mn, path length and sediment depth. Cobalt was also found to be strongly correlated with Mn ($P < 0.001$) with the highest Co concentration in surface sediment found in the front three cells (Table 4). However, most sediment Co in the CWF is native and not derived from mine water. This is implied because the total Co concentration in mine water is around $7 \mu\text{g/L}$ (G. Parker, pers comm). Hence the total Co load to the CWF over 1995 and 1996 was around 4.3 kg which is more than accounted for by the Co found in the surface 0–5 cm of sediment (ie 10.8 kg) in the CWF. Manganese oxides strongly adsorb Co (Murray, 1975), and, in soil, most Co is associated with oxyhydroxides, particularly Mn oxides (McLaren et al., 1986). The similar pattern of Co and Mn distribution in the surface sediment of the front three cells supports the hypothesis that Mn colloids floc quickly once mine water enters the CWF. Around half the Mn load in the mine water is removed within approximately the first 300 m of the CWF, assuming a retention time of 11 days and a steady state (leGras & Klessa, 1997). There is also evidence from the lower ($P < 0.05$) stoichiometry of the total Co:total Mn ratio in the surface sediment of the CWF compared with the rest of the profile (Klessa et al., 1998) that Mn oxides are being deposited and that these are likely to provide a surface for U sorption.

By comparison with sediment, the proportion of retained U associated with *E. sphacelata* biomass was small. Taking account of surface cover over the Dry season (10–25%) and fresh weight yields ($1.30\text{--}1.75 \text{ kg/m}^2$), and assuming homogeneity over the whole CWF, this equated to a maximum shoot DM production of 15.34 t. In the absence of yield data for roots, a 1:1 ratio of above:below ground biomass was assumed. Uptake of uranium by roots and shoots of *E. sphacelata* equated to around 0.2–4.9% of retained U at any one time during the sampling interval. However, the mass of U compartmentalised by *E. sphacelata* over the operating period (ie 1995–1997) will be proportionately greater since the larger part of this U is turned over in organic matter. Determining the importance of organic matter turnover to the fate of uranium remains an important aspect to understanding the long-term efficacy of CWFs as passive mine water treatment systems.

Little attention has been paid to the physiology of U uptake by higher plants. Evidence suggests that U can be absorbed efficiently by the root (Koul et al., 1983) where it may outcompete Mg for cell wall binding sites and be prevented from transporting to the shoot (Sela et al., 1988). Other studies which have examined algae (Crist et al., 1988) and microbial cells (Premuzic et al., 1991) have also shown a propensity for cell walls to adsorb and retain UO_2^{2+} . For wetland plants, the role of foliar absorption as opposed to root uptake of U has not been elucidated but the work described here suggests that the presence of Fe as plaque, especially on roots (Taylor & Crowder, 1989; Otte et al., 1989) or possibly as ferrihydrite on periphyton attached to the shoot is an important sequester of U. Plaque provides a surface for metal adsorption (Twining, 1993) and can constitute as much as 6.4% of root dry weight as Fe (Crowder & Macfie 1986). McBride & Noller (1995) have drawn attention to the problems of

sampling wetland plants and the confounding effects of attached periphyton which can only be removed with difficulty. Periphyton are efficient at removing heavy metals from solution (Vymazal, 1984) particularly in low alkalinity waters which favour precipitation of metals inside algal biofilms (Liehr et al., 1994).

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Wydzielanie uranu i metali ciężkich do osadu i roślinnej biomasy w segmentowym filtrze roślinnym (CWT)

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Streszczenie: Badano rozdzielanie zanieczyszczeń wody przepuszczanej przez nowo skonstruowany filtr (CWF) w kopalni uranu Ranger, terytorium północne, Australia. CWF składa się z 8 komór i zbiornika ściekowego). Do procesów oczyszczania wykorzystuje *Eleocharis sphacelata*. Po dwóch okresach suchych, w czasie których czas zatrzymywania wody był regulowany przez CWF, pobierano próbki osadu z głębokości 0-10 cm. Osad charakteryzował się odczynem od średnio do słabo kwaśnego pH (4,5-6,5), bardzo niską do średniej zdolnością do wymiany kationowej (0,4-11,3 cmol+/kg) i niską zawartością węgla organicznego (0,6-1,6%). Całkowita zawartość U zmniejszyła się w przybliżeniu wykładniczo w stosunku do długości CWF i głębokości osadów z maksymalnej 570 mg/kg w powierzchniowym osadzie komory 1. Całkowita ilość U była skorelowana z całkowitą ilością Mn, co mogłoby sugerować aktywne maskowanie U przez powłokę tlenku Mn. Podobnie wysoką korelację znaleziono

miedzy Mn i Co, co przypisano w dużym stopniu naturalnym minerałom znajdującym się w glebie. Jednakże względne wzbogacenie powierzchniowych osadów w Mn i Co, zwłaszcza w początkowych segmentach, sugeruje powstawanie tlenków Mn i sorpcję Co jako aktywnego procesu. Średnio 51% U zostało wyekstrahowane przez dwuwęglan sodu (0,5 M; pH 8,5). Oszacowano, że 64-77% zatrzymanego ładunku U z wody kopalnianej mogło stanowić osad w CWF. Masa U związana z korzeniami i pędami *E. sphacelata* była niewielka w porównaniu z ładunkiem osadu.