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PSI

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Patrick Steinegger :: Heavy Elements group :: Paul Scherrer Institute | ETH Zurich

Status and plans of chemical research with heaviest elements at PSI and FLNR

TASCA Workshop 2021, June 21 – 23, 2021

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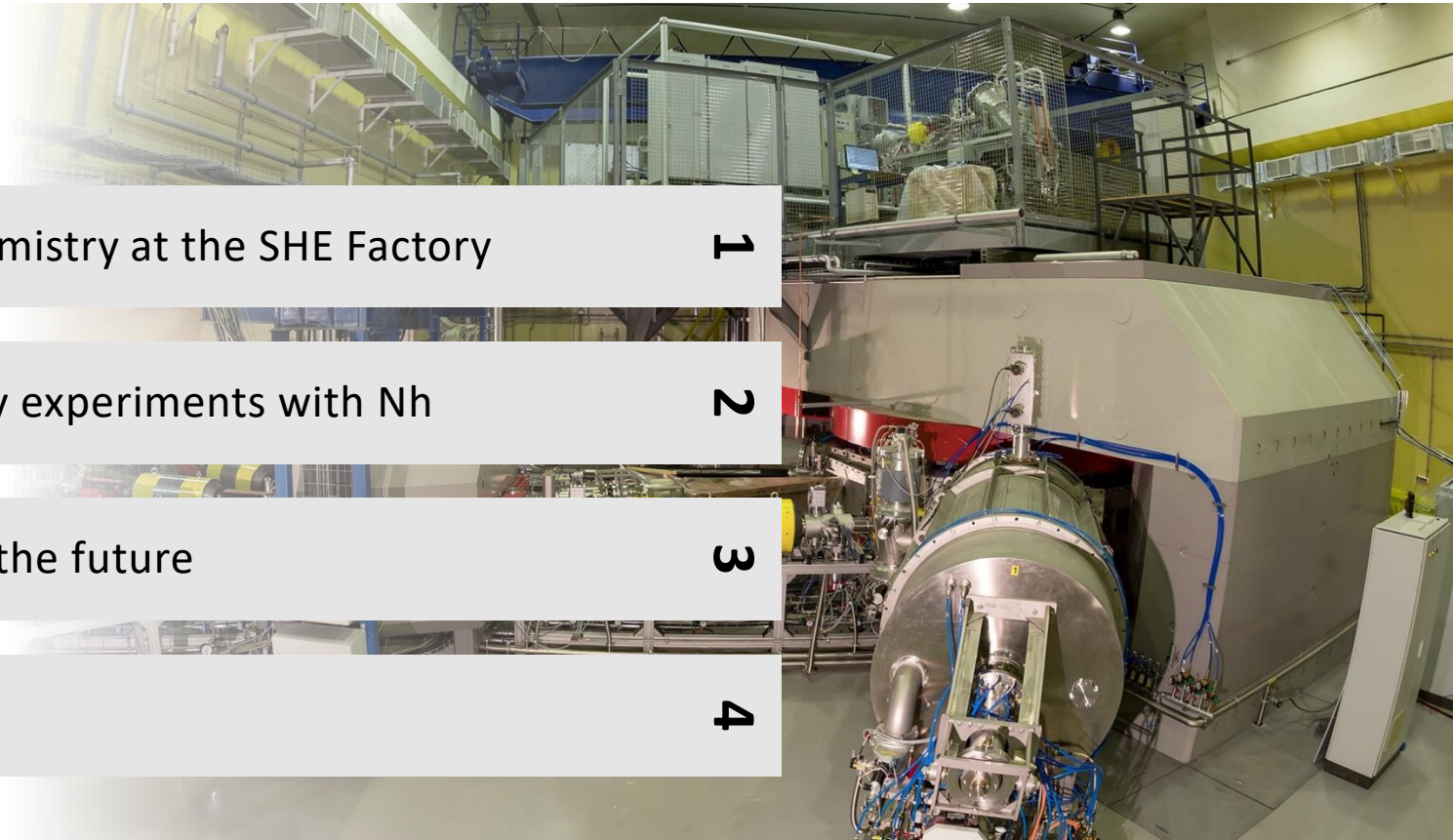
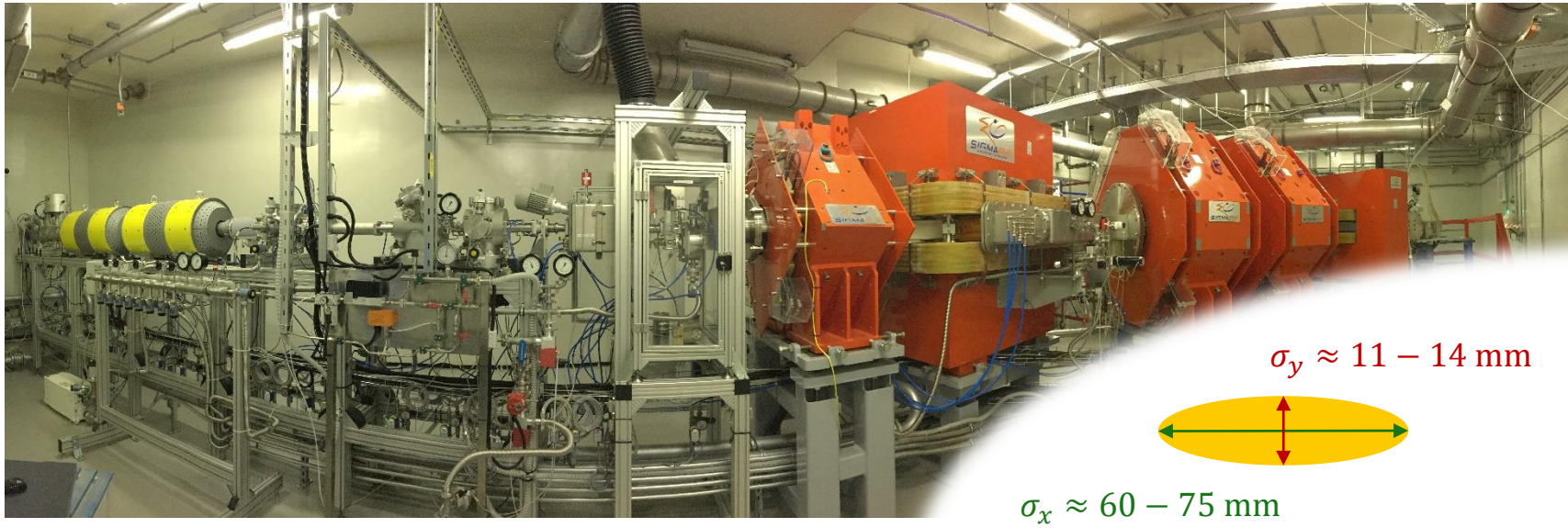
Outline



Fl/Cn chemistry at the SHE Factory

Status DGFRS-II



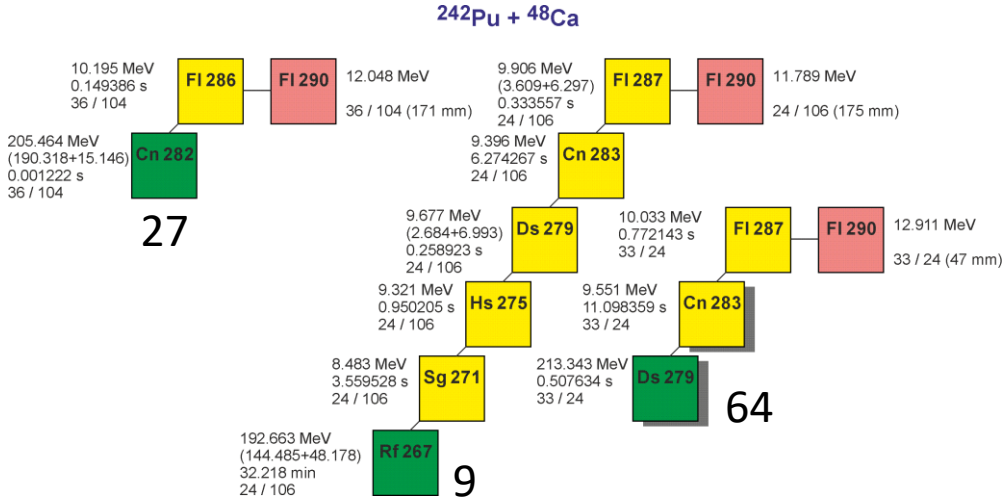
Magnetic fields / transmission: ^{48}Ca on ^{170}Er/^{174}Yb/^{206}Pb

1st physics experiments: $^{243}\mathrm{Am}(^{48}\mathrm{Ca}, x\mathrm{n})^{291-x}\mathrm{Mc}$ $(x = 2, 3) \rightarrow$ ^{289}Mc (6) and ^{288}Mc (55)

Data by courtesy of V. K. Utyonkov

Fl/Cn chemistry at the SHE Factory

Status DGFRS-II



1st chemistry experiments: $^{242}\mathrm{Pu}(^{48}\mathrm{Ca}, x\mathrm{n})^{290-x}\mathrm{Fl}$ $(x = 3, 4) \rightarrow I = 1.5 - 3.0$ pμA

$E_{lab} = 242$ MeV, $1.1 \cdot 10^{19}$ ion beam dose → $\mathrm{N}(^{287}\mathrm{Fl}/^{286}\mathrm{Fl}) = 70/12$

$E_{lab} = 247$ MeV, $5.0 \cdot 10^{18}$ ion beam dose → $\mathrm{N}(^{287}\mathrm{Fl}/^{286}\mathrm{Fl}) = 3/15$

Data and decay scheme by courtesy of V. K. Utyonkov (state of stats: June 21, 2021); picture taken on October 2, 2019

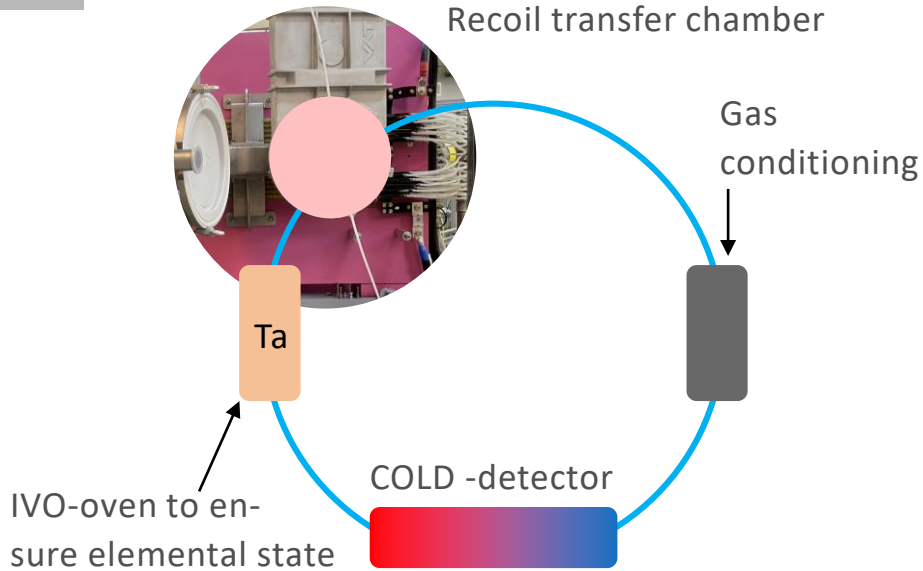
Fl/Cn chemistry at the SHE Factory

Status DGFRS-III

Picture by courtesy of A. I. Svirikhin

Fl/Cn chemistry at the SHE Factory

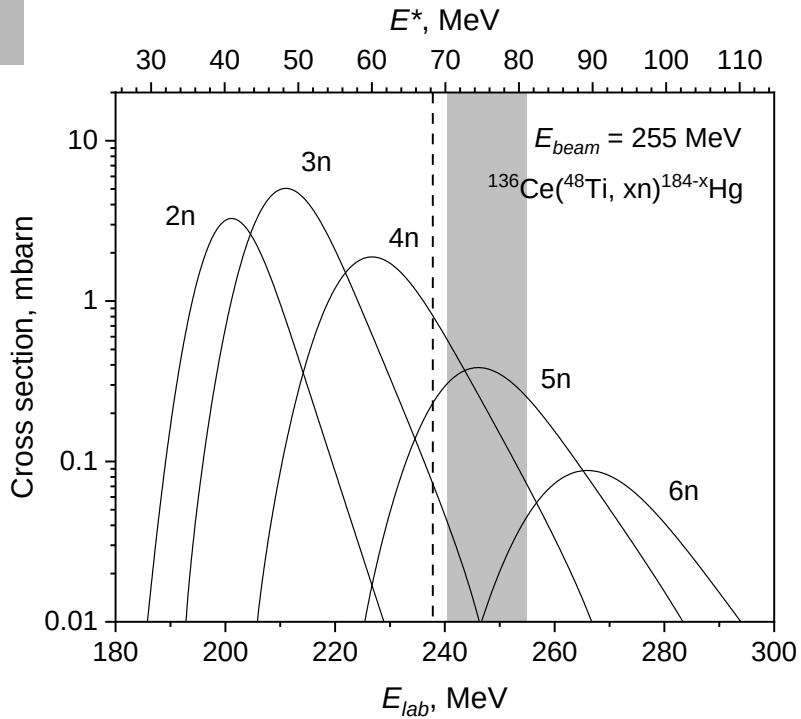
The experimental setup COLD

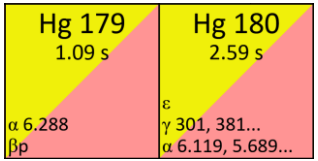


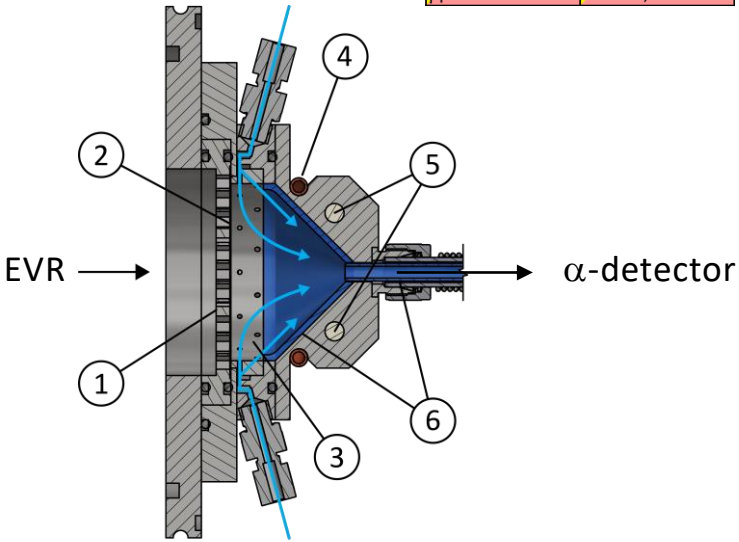
Currently upgrading the control system…

Fl/Cn chemistry at the SHE Factory

Flushing time experiments: Preparation of RTC for DGFRS-II/III

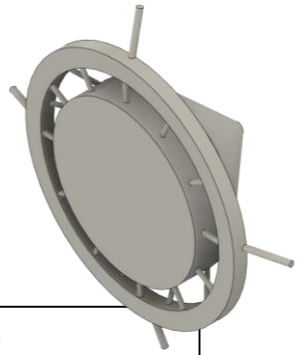




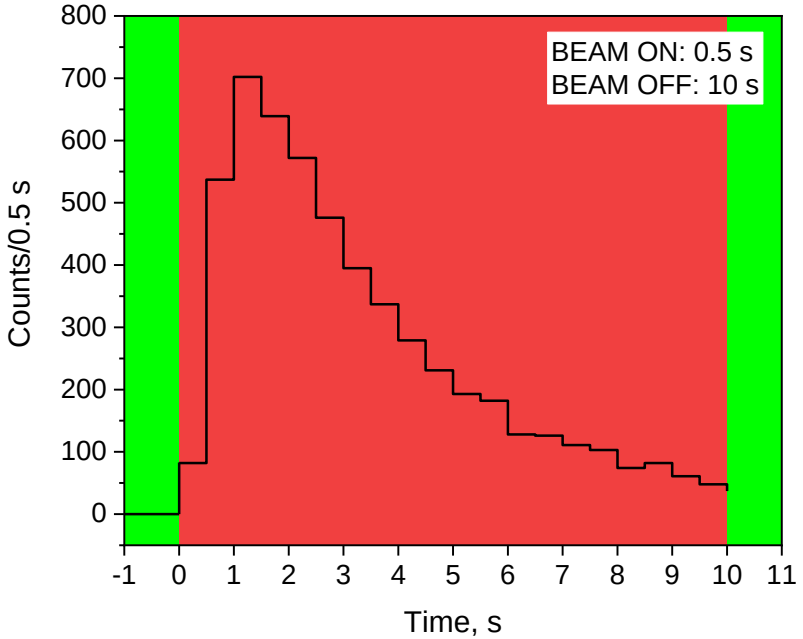


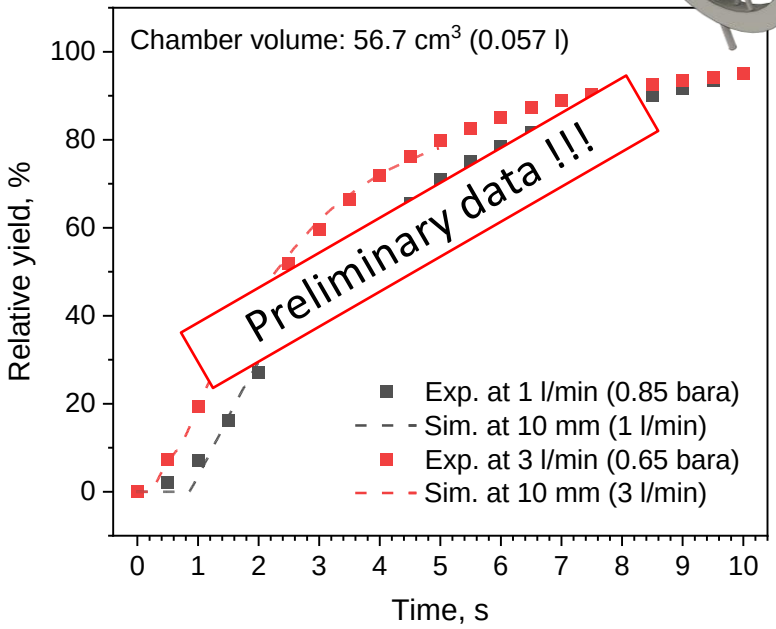
A. V. Karpov et al., *Nuclear Instruments and Methods A* **859** (2017), pp. 112 – 124 → nrv.jinr.ru

Fl/Cn chemistry at the SHE Factory



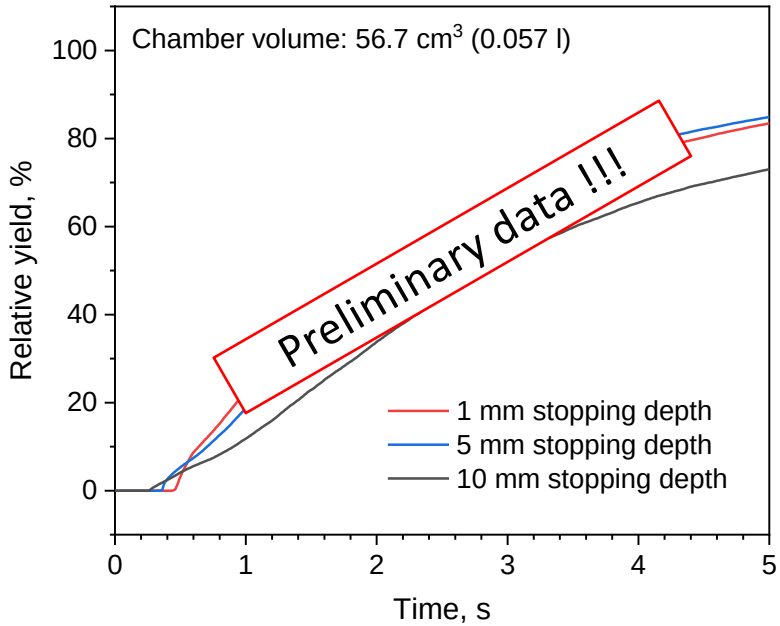
Flushing time experiments: Comparison experiment vs. simulation (simulation corrected for the half-life).

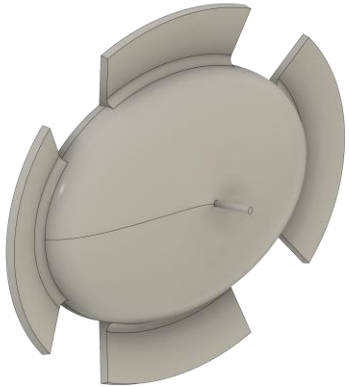




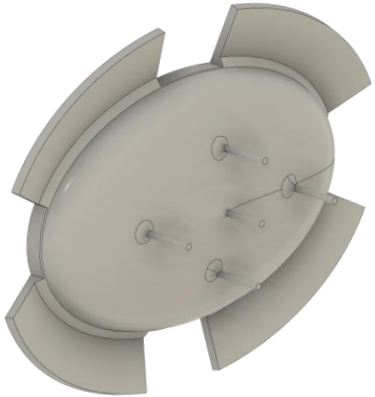
Fl/Cn chemistry at the SHE Factory

Flushing time experiments: Preparation of RTC for DGFRS-II/III





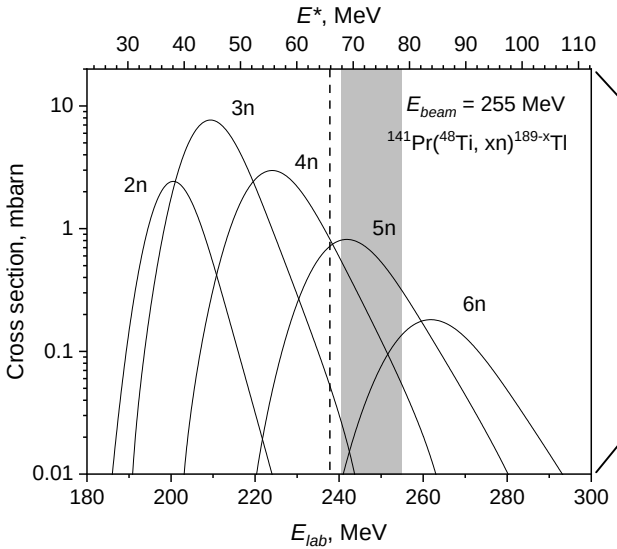
Best coverage of focal Plane + smallest volume

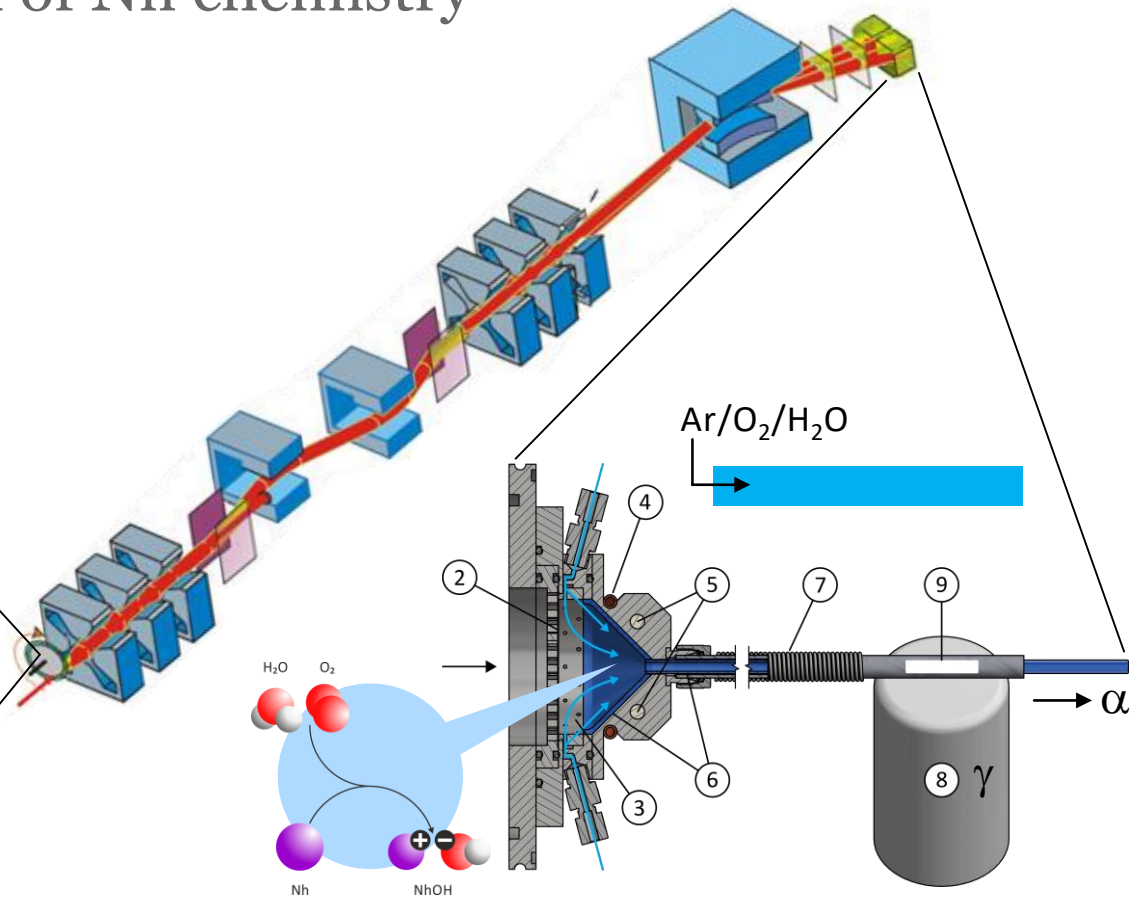


Preparation of Nh chemistry

Chemistry experiments behind the vacuum separator SHELS@FLNR

$^{141}\mathrm{Pr}(^{48}\mathrm{Ti}, [x\mathrm{p}]y\mathrm{n})^{187-x-y}\mathrm{Tl}$

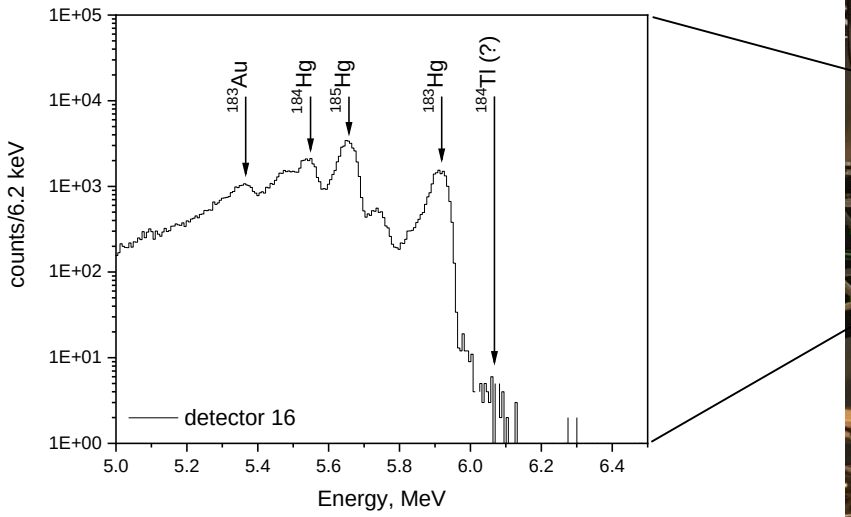




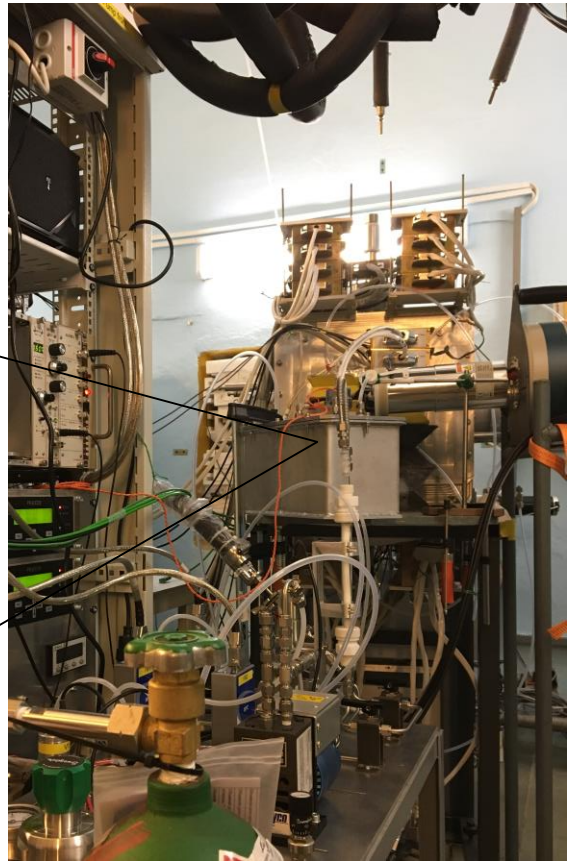
Preparation of Nh chemistry

Results of model experiments with thallium
(≈1 month of accelerator time)

- Heated RTC at a vacuum separator with constant access
- **Observation of a volatile Tl(III) species***



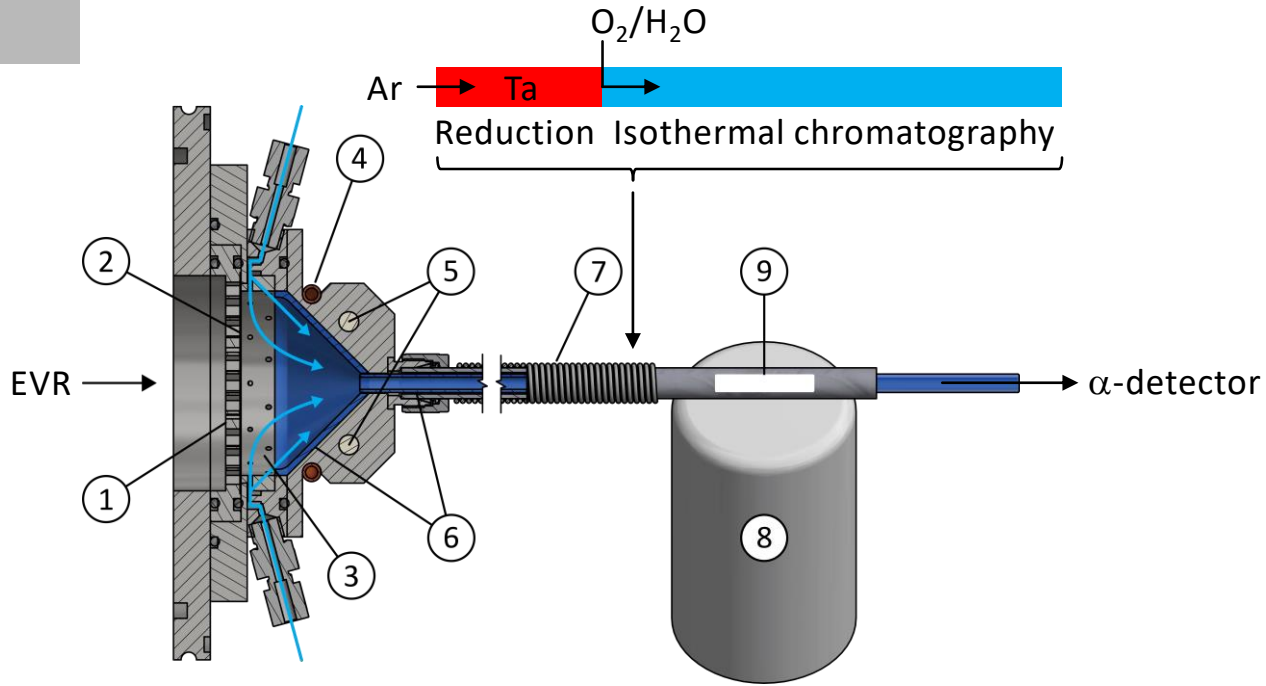
α/γ-detector
≈1 m away

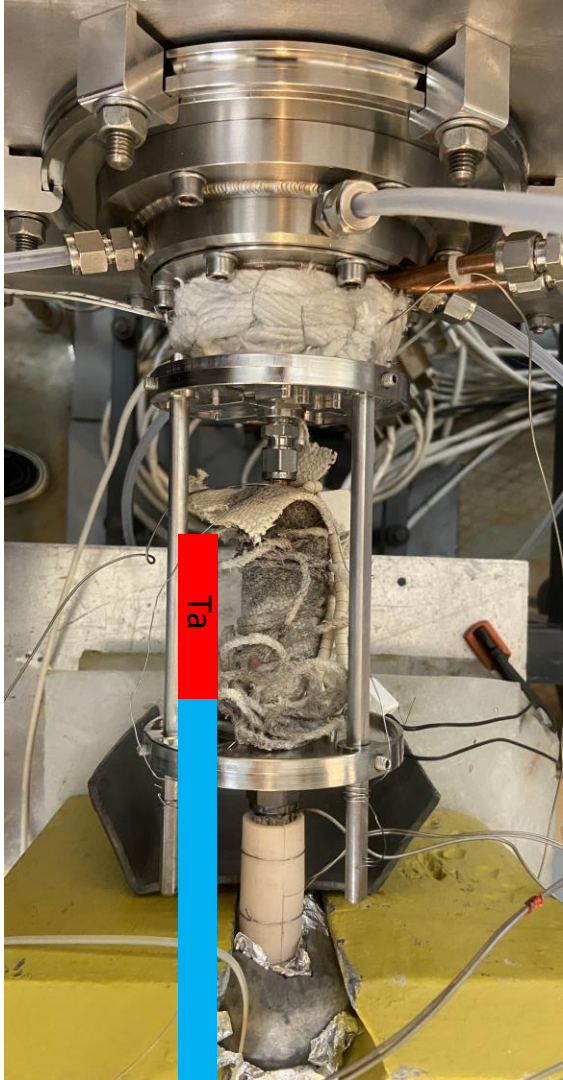


* Also supported by: E. E. Tereshatov et al., *New J. Chem.* **45** (2021), pp. 3377 – 3381

Preparation of Nh chemistry

Latest adjustment: Ensuring low oxidation states of thallium

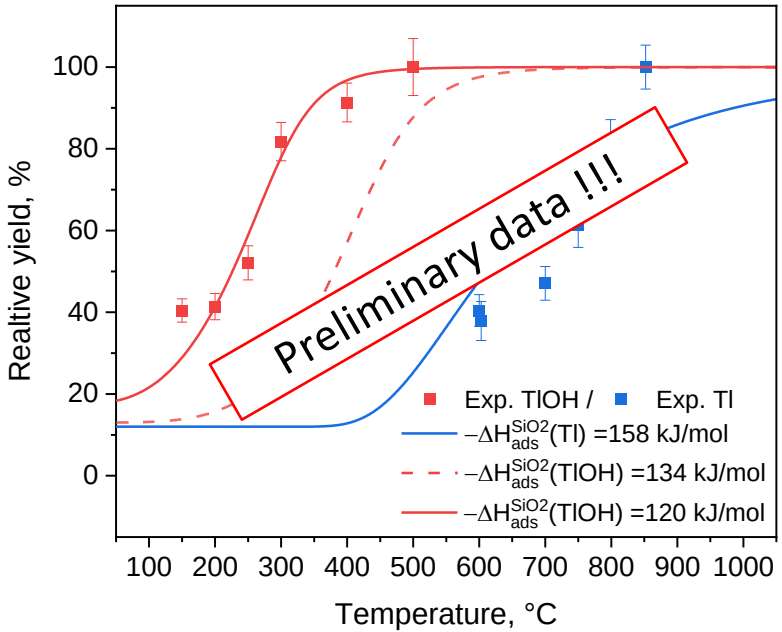


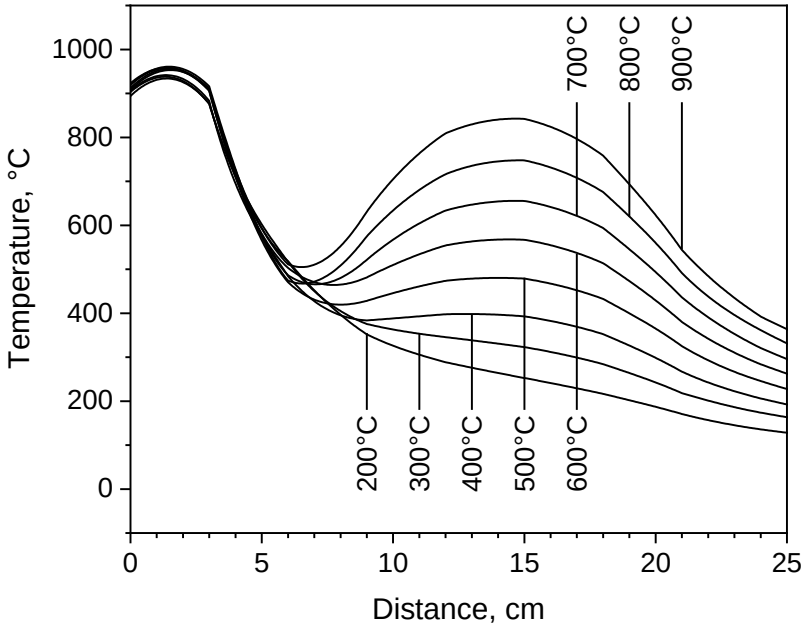


Preparation of Nh chemistry

Tl(I)OH and Tl(0) on quartz

1 l/min Ar + 0.1 l/min O_2 + H_2O (!)



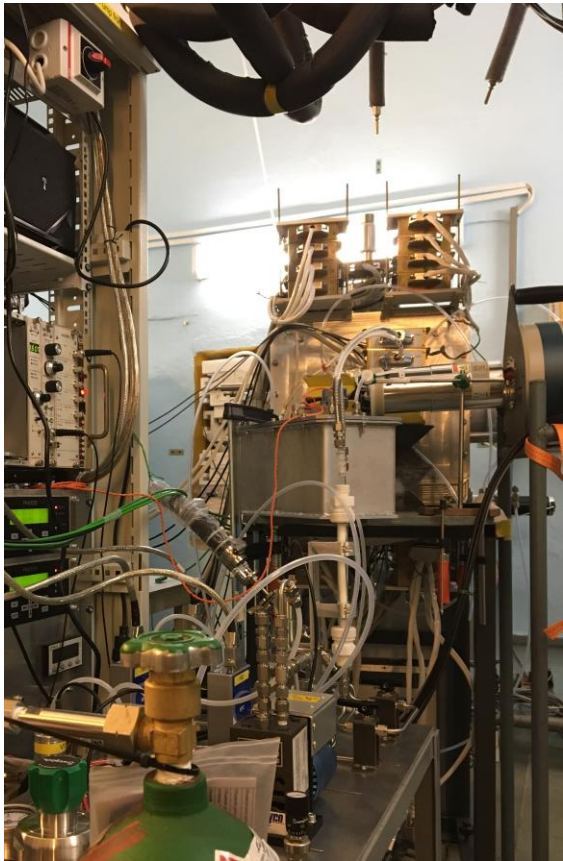


Preparation of Nh chemistry

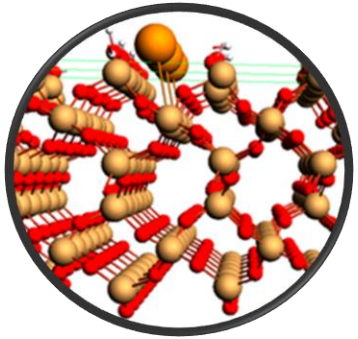
Results of model experiments with thallium
(≈1 month of accelerator time)

- Heated RTC at a vacuum separator with constant access
- **Observation of a volatile Tl(III?) species**
- **Identification of TlOH and Tl**

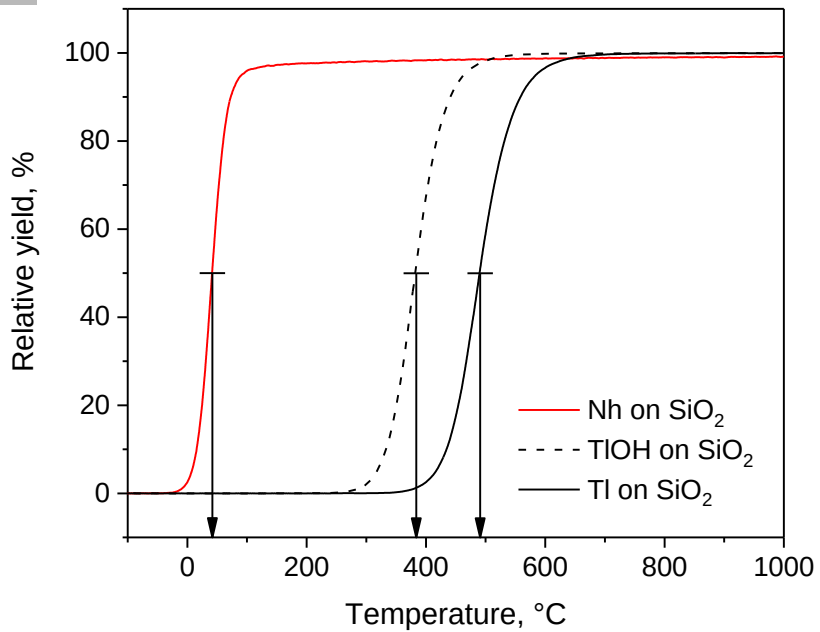
→ TlOH forms in a surface-bound reaction
→ Preservation of elemental thallium due to progressive dehydroxilation of quartz surface at $T_{iso} > 400°C$
→ **Three different chemical species observed (!)**



Preparation of Nh chemistry



Theoretical expectations:
TlOH/Tl and NhOH/Nh on quartz



Exp.: $-\Delta H_{ads}^{SiO_2}$ (Tl) = 158 ± 3 kJ/mol

Theo.: $-\Delta H_{ads}^{SiO_2}$ (Tl) = 150.2 kJ/mol

Theo.: $-\Delta H_{ads}^{SiO_2}$ (Nh) = 60 kJ/mol

Exp.: $-\Delta H_{ads}^{SiO_2}$ (TlOH) = 134 ± 5 kJ/mol

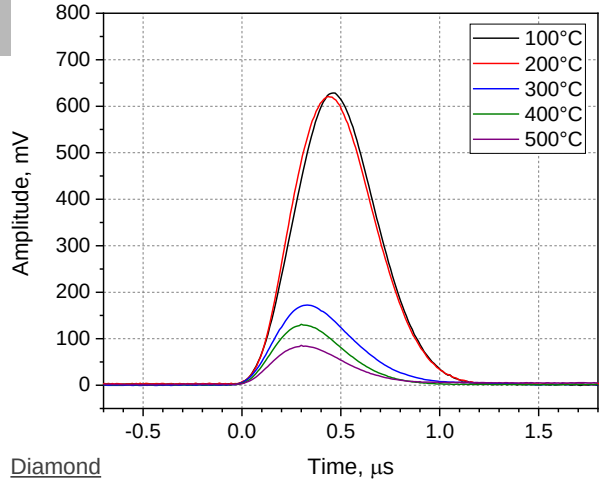
Theo.: $-\Delta H_{ads}^{SiO_2}$ (TlOH/NhOH) = ? kJ/mol

Theo.: $-\Delta H_{ads}$ (TlOH) $< -\Delta H_{ads}$(NhOH)?

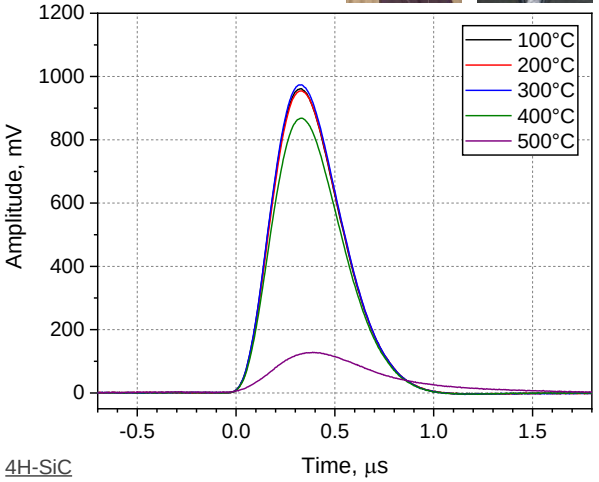
V. Pershina, *J. Phys. Chem. C* **120** (2016), pp. 20232 – 20238, A. Serov et al., *Radiochim. Acta* **101** (2013), pp. 421 – 425
V. Pershina, M. Ilias, *Inorg. Chem.* **58** (2019), pp. 9866 – 9873, P. Steinegger et al., *J. Chem. Phys. C* **120** (2016), pp. 7122 – 7132

4H-SiC test for HT alpha-spectroscopy

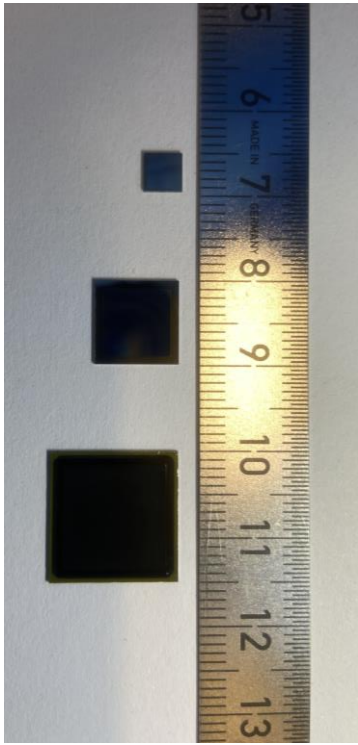
From diamond to silicon carbide



Diamond



4H-SiC



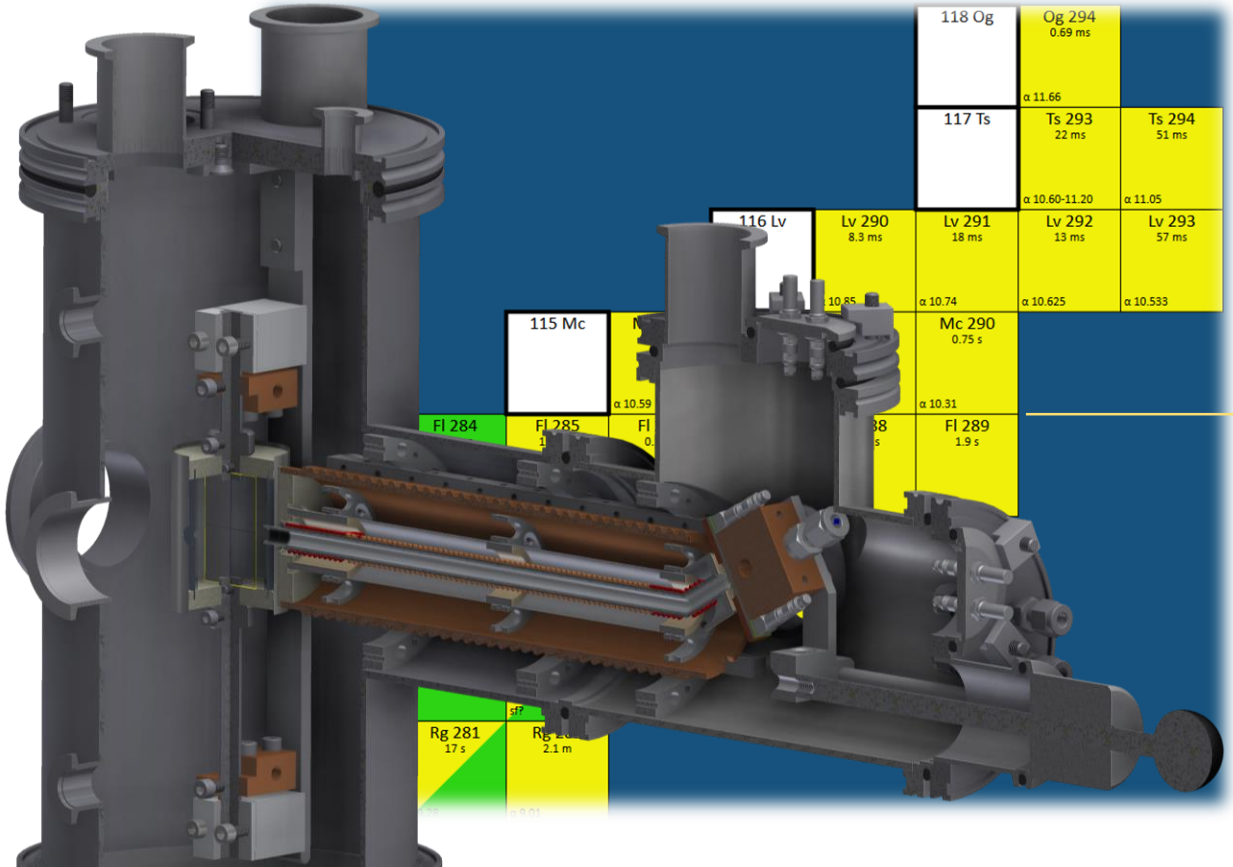
cividec Instrumentation

SENSIC .CH

Temperature limit: **200°C**

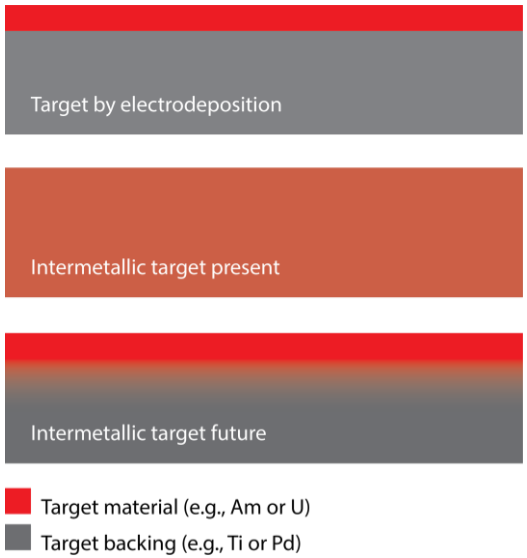
Temperature limit: **≈400°C**

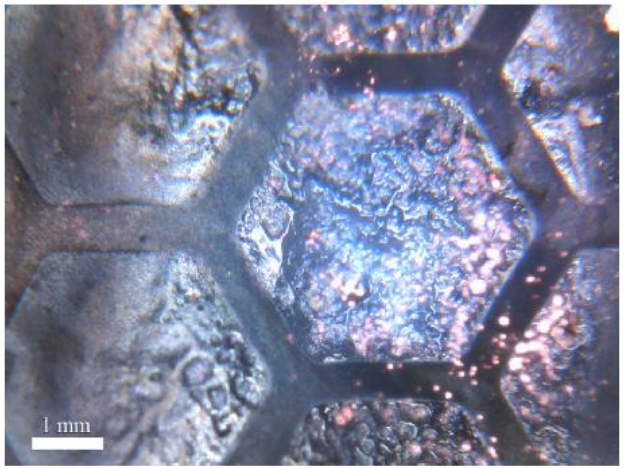
Isothermal vacuum chromatography



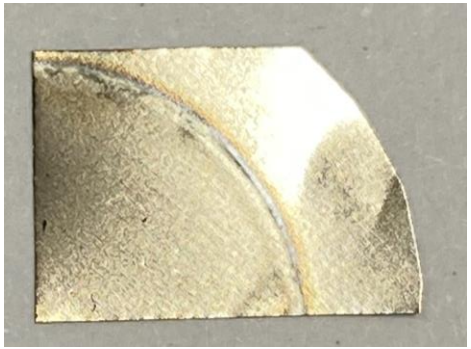
$t_{1/2} < 1$ second

Intermetallic targets





^{243}Am/Pd



Reduced Eu in (?) Pd on Ni

I. Usoltsev et al., *Nuclear Instruments and Methods B* **318** (2014), pp. 297 – 305

Conclusions

✓ Preparation for the first chemistry experiment at the SHE Factory of FLNR are well on track.

→ Long term tests of entire system at PSI.

→ Design and test of recoil transfer chamber for DGFRS-II/III

✓ Model experiments for an unambiguous chemical characterization of Nh are closing in.

→ **Tl(III) → Theory has to help us identify this species, e.g., $Tl(OH)_3$.**

→ **Tl(I) → Probable formation of TlOH.**

→ **Tl(0) → After progressed dehydroxylated quartz surface.**

✓ Fit for the future.

→ High-temperature alpha-spectroscopy → **higher stationary surface temperatures**

→ Vacuum chromatography → **shortest half-lives**

→ Intermetallic targets → **coping with high-intensity ion beams**

→ Theory: Species of **thallium at high oxidation states**

The Heavy Elements group at PSI & FLNR

Wir schaffen Wissen – heute für morgen

Involved people

N. V. Aksenov, Y. V. Albin,
Z. Asfari, G. A. Bozhikov,
V. I. Chepigin, I. Chuprakov,
P. Dutheil, R. Dressler,
B. Gall, N. S. Gustova,
R. Eichler, D. Herrmann,
P. Ionescu, A. V. Isaev,
D. E. Katrasev, B. Kraus,
A. Sh. Madumarov,
O. N. Malyshev, E. Melnik,
P. Nagy, D. Piguet, Y. A. Popov,
A. V. Sabel'nikov, T. K. Sato,
A. V. Svirikhin, G. Tiebel,
M. G. Voronyuk, A. Vögele,
J. Wilson, A. V. Yeremin, V. Zobnin,
S. N. Dmitriev

Wir schaffen Wissen – heute für morgen

Thank you for your kind attention!

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

→ https://www.psi.ch/en/lrc
→ http://flerovlab.jinr.ru/

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Swiss National Science Foundation

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