Towards livermorium chemistry: Homologue studies with polonium and tellurium

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for the JGU-GSI-HIM-CTU-ÚJF-UiO collaboration

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

GSI

HIM HELMHOLTZ Helmholtz-Institut Mainz

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

ÚJF

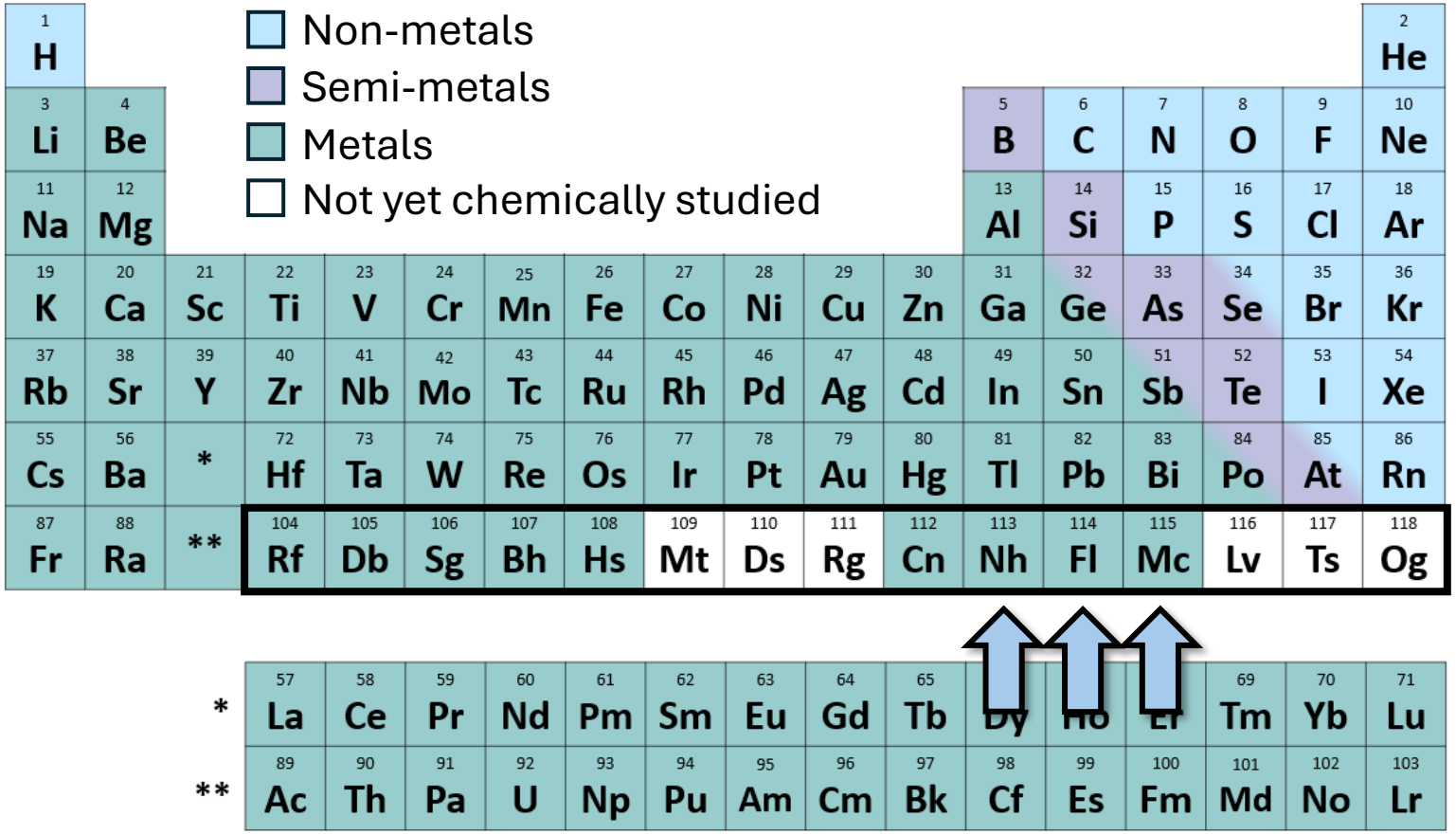
UiO University of Oslo

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Pushing the heavy element chemistry frontier



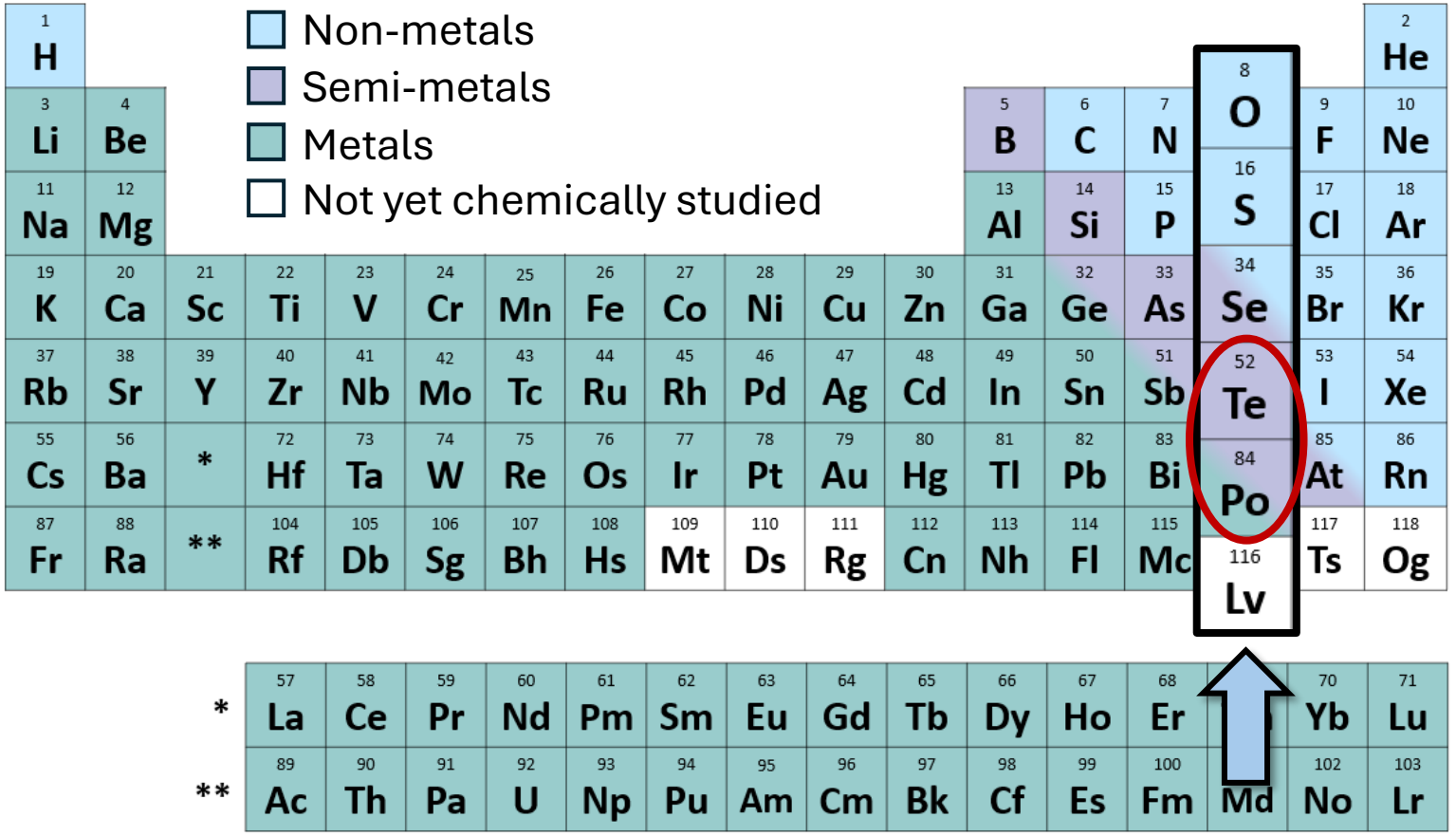
Chemistry of nihonium (Z = 113), flerovium (Z=114) and moscovium (Z = 115) studied recently in gas chromatography experiments

284 Nh	288 Fl	288 Mc
0.97 s	0.64 s	0.17 s

A. Yakushev et al., *Front. Chem.* **2024**, *12*, 1474820.

A. Yakushev et al., *Front. Chem.* **2022**, *10*, 976635.

Pushing the heavy element chemistry frontier

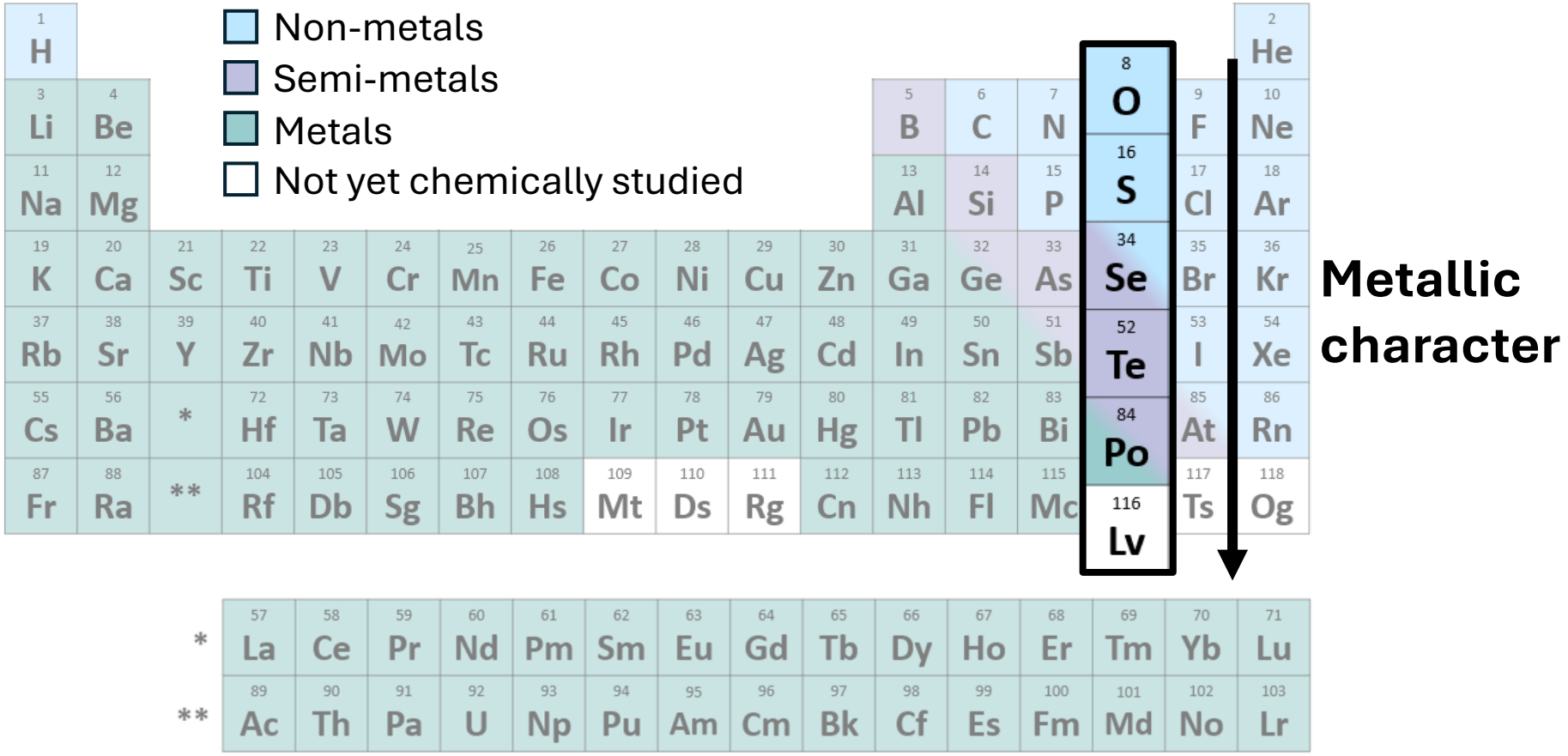


Next goal: first livermorium chemistry

293
Lv
57 ms

First step: Studies of lighter homologues using similar experimental methods

What is known about the lighter homologues?



What is known about the lighter homologues?

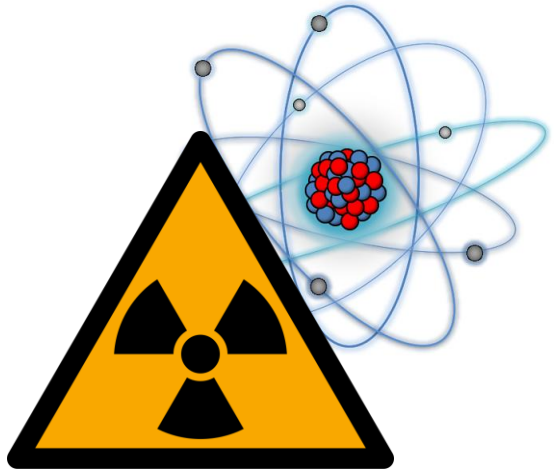
8	O
16	S
34	Se
52	Te
84	Po
116	Lv

Elements form similar compounds:

Oxides	Oxoacids
(SO), SO_2, SO_3	H_2SO_3, H_2SO_4
(SeO), SeO_2, SeO_3	H_2SeO_3, H_2SeO_4
(TeO), TeO_2, TeO_3	H_2TeO_3, $(H_2TeO_4)_n$
PoO, PoO_2, PoO_3	H_2PoO_3, $PoO_3 \cdot$ aq

Most stable oxidation state of Te and Po: +IV

Chemically studying Po is difficult:



Highly radiotoxic, only available in small amounts

What is known about the lighter homologues?

Thermochromatography experiments on metals show strong adsorption of polonium to metal surfaces

$-\Delta H_{ads}^{Au}$ (Po) = (250 ± 7) kJ/mol

E. A. Maugeri et al., *Radiochim. Acta*. **2016**, *104*, 757-767

Similar reactivity of polonium and livermorium predicted in fully relativistic quantumchemical calculations



V. Pershina, M. Iliaš, *Mol. Phys*. **2025**, *123*, 2573831

A. Ryzhkov et al., *Phys. Chem. Chem. Phys*. **2023**, *25*, 15362

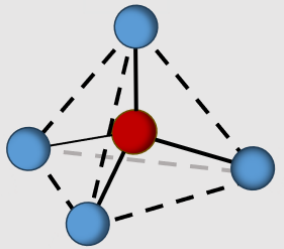




Experiments with polonium and livermorium on metal surfaces demand high temperatures

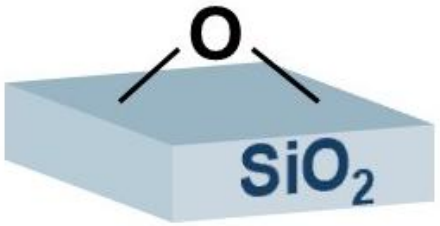
Lower temperatures needed on quartz (SiO_2) surfaces

Quartz is the suitable material for future chemical studies of livermorium

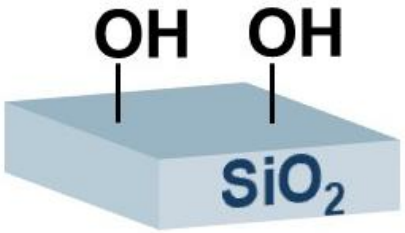


Unravelling the influence of the quartz surfaces

Quartz surface reactivity is not constant:



Siloxane
Less reactive



Silanol
More reactive

$$\text{-Si-O-Si-} + H_2 \longrightarrow \text{-SiOH} + \text{-SiH}$$

$$\text{-Si-O-Si-} + H_2O \rightleftharpoons 2\ \text{-SiOH}$$

Can be reversed by high temperature treatment

The degree of hydroxylation is influenced by:

The production method

Melting of quartz in hydrogen flame Vs. Electromelting in vacuum

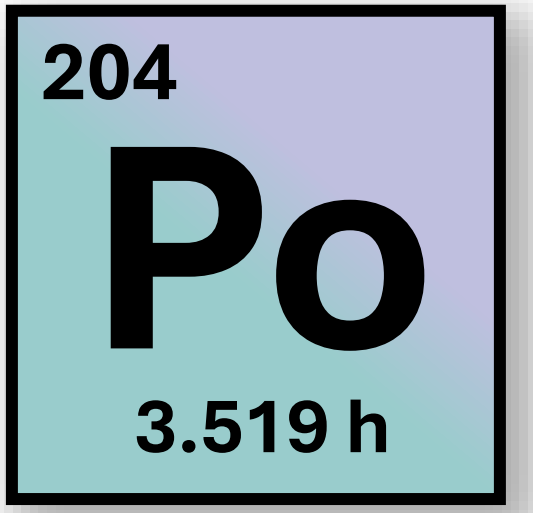
Storage conditions

Quartz reacts with atmospheric water

Thermal pretreatment

Under inert conditions Vs. With reactive gases

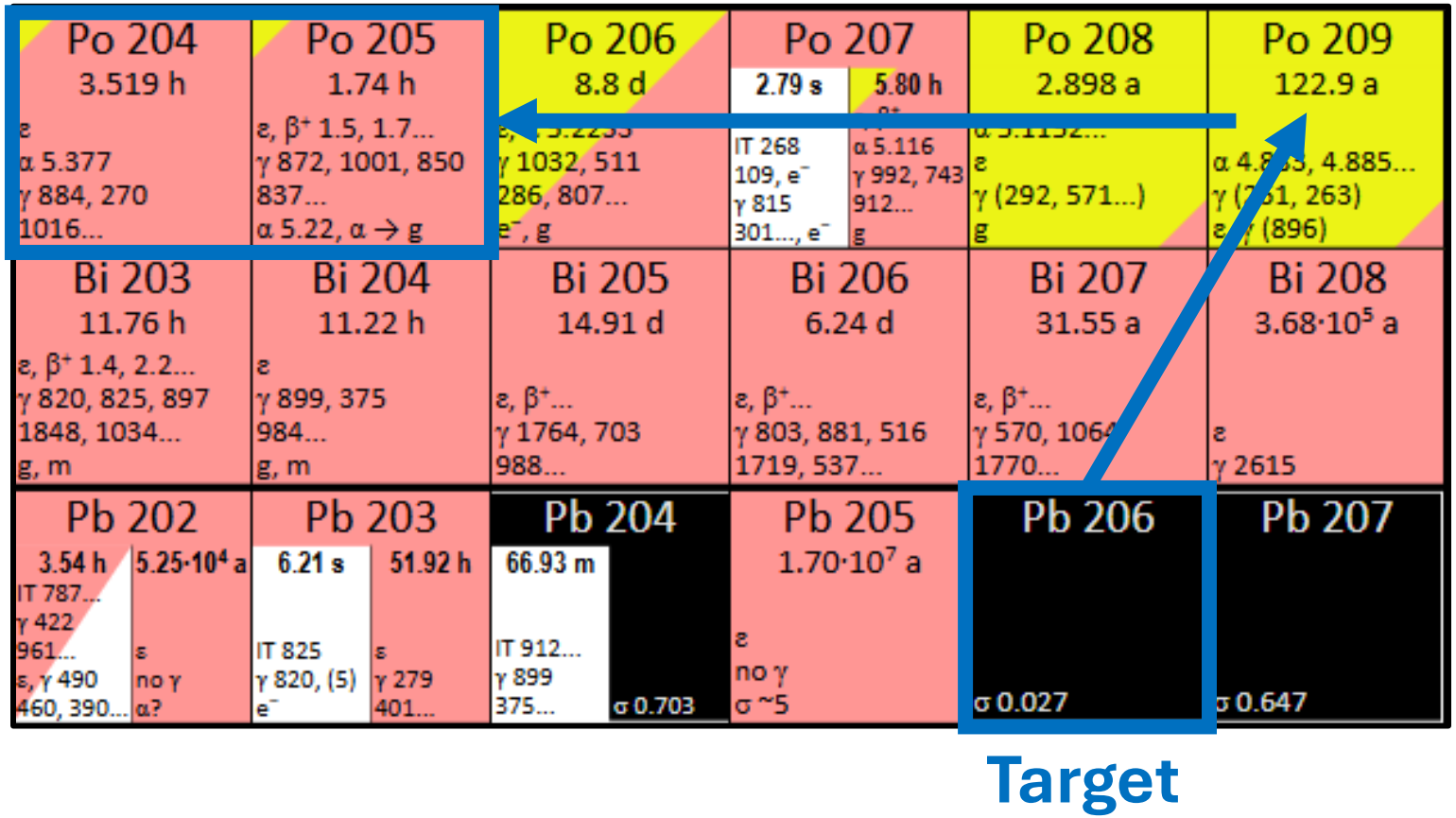
K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423. J. E. Shelby, *J. Non-cryt. Solids* **1994**, *179*, 138-147.



Experiments with polonium

Production of Polonium

Experiments conducted at the Nuclear Physics Institute CAS in Husinec-Řež



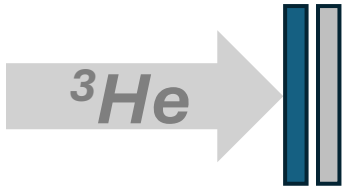
Target

Production in fusion reaction:
$^{206}Pb(^{3}He, 4\text{-}5n)^{205,204}Po$

Beam energy: 48 MeV

Beam current: 200 particle nA

Collection of produced activity in catcher foil (offline experiments)

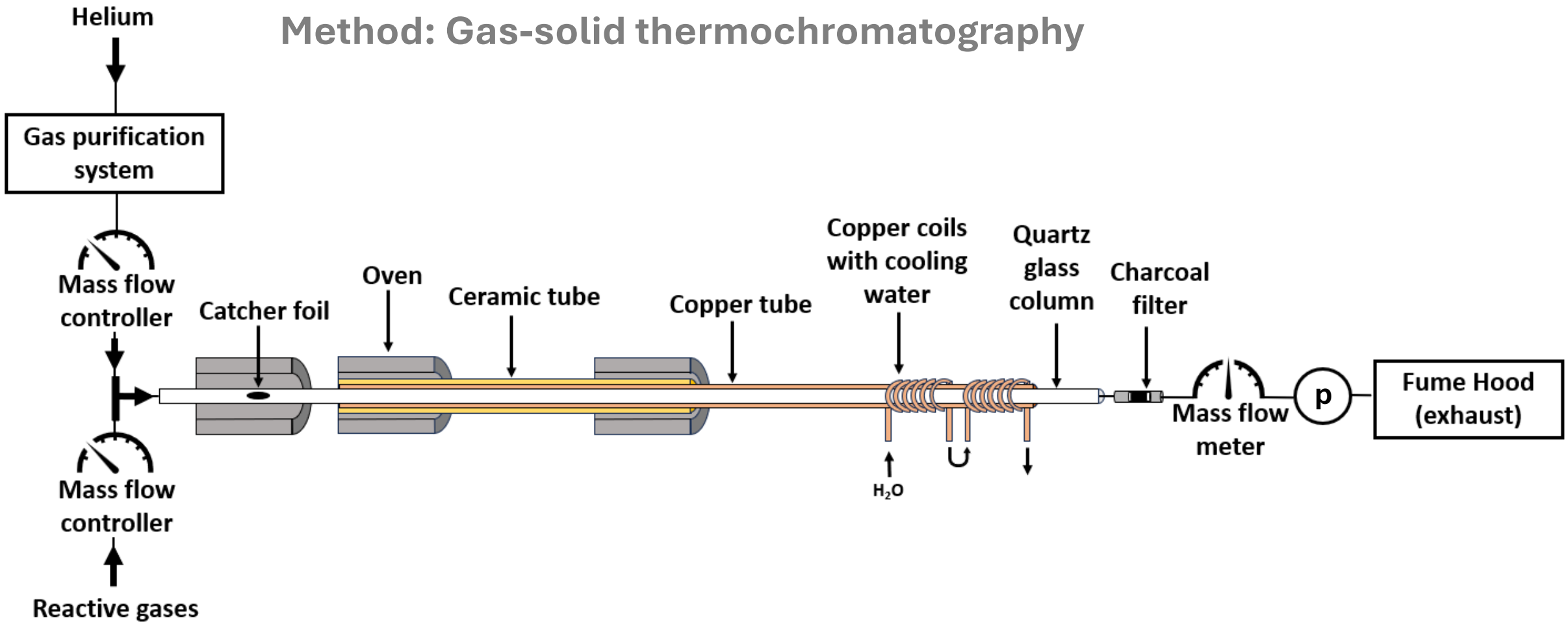


Target (^{206}Pb) Catcher (containing Po)

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

Studying homologues at the atom-at-a-time regime

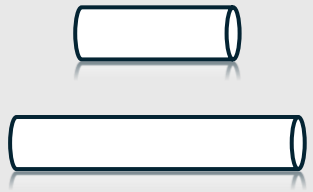
Method: Gas-solid thermochromatography



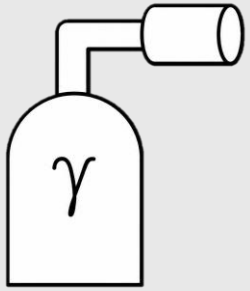
K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

Studying homologues at the atom-at-a-time regime

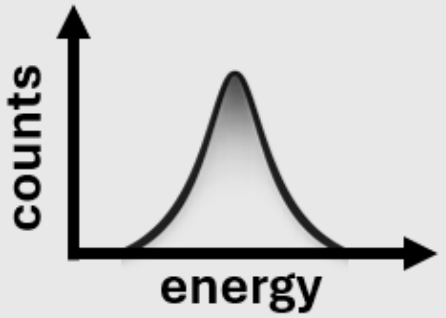
Detection of polonium/tellurium in the column



Column cut in 2 or 4 cm pieces



γ-Spectra of individual column pieces measured

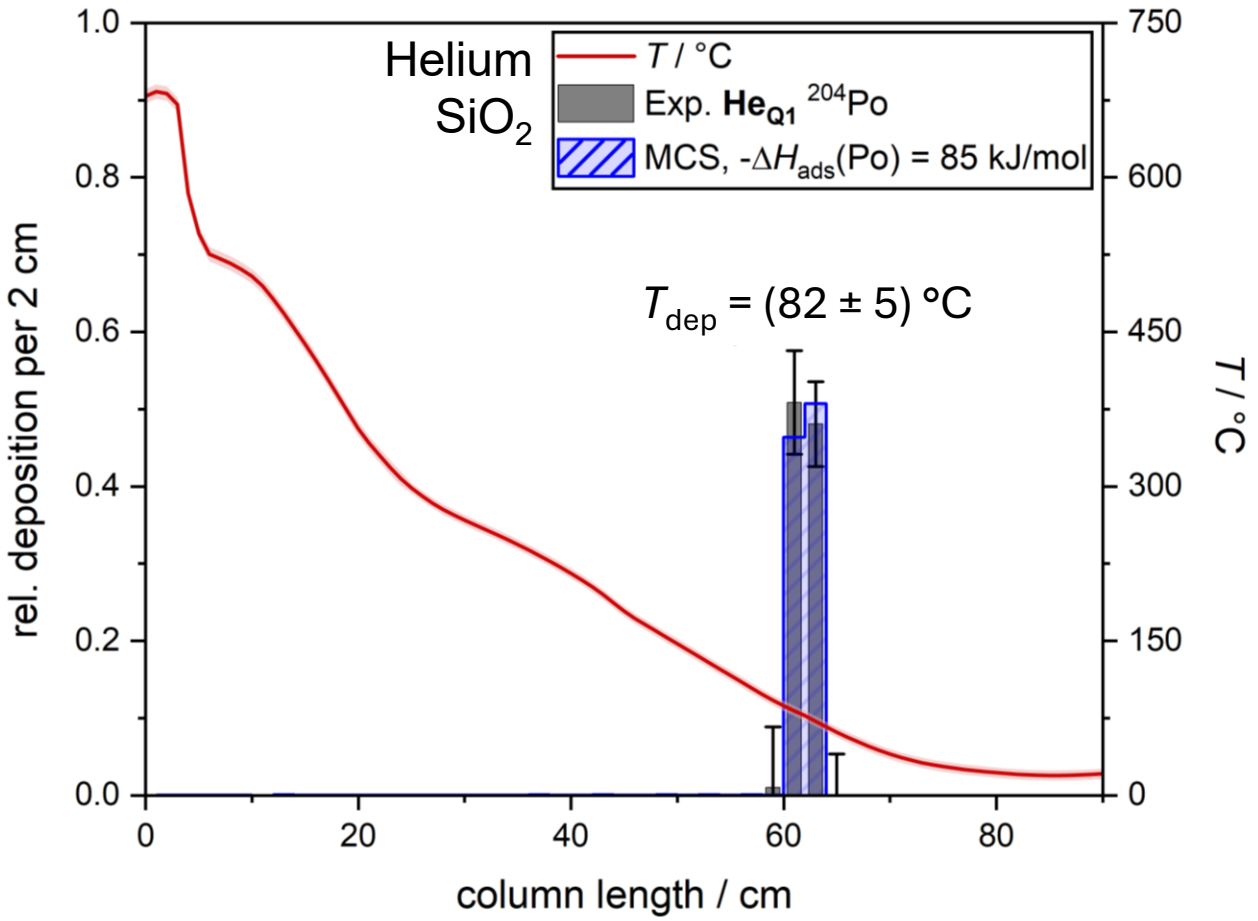


Polonium/tellurium γ-peaks integrated and baseline- and decay-corrected

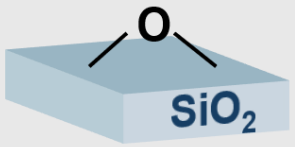
Corrected integrals were normalized to total polonium/tellurium activity

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

Adsorption enthalpy of elemental Po



Quartz was pretreated at 1000 °C in inert atmosphere for multiple hours



Only one chemical species observed

$-\Delta H_{ads}^{SiO_2}$ (Po) = 85^{+3}_{-2} kJ/mol,

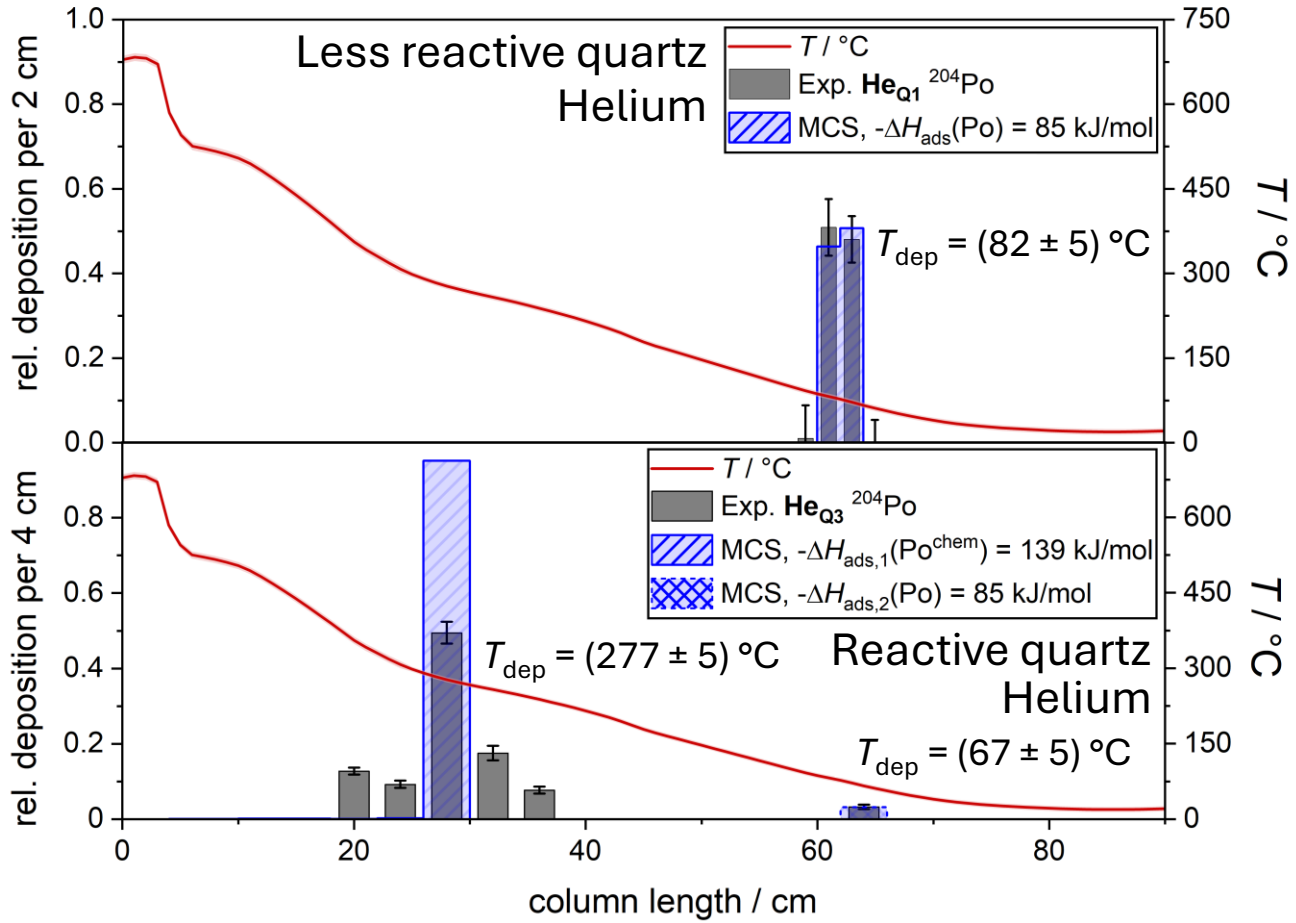
Species assigned to elemental polonium,

in agreement with literature

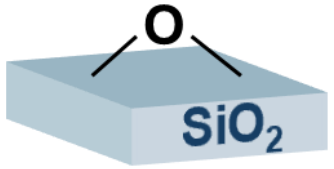
B. Eichler, *Kernenergie* **1976**, *19*, 307-311.
M. Gärtner, PhD Thesis, University Bern, Bern **2001**.

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

Unravelling the influence of the quartz surfaces



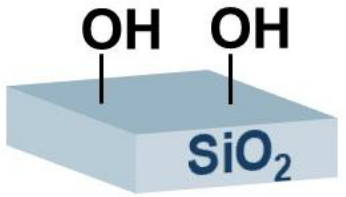
Only the quartz changed, all other parameters constant



$-\Delta H_{ads}(\mathrm{Po}) = 85^{+3}_{-2}$ kJ/mol

- $-\Delta H_{ads}$ is in agreement with work B. Eichler and M. Gärtner

B. Eichler, *Kernenergie* **1976**, *19*, 307-311.
M. Gärtner, PhD Thesis, University Bern, Bern **2001**.



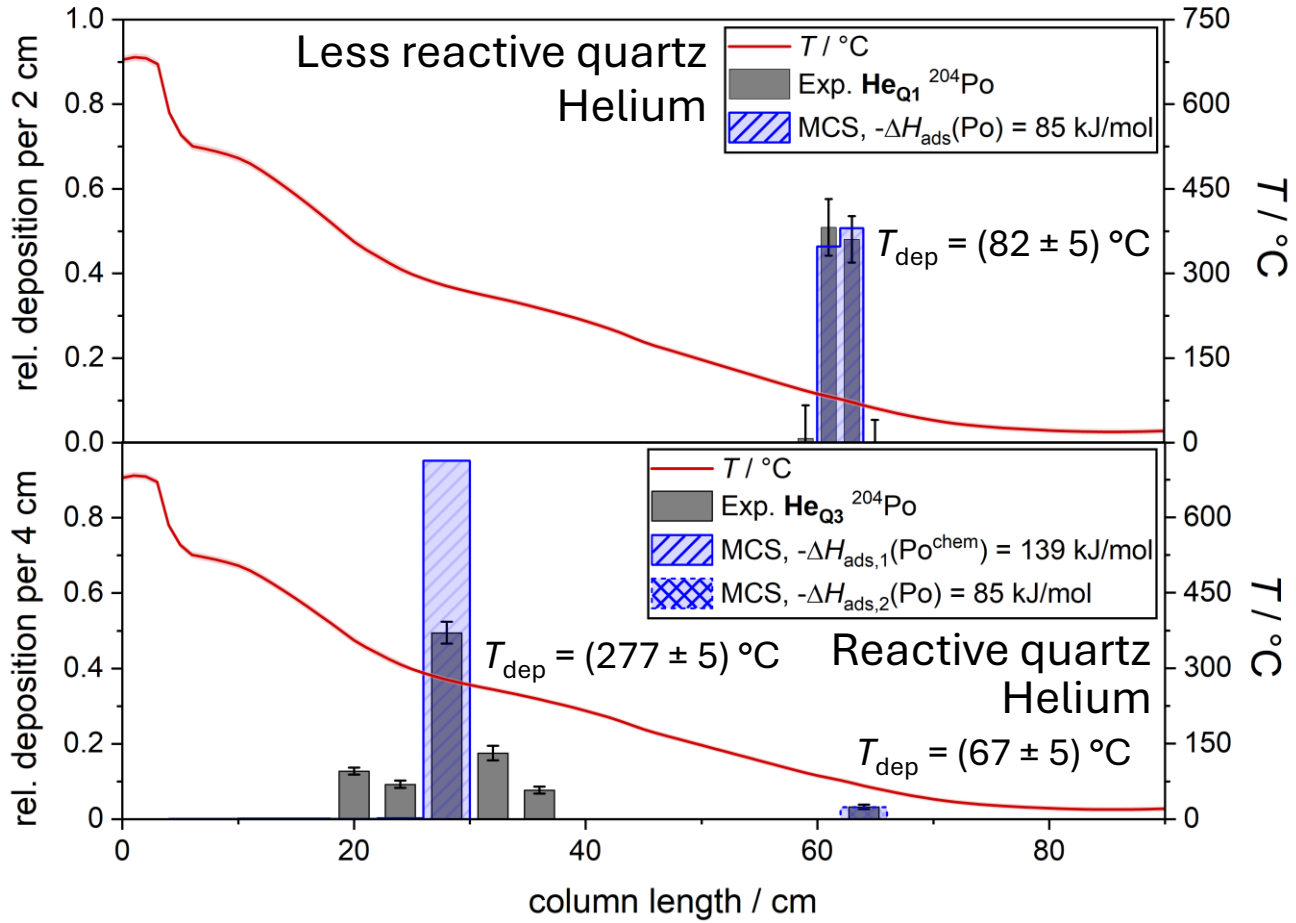
$-\Delta H_{ads}(\mathrm{Po^{chem.}}) = 139^{+6}_{-5}$ kJ/mol

- $-\Delta H_{ads}$ is in agreement with work by E. A. Maugeri et al.

E. A. Maugeri et al., *J. Nucl. Mater.* **2014**, *450*, 292-298.

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

Unravelling the influence of the quartz surfaces

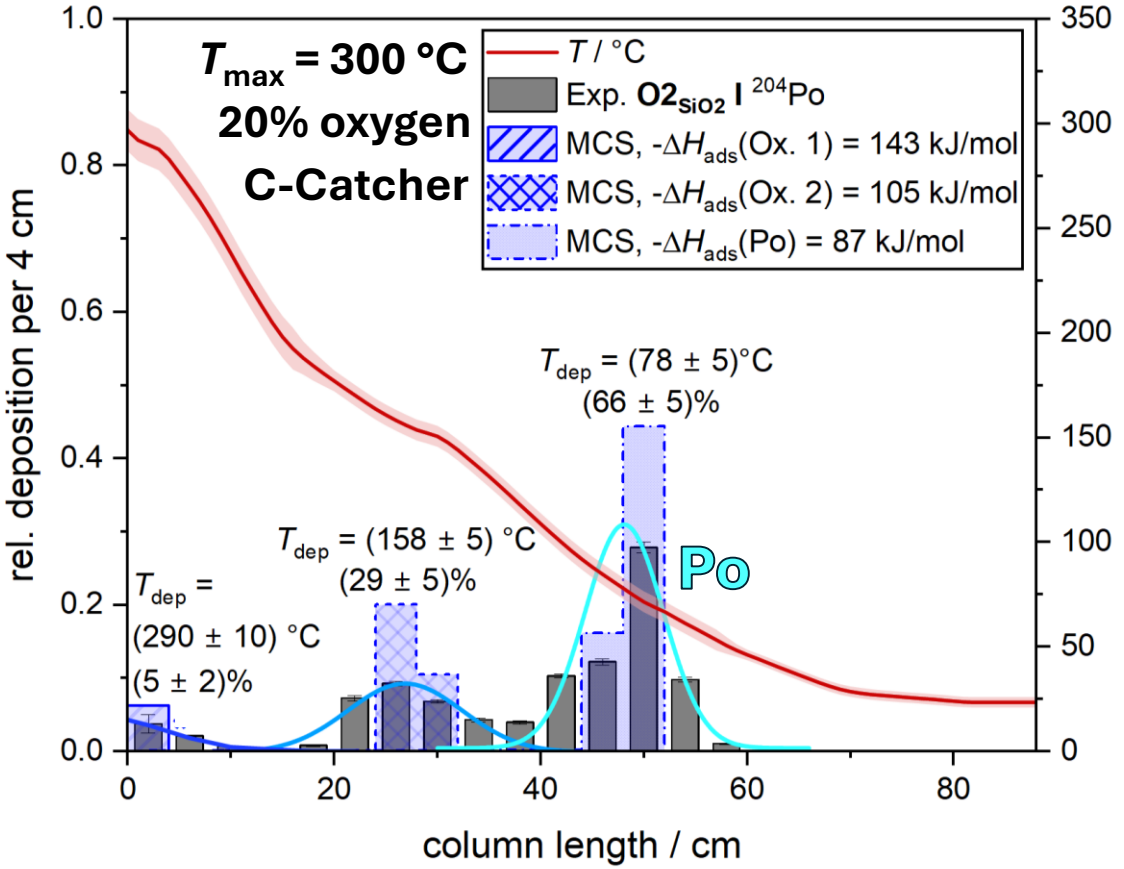


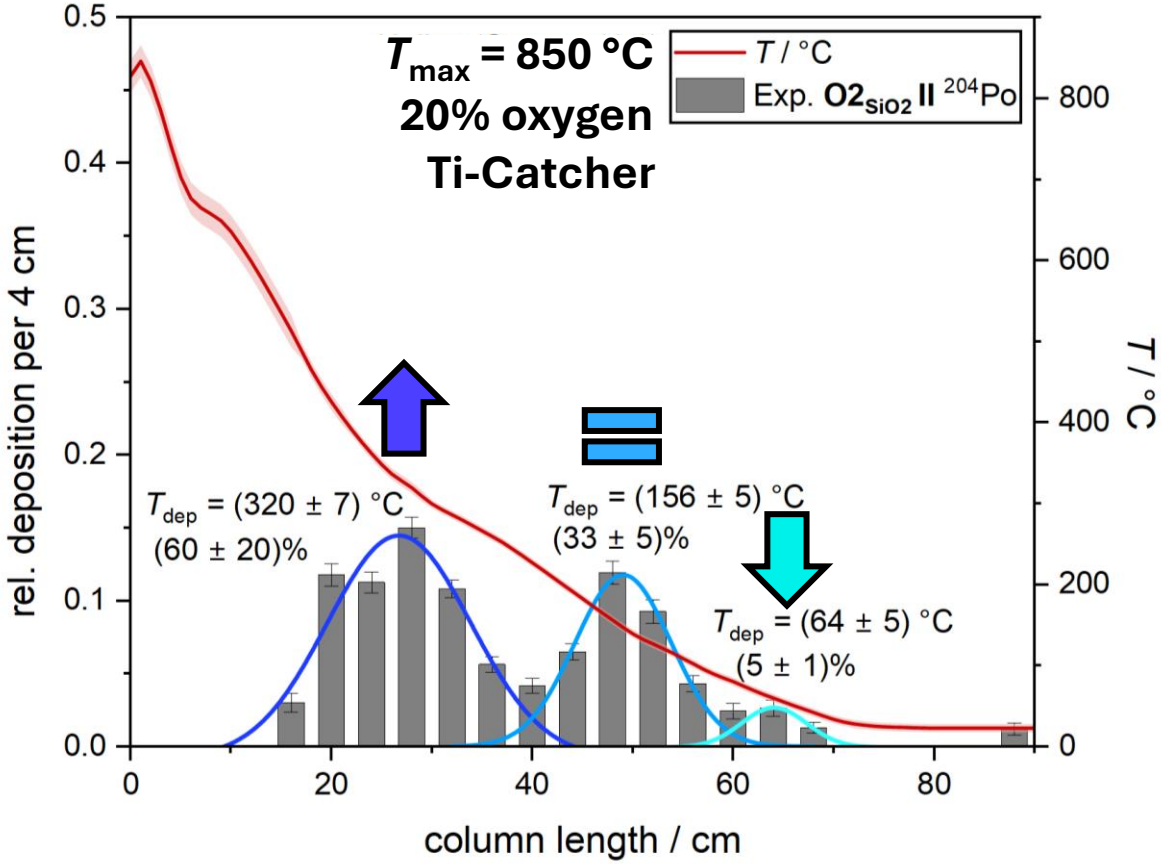
Results have been published:



K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

Reaction of polonium with oxygen

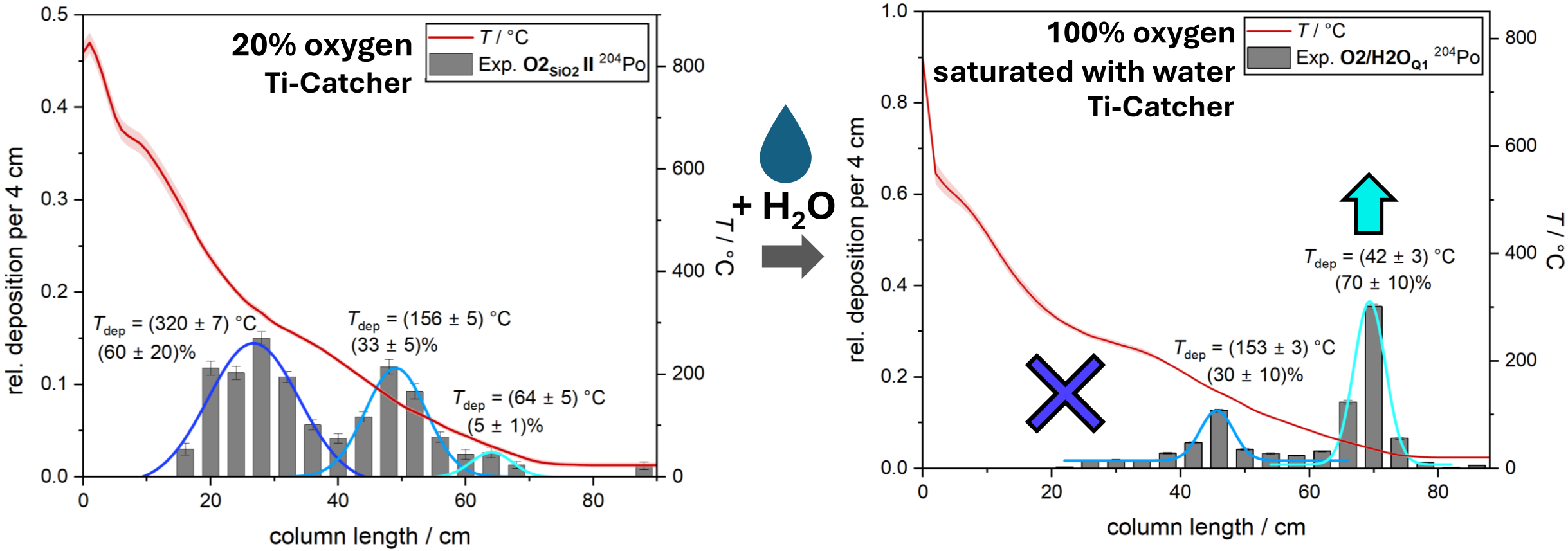




- Two oxidized species involved.
- Signs of chemical reaction!

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2026**, *28*, 7617-7628.

Reaction of polonium with oxygen and water



- Addition of water significantly effects proceeding chemical reaction.

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2026**, *28*, 7617-7628.

Reaction of polonium with oxygen and water

Two possible explanations:

Volatility: PoO_2 < PoO < Po

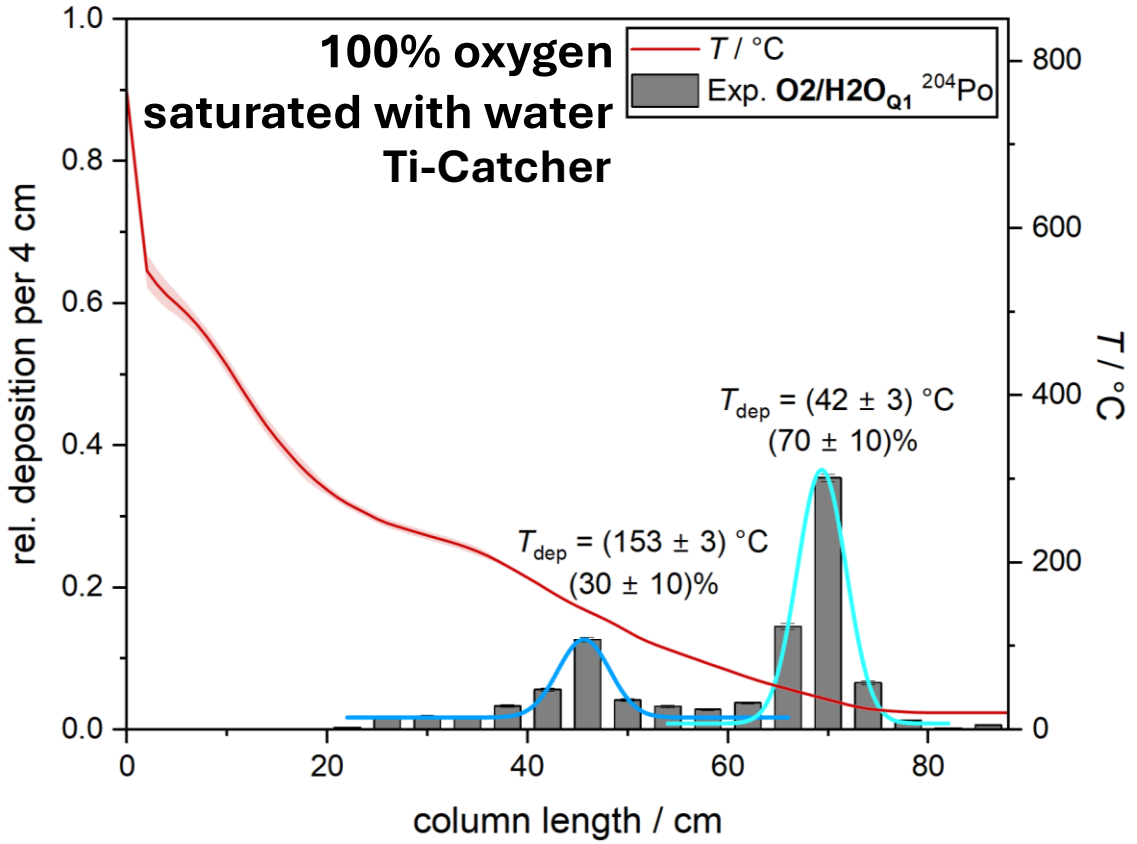
Decomposition of formed oxide species due to *in situ* modification of the surface.

- ➢ In agreement with theory

Volatility: PoO_2 < Oxoacid (H_2PoO_3) < Po

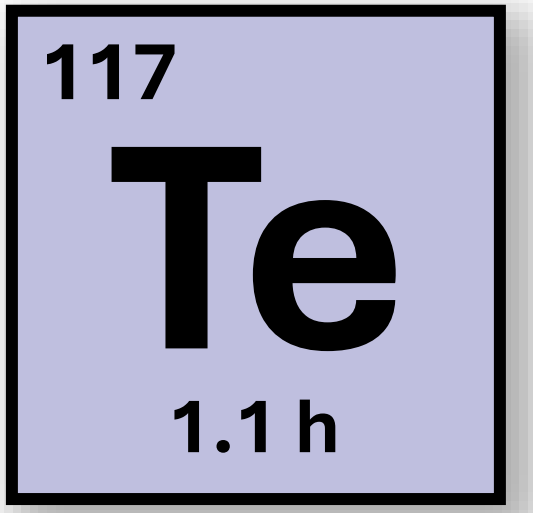
Stepwise reaction: First formation of oxide, then reaction to the more volatile oxyhydroxide.

- ➢ In accordance with Te chemistry



- ➢ Oxidation of polonium in oxygen depends on the maximum temperature and the water content in the carrier gas.

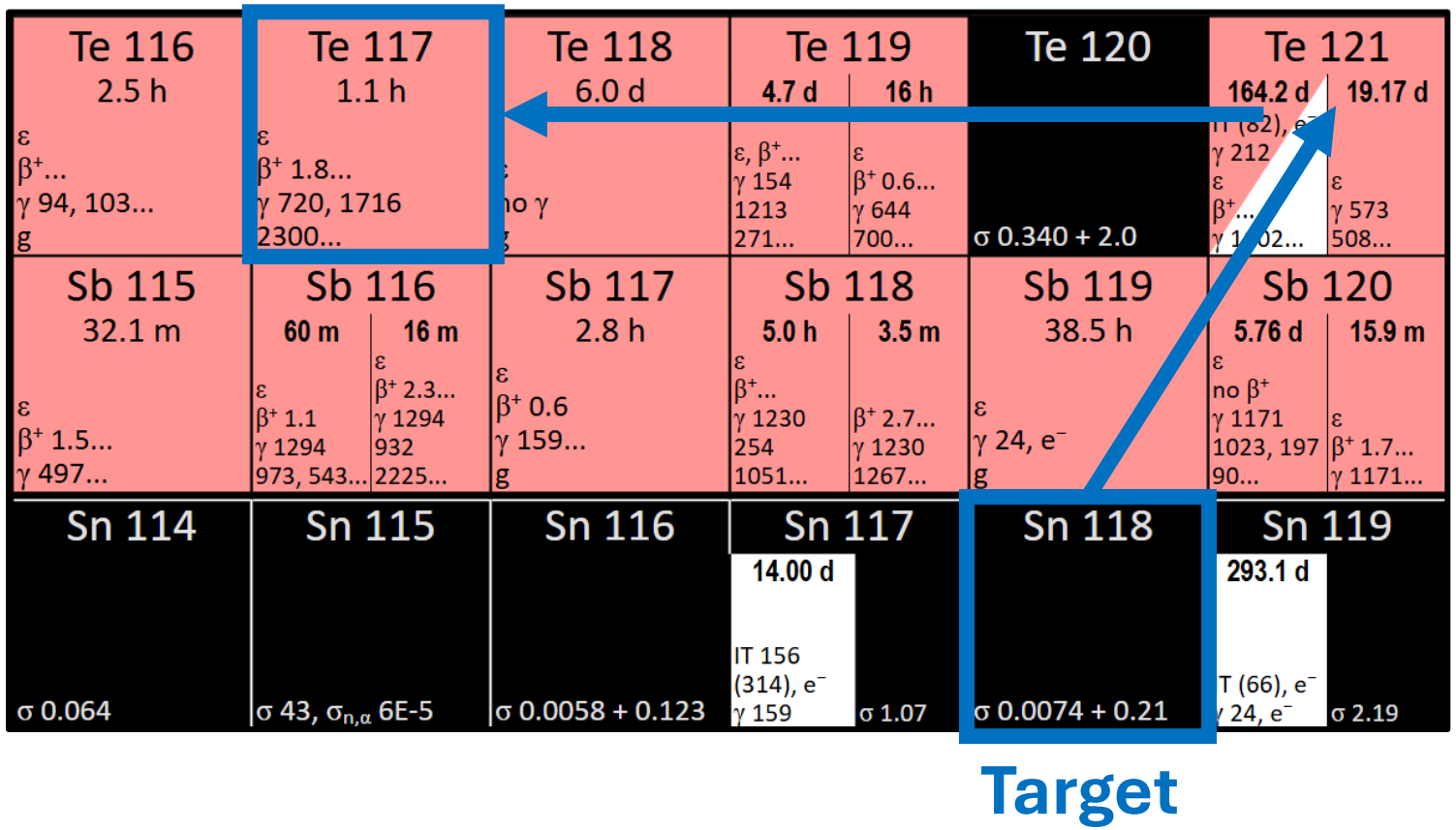
K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2026**, *28*, 7617-7628. V. Pershina, M. Iliaš, *Mol. Phys.* **2025**, *123*, 2573831



Experiments with tellurium

Exploring the trends in group 16

Additional experiments with tellurium conducted – same experimental setup



Production in fusion reaction: $^{118}Sn(^{3}He, 4n)^{117}Te$

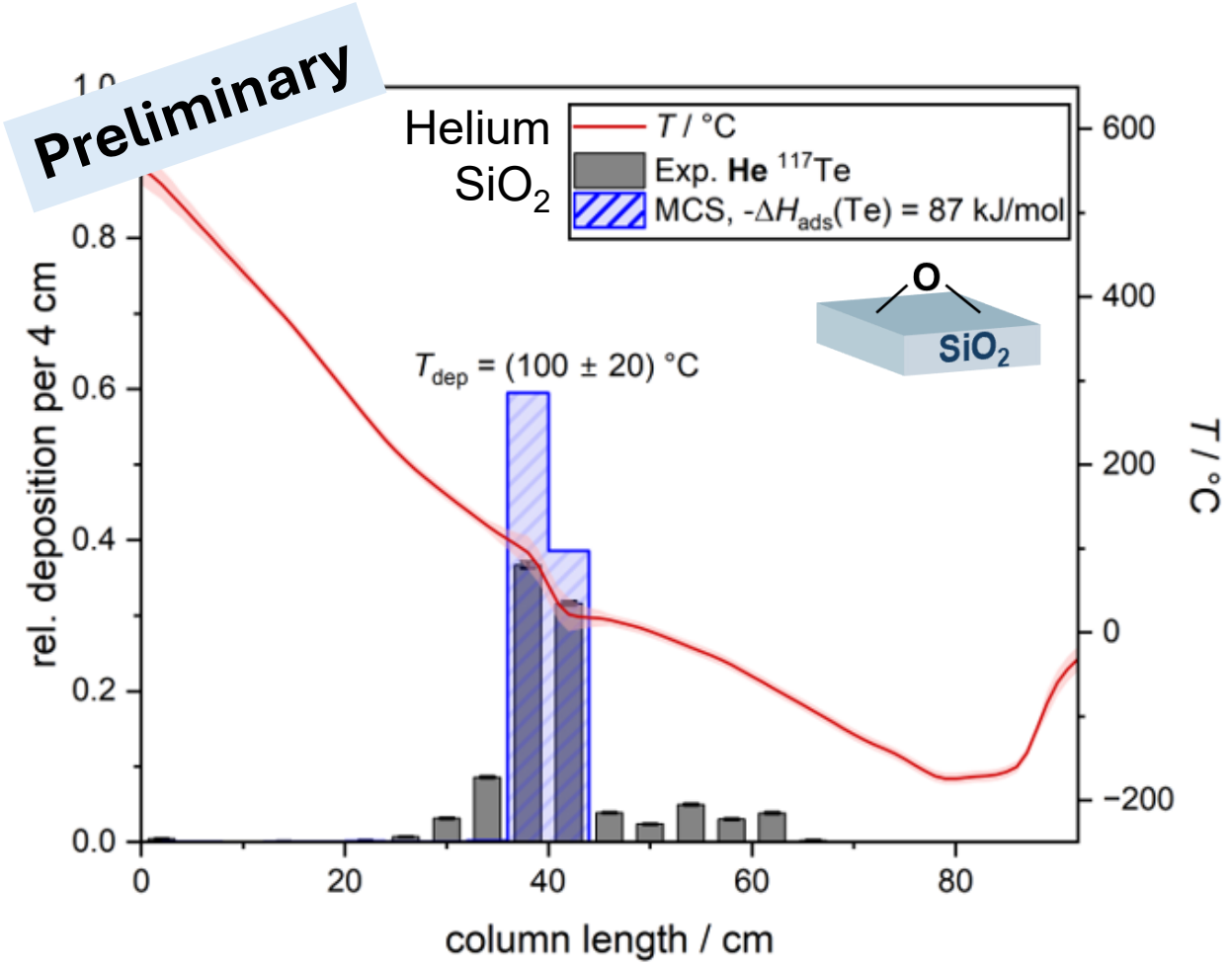
Beam energy: 48 MeV

Beam current: 200 particle nA

Collection of activity in catcher foils

Gas-solid thermochromatography on quartz glass

Exploring the trends in group 16



$-\Delta H_{ads}^{SiO_2}$ (Te) = 87^{+9}_{-7} kJ/mol,

Species assigned to elemental tellurium

Very similar $-\Delta H_{ads}$ as polonium

E. A. Maugeri et al. measured –(163 ± 10) kJ/mol, however speciation and used quartz surface unclear

E. A. Maugeri et al., *J. Nucl. Mater.* **2014**, *452*, 110-117.

More Te experiments are currently under evaluation to establish adsorption trends in group 16

Summary

- Adsorption enthalpy of polonium on quartz in the elemental state: $-\Delta H_{ads}(Po) = 85^{+3}_{-2}$ kJ/mol.
- Reaction of polonium with silanol groups on hydroxylated quartz surface leads to formation of less-volatile species.

- Two oxidized, less volatile species than elemental polonium are formed in oxygen atmosphere.

- Adsorption enthalpy of tellurium on quartz in the elemental state: $-\Delta H_{ads}(Te) = 87^{+9}_{-7}$ kJ/mol.

Experiments suggest to study livermorium in the elemental state

HOT Article



K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2025**, *27*, 21414-21423.

K. Hermainski et al., *Phys. Chem. Chem. Phys.* **2026**, *28*, 7617-7628.

Acknowledgements

All experiments conducted in the frame of FAIR phase 0

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