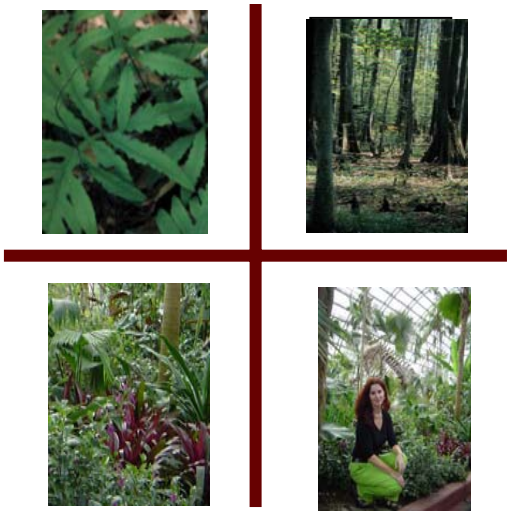
Elevated Uptake of Th and U by Netted Chain Fern (*Woodwardia areloata*)



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Uranium Behavior in Plants

- Uranium is not considered essential for plant growth by most authors.
- Plant uptake of U is limited to mobile species and is affected by soil pH. Typical concentration factors are usually in the 10-2 to 10-4 range.
- Recently, there have been reports on the high bioavailability of U to agricultural plants. Some legumes species from the *Brassicaceae* family accumulate more U than grasses. Also sunflower and leafy vegetables accumulate more U than other plants (Hossner et al. 1999; Saric et al. 1995; Dushenkov et al. 1997).
- Mobilizing agents to increase U uptake by plants are chelating agents, inorganic and organic acids (citric acid- Ebbs et al. 1998, Huang et al. 1998, Hossner et al. 1999). For example, Huang et al. (1997) observed that organic acids increased U accumulation in plant shoots more than 1000-fold. Shoot U concentration of *Brassica juncea* increased from 5mg/kg to more than 5000 mg/kg in organic treated soil.

Thorium Behavior in Plants

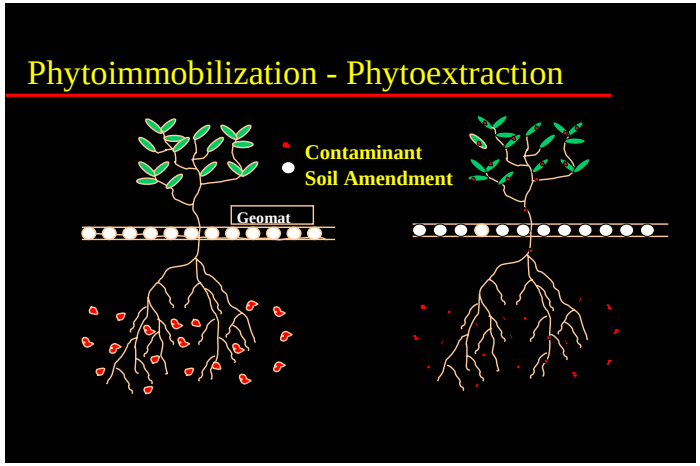
- Thorium is not considered essential for plant growth.
- It has been reported that the mobility of thorium is restricted in plants because of adsorption on cell wall material, and that thorium plant concentrations were typically several orders of magnitude lower than soil concentrations (CR values in annual grass species range from 0.001-0.05; Zararsiz et al., 1997).

Background information

- A field screening study and a greenhouse study were conducted to assess the ability of selected plant species to extract U and Th form contaminated soils. The study site was an ecologically sensitive wetland located on the U.S. Department of Energy's Savannah River Site near Aiken, South Carolina.

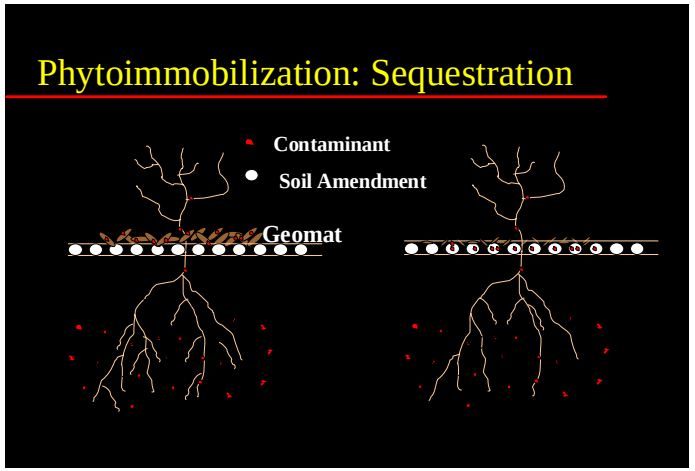
Phytoimmobilization

Phytoimmobilization is a two-stage remediation process. It was patented by Dr. S.Serkiz (patent number: 6560920) and successfully demonstrated by Kaplan et al, 2001. This study evaluated the potential use of native plants to phytoimmobilize inorganic contaminants in a wetland environment.



In the first stage, phytoextraction, plants are used to translocate contaminants from the soil to the above-ground plant biomass.

In the second stage contaminants released from decomposing plant material are immobilized in either a mineral-amended surface soil or a mineral-containing mat (geomat) deployed at the ground surface.



Elemental composition and total concentration ratio (plant concentration/total soil concentration) of wetland plants

Plant/Tree species	Co		Cr		Hg		Pb		U		Th	
	ppm	CR	ppm	CR	ppm	CR	ppm	CR	ppm	CR	ppm	CR
Netted chain fern	**2.4**	**0.65**	**4.7**	**0.11**	**0.8**	**0.12**	**0.7**	**0.17**	**20.7**	**0.11**	**21.5**	**0.107**
Switch cane	0.8	0.10	1.7	0.04	BDL	---	0.6	0.15	0.6	0.003	0.8	0.004
Red maple	0.3	0.08	1.0	0.02	0.1	0.01	0.3	0.07	0.3	0.002	0.3	0.002
Bald-cypress	0.4	0.11	0.8	0.02	0.0	0.00	0.2	0.05	0.2	0.001	0.3	0.002
Sweetgum	0.5	0.14	1.0	0.02	0.1	0.01	0.2	0.05	4.0	0.021	0.3	0.002

B.D.L. = below detection limit (~0.01 mg/L Hg)

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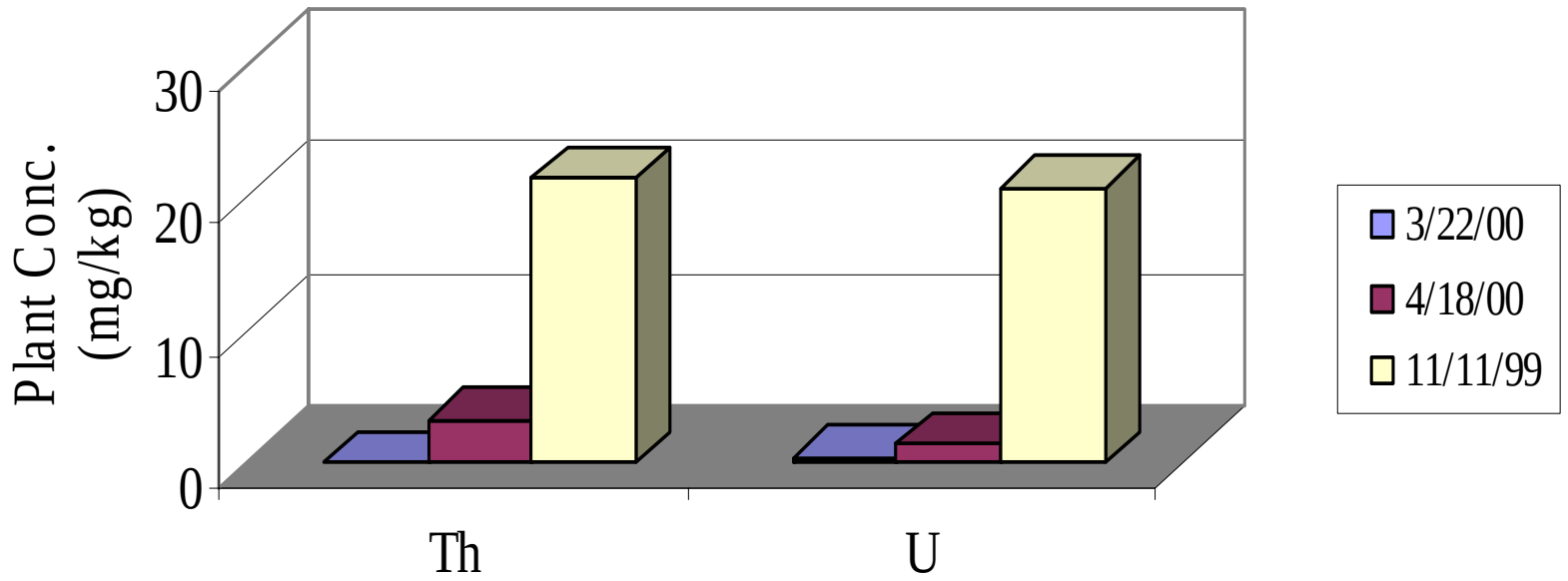
Netted Chain Fern *(Woodwardia aerolata)*

- Netted chain fern has fronds with unpaired leaflets, most are not cut to the stalk; leaflets have net-like veins. Sterile fronds are broad and dark green; fertile fronds are narrow and more erect. Two chain-like rows of spore cases may be seen on the back of the leaf.
  Habitat: Bogs and swamps.

Thorium and U concentrations in netted chain fern as a function of harvesting date



Soil physical and chemical characteristics

Sand	Silt	Clay	Fe-oxide	pH	OC	AEC	CEC
----------% wt.----------					mg/kg	---cmol/kg---	
57.5	24.5	11.7	0.07	4.7	1299	1.7	8.0

Sequential extraction of U and Th (%)

Sequential extraction results show high percentages of U and Th were removed in exchangeable and organically bound fractions (mean ± SD; n = 5)

Element	Exchangeable	Organic	Amorphous	Crystalline	Residual
Th	0.6 ± 0.5	81 ± 10	9 ± 4	5 ± 2	4 ± 6
U	31 ± 8	50 ± 10	4 ± 1	2 ± 1	13 ± 2

Exchangeable: extracted by diluted acetic acid [0.44 *M* CH_3COOH + 0.1 *M* $Ca(NO_3)_2$]
Organic: extracted by sodium pyrophosphate [0.1 *M* ($Na_4P_2O_7$)]
Amorphous: associated with amorphous Al- and Fe-oxides, pH 3 [0.17 *M* $(NH_4)_2C_2O_4$ + 0.1 *M* $H_2C_2O_4$]
Crystalline: crystalline Al_2O_3 and Fe_2O_3 [3.3% Na-dithionite in 0.15 *M* Na-citrate + 0.05 *M* citric acid]
Residual: 1 part HNO_3, 3 parts HCl, and 1 part H_2O

Site-Specific Phytoextraction Potential*

Site-Specific Phytoextraction Potential (SPP) is a rough index of a plant's potential to remove *x* grams of contaminants from a hectare of soil over one year. The SPP is calculated as:

$SPP = C_{soil} \times CR \times M_{plant} \times CF$

SPP = site-specific phytoextraction potential (g of contaminant removed ha^{-1} y^{-1});

C_{soil} = contaminant concentration in soil (mg kg^{-1});

CR = concentration ratio (mg kg^{-1} contaminant in dry plant / mg kg^{-1} contaminant in dry soil);

M_{plant} = plant's annual biomass production (kg ha^{-1} y^{-1}); and

CF = mg to g conversion factor of 0.001

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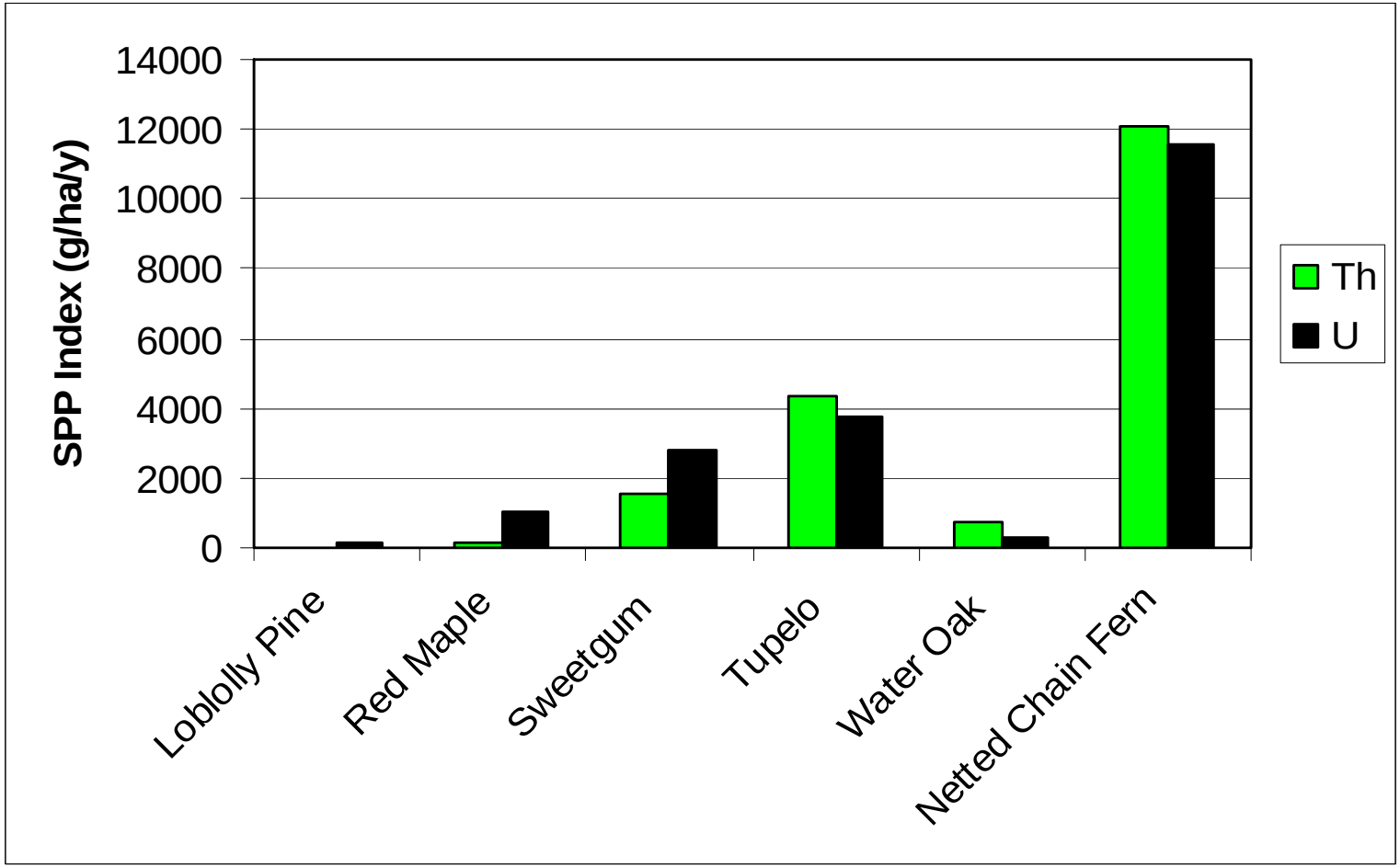
Site-Specific Phytoextraction Potential



Greenhouse experiments

The objective of the experiment was to determine the proportion of contaminants, mainly U and Th, that netted chain fern (*Woodwardia areolata)* and Bermuda grass (*Cynnodon dactylon*) would take up from three wetland soils.

Materials

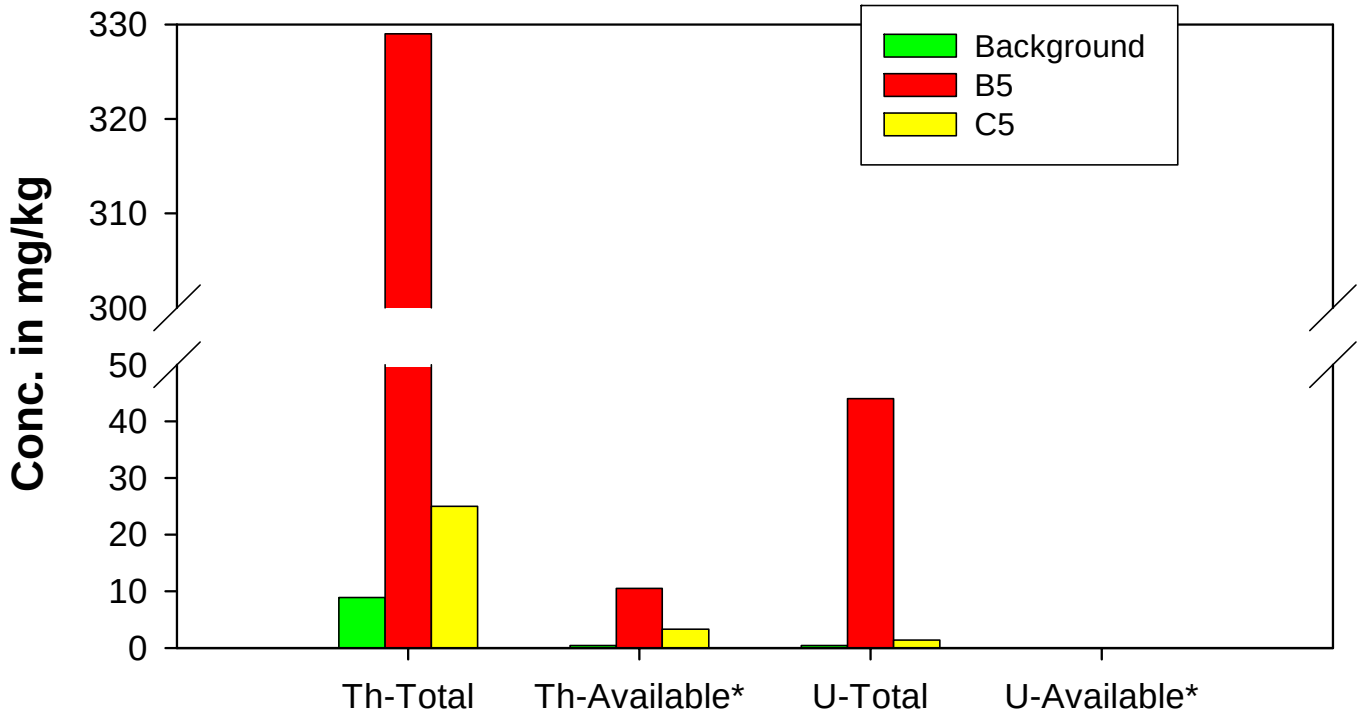
SOIL

- Two of the soils were collected from a contaminated site (coordinates B-5 and C-5)
- One soil was collected from a nearby non-contaminated area (referred to as the background soil)

PLANTS

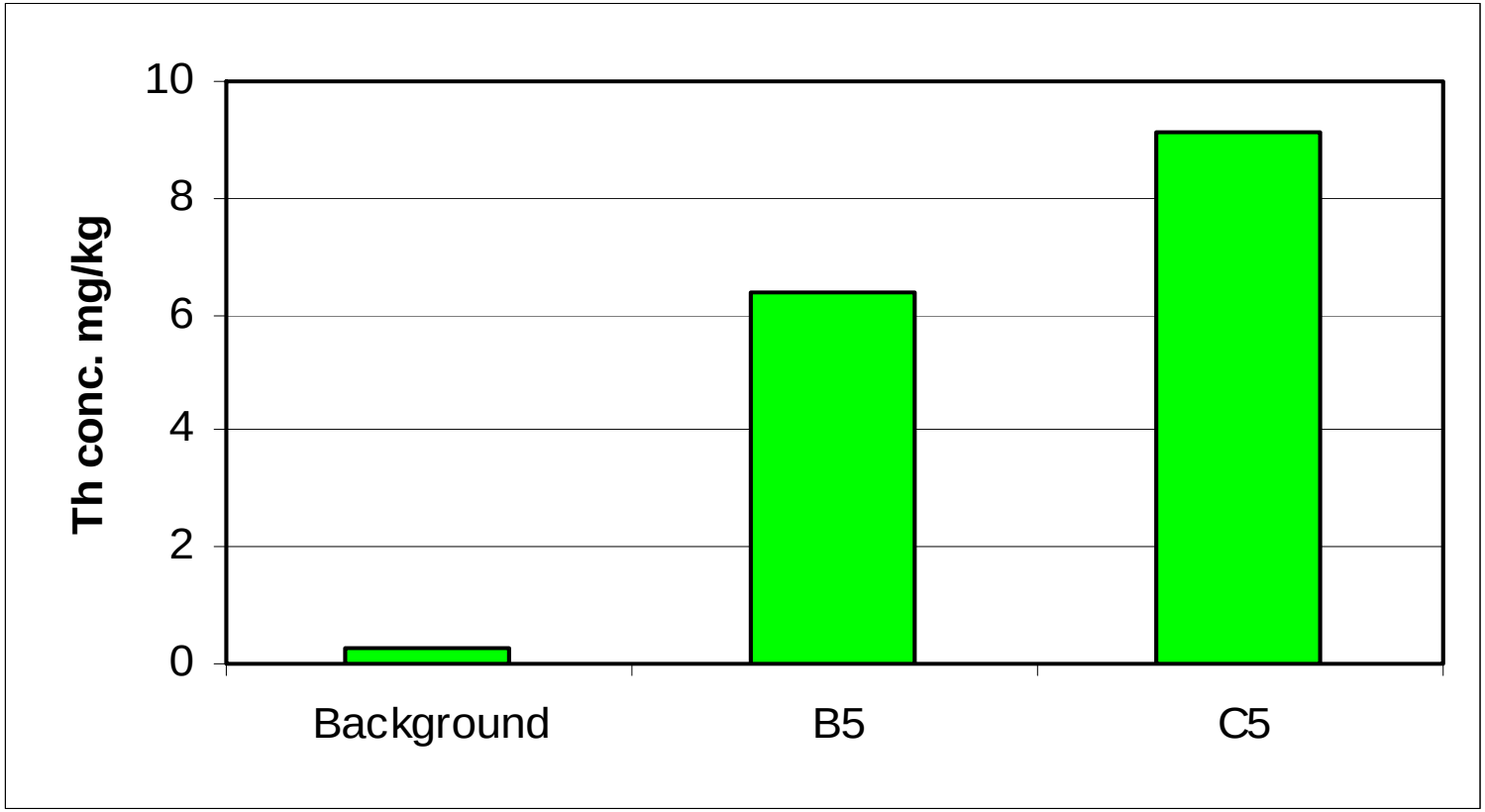
- The netted chain fern was selected for this test because a preliminary survey of plant uptake at the study site showed that this plant had relatively high concentration ratios.
- The Bermuda grass was selected as an example of a monocotyledon, which generally do not translocate metals from roots to the aboveground portion of the plant.

Thorium and U concentrations in soils

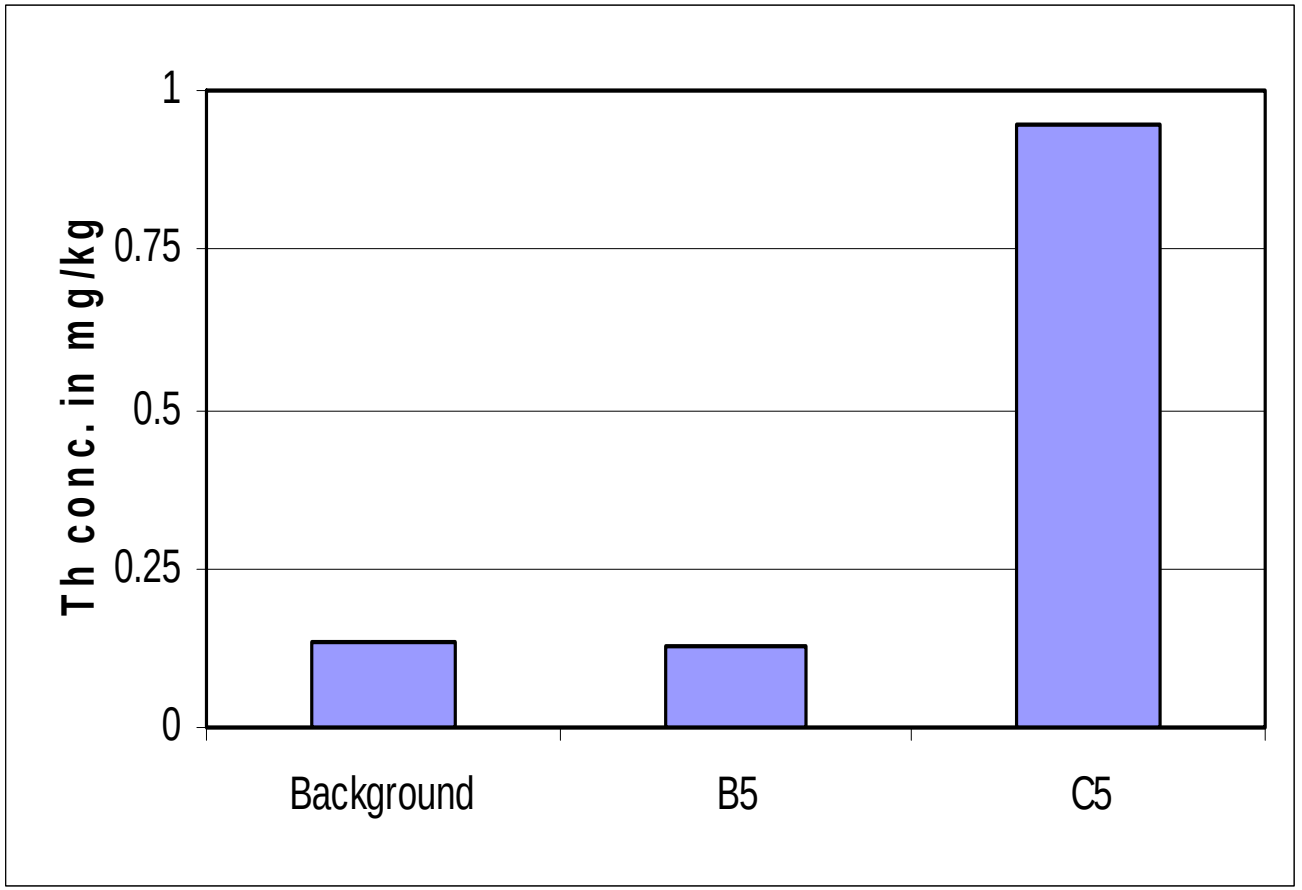


*Available pool of elements was determined by DTPA chelation method (Lindsay and Norvell, 1978).

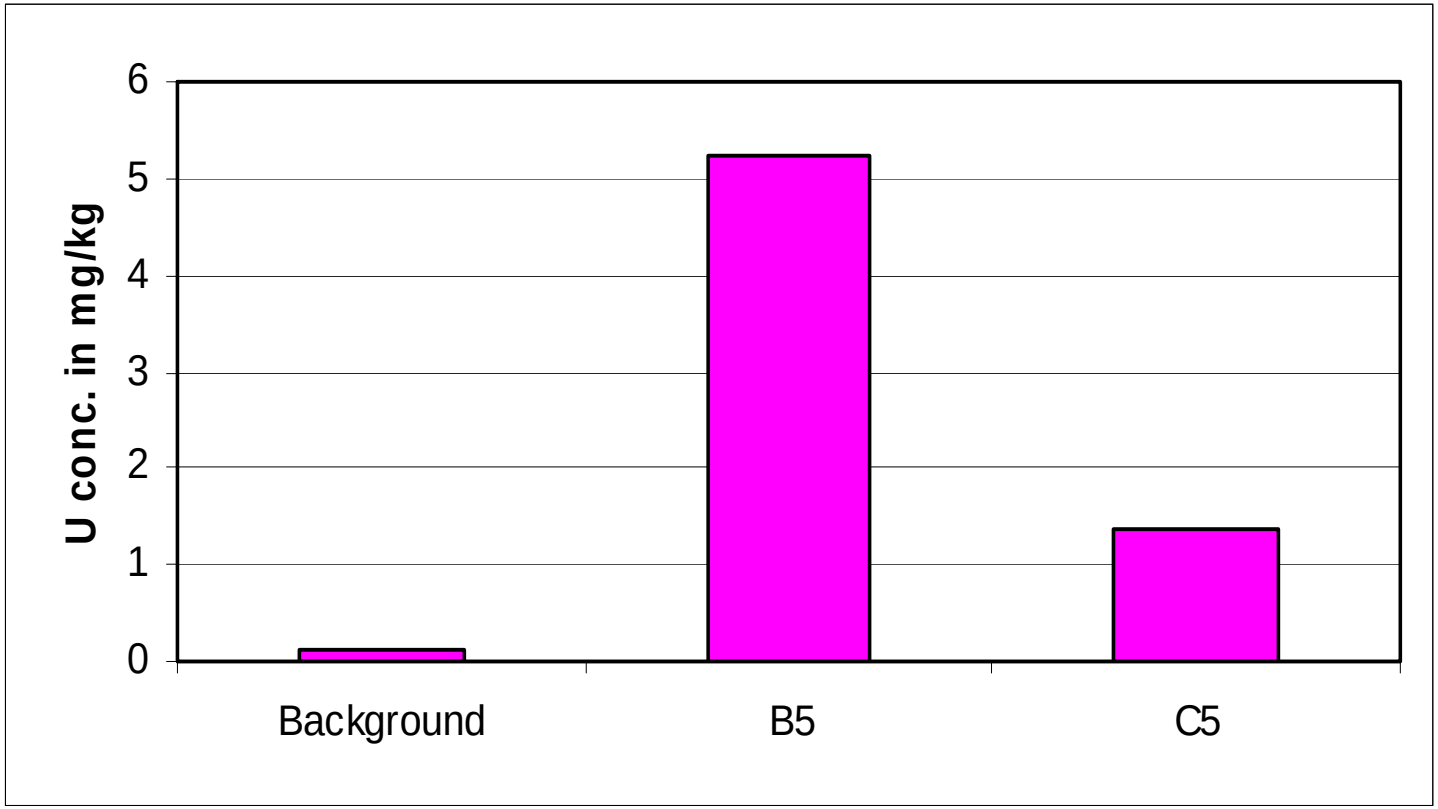
Thorium concentration in netted chain fern



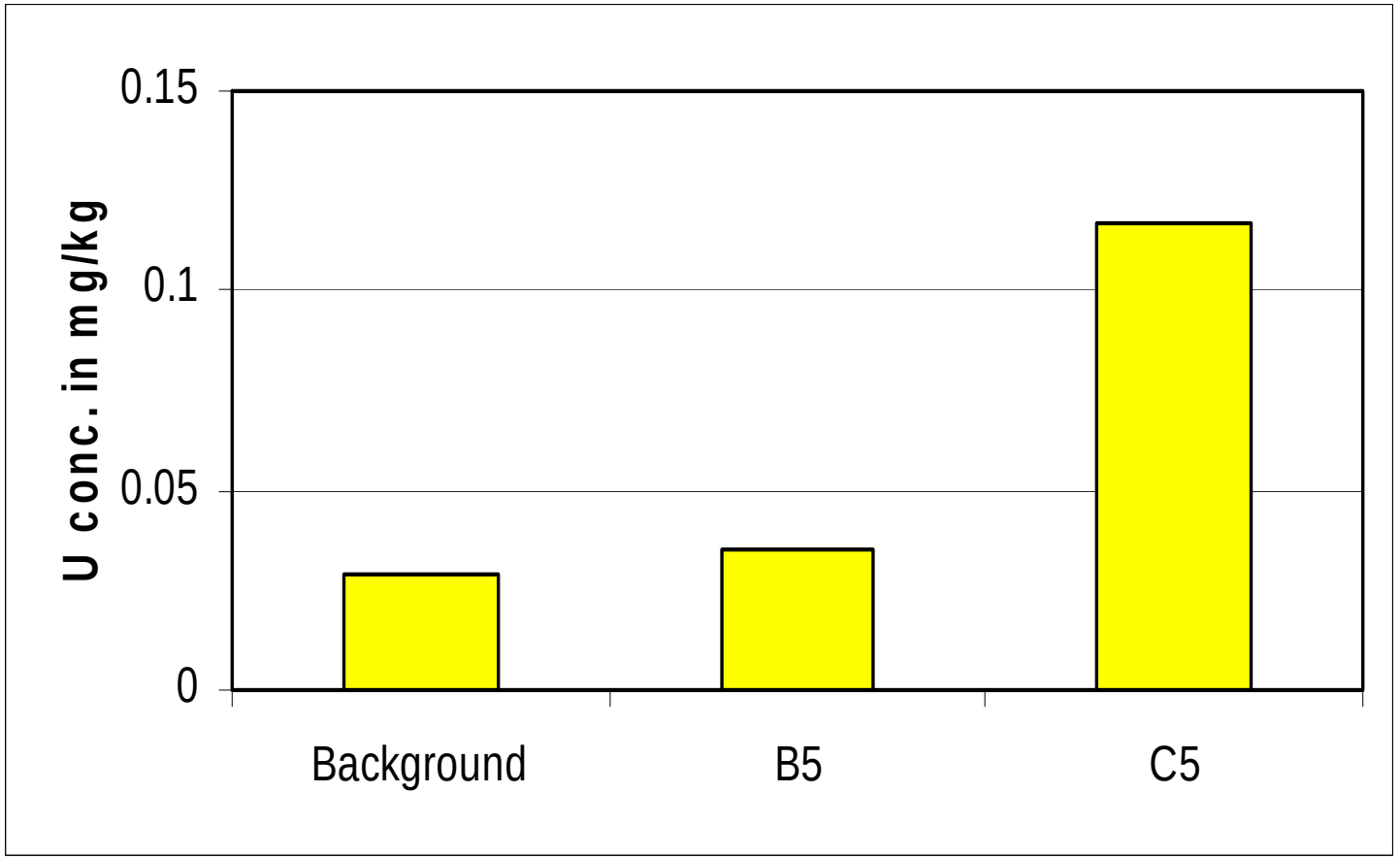
Thorium concentration in Bermuda grass



Uranium concentration in netted chain fern



Uranium concentration in Bermuda grass



Concentration ratio (CR) for fern and grass harvested after six weeks of growth on the contaminated soil

Soil/Location	Th		U	
	Fern	Bermuda	Fern	Bermuda
Background	0.03	0.01	0.30	0.06
B5	0.20	0.0004	0.12	0.0008
C5	0.36	0.10	0.97	0.08
Literature review of more than 100 CRs for different plant species*				
Geometric mean	0.0045		0.0036	

* Sheppard and Evenden, *J. Environ. Radioact*., 8 (1988); 255.

Summary

- Thorium and U concentrations in both contaminated soils were high, e.g., 329 mg kg^{-1} of Th in soil B. The bioavailability of Th and U was estimated by the concentrations of these elements in DTPA extracts. Thorium and U DTPA-concentrations were low, 7.9 and 0.27 mg kg^{-1}, respectively.

- Ferns grown in the uncontaminated background soils (which contained 8.9 mg kg^{-1} Th and 0.4 mg kg^{-1} U) contained 0.3 mg kg^{-1} Th and 0.1 mg kg^{-1} U. Ferns grown in the contaminated soil (which contained 329 mg kg^{-1} Th and 44 mg kg^{-1} U) contained 6.4 mg kg^{-1} Th and 5.3 mg kg^{-1} U. The concentrations of these elements were at least an order of magnitude greater than in Bermuda grass.

- The elevated concentrations of Th and U in fern tissues could have potential in phytoremediation of Th and U contaminated soil, sediments, and perhaps water.

- Elevated uptake of U and Th by netted chain fern has implications for the assessment of ecological risks to organisms that consume this species in contaminated habitats.

Research needed to assess the potential application of netted chain fern in phytoremediation

- Evaluation of netted chain fern growth and element uptake in different environments, for example, upland or water
- Evaluation of element translocation from roots to shoot
- Applying agricultural practices to enhance biomass of this plant
- Chemically-induced phytoextraction of radionuclides and other metals by netted chain fern
- Genetic modification of netted chain fern to induce greater phytoextraction of contaminants and increased plant biomass
- Economic potential of netted chain fern in phytoremediation