Biomonitoring of trace element uptake by trees in a former uranium mining area in Germany

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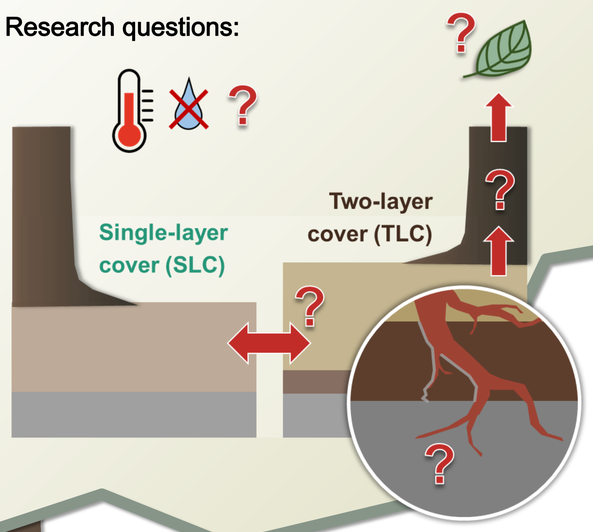
1) Introduction

- ~ 230,000 t uranium mined from 1947-1990 in Thuringia and Saxony (Germany) → In 1991, **Wismut GmbH** was founded to **remediate former uranium mining areas** [1]
- Nowadays, **climate change** poses **increasing challenges** due to more extreme hydrological conditions → e.g., could **affect** the **vitality of trees** planted for erosion protection
- In BMBF-funded **project MykoBEst, dendroanalysis using** laser ablation inductively coupled mass spectrometry (**LA-ICP-MS**) will be **established as a biomonitoring tool** for the study sites Beerwalde and Reuster Forst near Ronneburg (Thuringia, Germany)

Research questions:



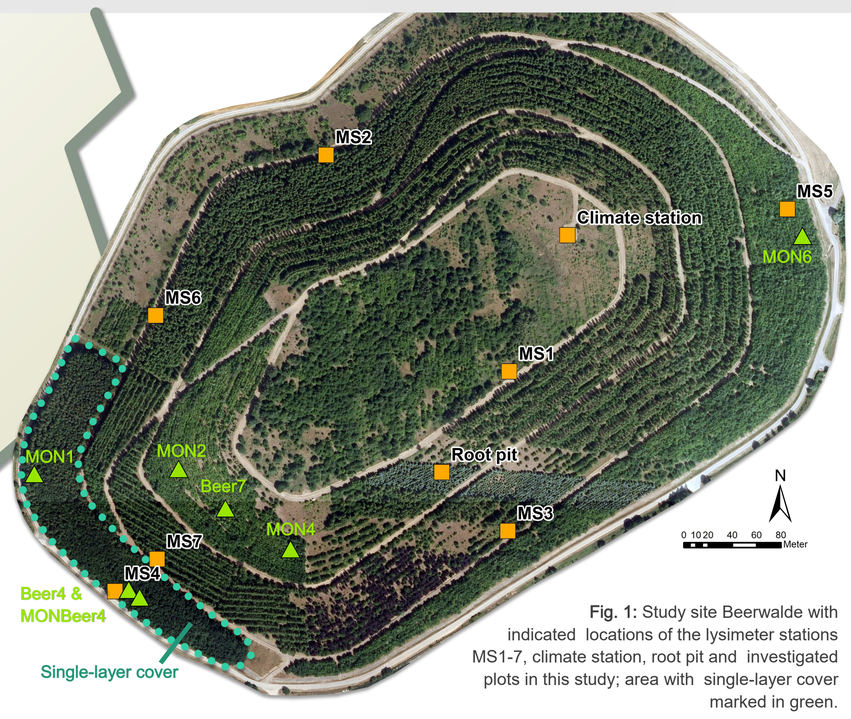


Fig. 1: Study site Beerwalde with indicated locations of the lysimeter stations MS1-7, climate station, root pit and investigated plots in this study; area with single-layer cover marked in green.

2) Materials & Methods

Study site:

- Waste rock dump **Beerwalde consists of 3 spoil heaps:** [2]
  - **Beerwalde** (4.5 Mio m^3): deposited 1967-1983 → **Single-layer cover (SLC)**
  - **Korbußen** (0.4 Mio m^3) & **Drosen** (3.9 Mio m^3): were moved to Beerwalde 1999-2002 → **Two-layer cover (TLC)**
- **Slopes** were **flattened**, waste rock material was **covered with uncontaminated soil,** the area was **afforested** until 2002
- **Climate station, root pit** and **seven lysimeter measuring stations** were installed for monitoring

Sampling and Analysis:

Leaves	Tree trunk	Soil	+
Sampling of leaves August 2024 Sampling of leaves November 2024 → Microwave digestion → **Element content** of leaves (**bulk value**) via ICP-MS and -OES	Sampling of tree cores via increment borer  → **Element content** of wood chips (**bulk value**) via ICP-MS and -OES → **Spatially** resolved **element contents** via LA-ICP-MS	Mixed soil sample around trees 1-3 (O=Oak, B=Beech) and at control (C) Soil sample Sampling depths: • S1: ~0-30 cm • S2: ~30-50 cm Tree1 Tree2 Tree3 C Soil profile Max. sampling depth: 80 cm → Sequential extraction → Element contents of the **bioavailable fraction (I & II)** via ICP-MS and -OES	Analysis of seepage water from lysimeters Vegetation mapping Chlorophyll fluorescence measurements of leaves

3) First Results

Leaves

- Variations in elemental composition of leaves detected → Depends on: Cover systems (different source materials) and tree species
- Soil and leaf analysis alone insufficient to assess integrity of the barrier layer → LA-ICP-MS required for time-resolved process understanding

Change August to November [%]	
K	-39
P	-4
S	-31
Al	+135
As	+191
Cd	+20
Cr	+169
Ni	+35
Pb	+142
U	+104
Th	+188

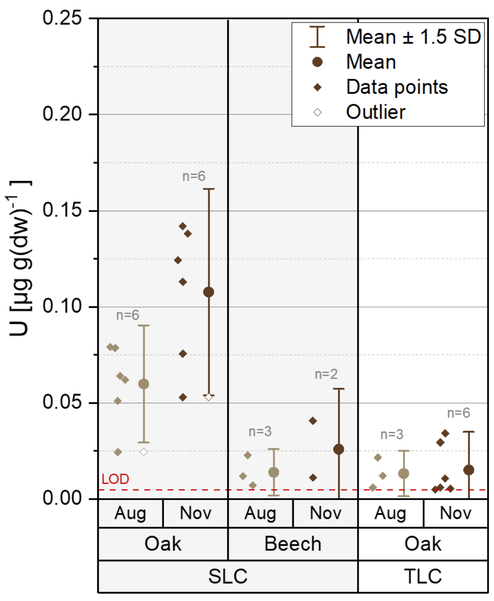


Fig. 2: Uranium content in the leaves of the plots Beer4, Beer7, MON1 and MON2 (Tree 1-3) in Aug and Nov 2024; Values < LOD were removed; Number of samples per plot and tree species: n(SLC-Oak)=6, n(SLC-Beech-Aug)=3, n(SLC-Beech-Nov)=2, n(TLC-Oak)=6; Number of values > LOD are indicated.

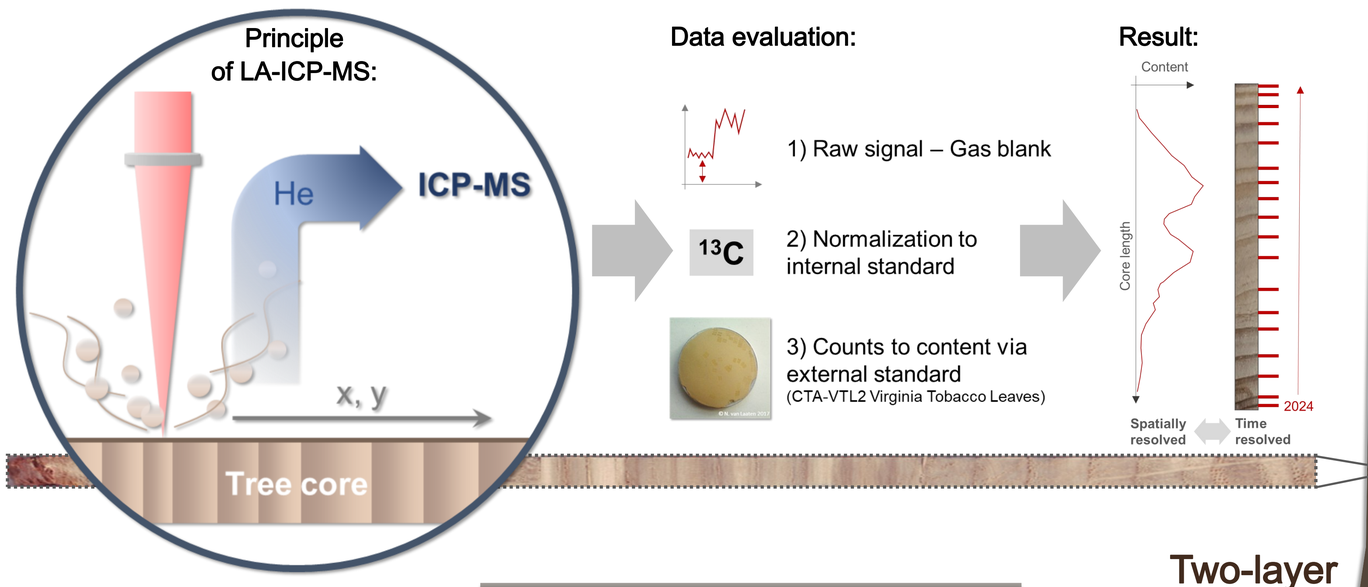
Transfer factor Soil to leaves
Content in leaves / Bioavailable content in soil

	Beer4		Beer7
Al	46.2	>	19.8
As	3.8	>	2.4
Cd	1.7	<	6.4
Cr	45.7	<	48.2
Pb	1.9	<	2.2
Th	7.2	>	3.6
U	1.7	<	2.2

Mean transfer factors for Beer 4 and Beer 7 calculated using depths S1 & S2 and fractions I + II; For values < LOD, the LOD was used in calculations.

Tree trunk

- Bulk analysis of tree cores from Beer4 & Beer7 indicated low trace element contents:
  - Content < LOD [LOD in µg g^{-1}]: As [0.03], Th [0.014], U [0.01]
  - Content > LOD [Range in µg g^{-1}]: Cd [<0.013-0.016], Cr [0.74-3.12], Cu [1.52-30.9], Ni [0.85-9], Pb [<0.04-0.34], Sr [1.524-5.01], Zn [1.02-10.3]
- **LA-ICP-MS: Essential for spatially resolved analysis** of trace element distribution in tree cores → Potential insight: Changes in element content may indicate root growth through the sealing layer into waste rock material



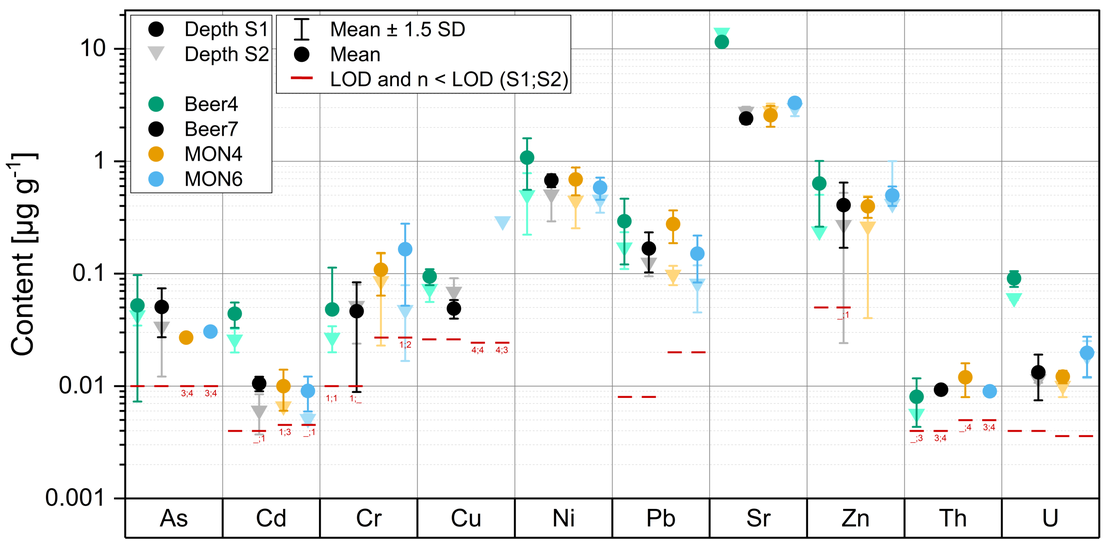


Fig. 3: Bioavailable content (sum of fraction I and II) of different trace elements at Beer4, Beer7, MON4 and MON6 at two different depths S1 (~0-30 cm) and S2 (~30-50 cm); samples: O1-3 and C; number of samples per plot and depth n=4; content < LOD: values not shown (n < LOD indicated below LOD).

Soil (Storage layer)

- **Storage layer material** for SLC and TLC originates from **different source materials** → Different soil properties and geogenic background:
  - **Soil texture:** SLC - weak silty clay (Tu2); TLC - heavy loamy sand (Sl4)
  - Beer4 (SLC), compared to Beer7 (TLC), was characterized by a higher **C, N, Al, Mn, Fe and nutrient content** (total)
  - Also **total content** of **trace elements** was higher at Beer4 (SLC) than at Beer7 (TLC) → similar pattern observed for **bioavailable fraction** of some elements
  - Bioavailable trace element content higher at depth S1 (~0-30 cm) than at depth S2 (~30-50 cm)

Single-layer cover (SLC)
Tree age ~ 40 years
Ly1 (Surface Run Off)
1.2 m
Storage layer (loam)
Ly2 (Percolation)
Waste rock material

Two-layer cover (TLC)
Tree age ~ 20 years
Ly1 (Surface Run Off)
Storage layer (sand and loam mixture)
1.5 m
Ly2 (Lateral Flow)
Sealing layer (clayey loam)
0.4 m
Ly3 (Percolation)
Waste rock material

(*) Ly = Lysimeter

References:

[1] A. Märten, D. Berger, M. Köhler, D. Merten, „The dendroanalysis of oak trees as a method of biomonitoring past and recent contamination in an area influenced by uranium mining", *ESPR*, 22(24):19417-25, Dec. 2015, doi: 10.1007/s11356-015-4902-z.

[2] U. Barnekow, M. Roscher, R. Sieland, M. Köhler, „After-care monitoring on the covered mine waste dump Beerwalde - Lessons learned", in *Reclaimed Mining Sites between Post-Remedial Care and Reuse - Proceedings des Internationalen Bergbausymposiums WISSYM_2015*, pp. 287-295, 2015.

Illustration of the different cover systems based on:
[3] A. Schramm and M. Roscher, „Two-layer soil covers on selected radioactive waste rock dumps at Wismut: results of more than ten years of hydrological monitoring", in M. Tibbett, A. B. Fourie & C. Digby (eds), *Mine Closure 2013: Proceedings of the Eighth International Seminar on Mine Closure*, Australian Centre for Geomechanics, Cornwall, pp. 207-222, doi: 10.36487/ACG_rep/1352_18_Schramm.

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