# Present Status of SHE Chemistry at JAEA

**Tetsuya K. Sato**
**Advanced Science Research Center**
**Japan Atomic Energy Agency**

# Research Group for Heavy Element Nuclear Science

**Group leader**: A.Andreyev **Adviser** : Y. Nagame

**Nucl. Phys.**

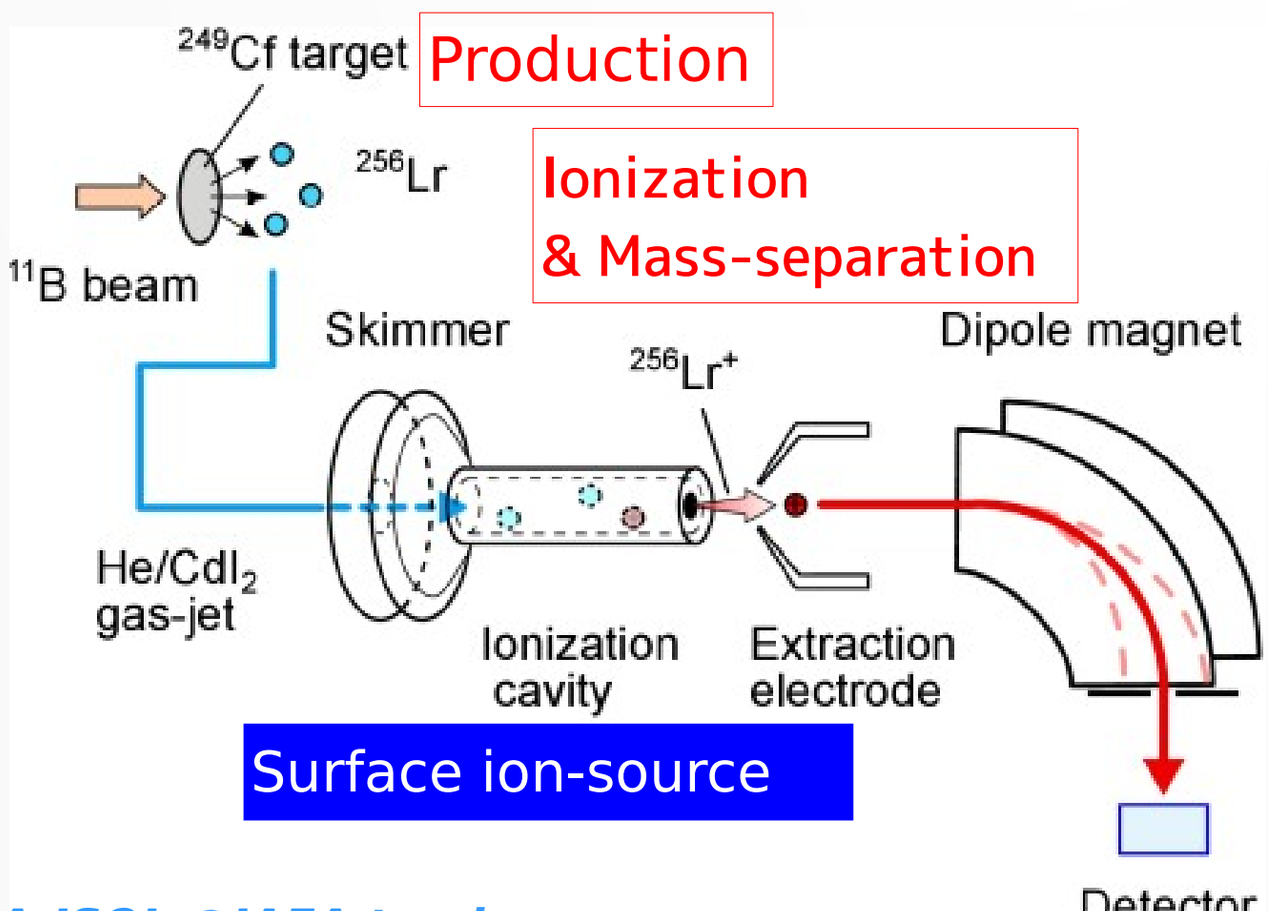
K.Nishio (Manager, Exp.)
H.Koura (Theory)
Y.Utsuno (Theory)
K.Hirose (Exp.)
H.Makii (Exp.)
R.Orlandi (Exp.)
K.Ratha (Exp.)
S.Tanaka(Theory)
R.Yanagihara(Exp.)

**Nucl. Chem.**

K.Tsukada(Exp.)
M.Asai (Exp.)
T.K.Sato (Exp.)
~~A.Toyoshima~~
Y.Ito (Exp.)
N.M.Chiera (Exp.)
T.Tomitsuka (Exp.)
K.Tokoi (Exp.)
H.Suzuki (Exp.)

| | |
|---|---|
| Staff: | 11 (6+4) |
| PostDoc: | 1 |
| Student : | 6 (3 + 3) |
| Total: | 18 |

# IP₁ of Heavy Actinides



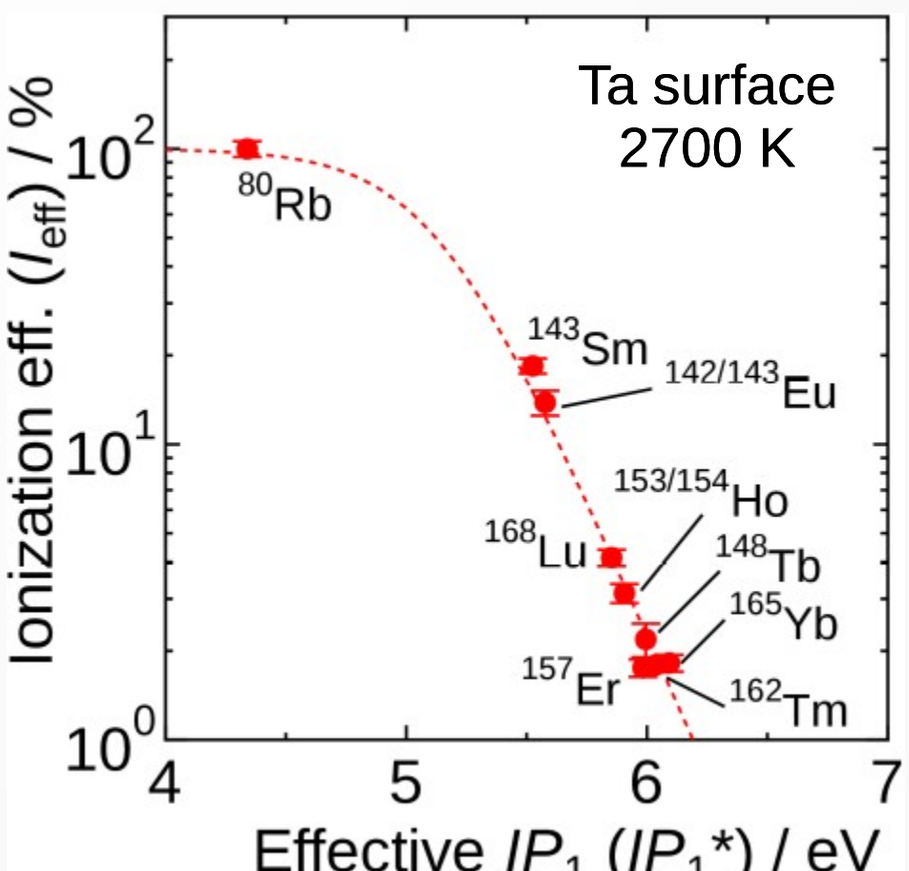

*JAEA-ISOL @JAEA tandem acc.*

Detection

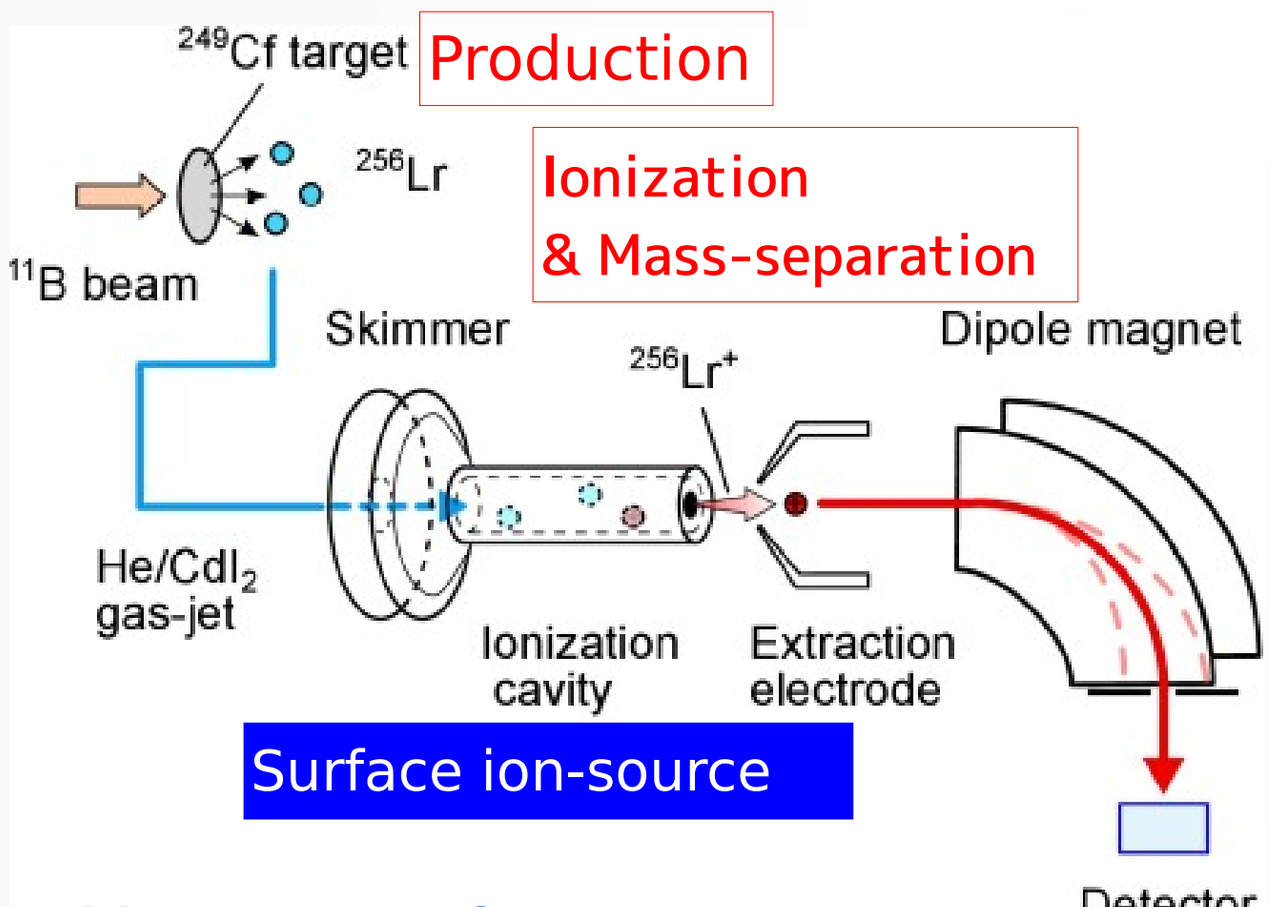
**Saha-Langmuir eq.**

$$I_{\mathrm{eff}} = \frac{N \exp\left((\phi - \mathrm{IP}_1^*)/kT\right)}{1 + N \exp\left((\phi - \mathrm{IP}_1^*)/kT\right)}$$

Effective IP₁(IP₁*) : $\mathrm{IP}_1^* = \mathrm{IP}_1 - kT \ln (Q_i/Q_o)$



# $IP_1$ of Heavy Actinides

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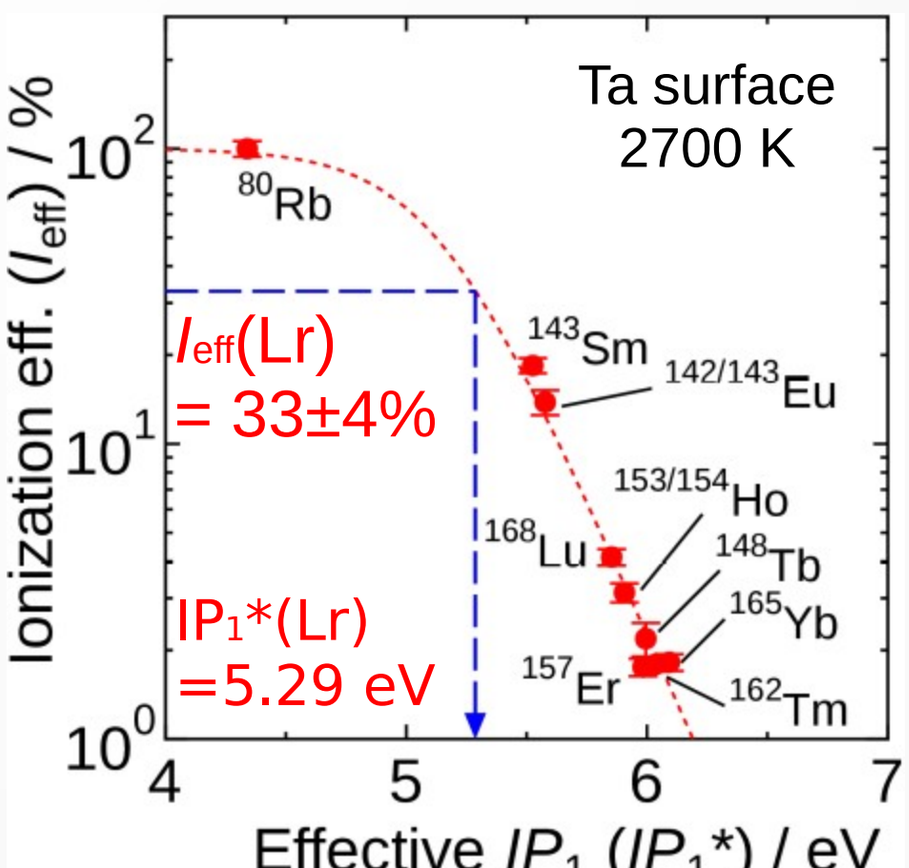
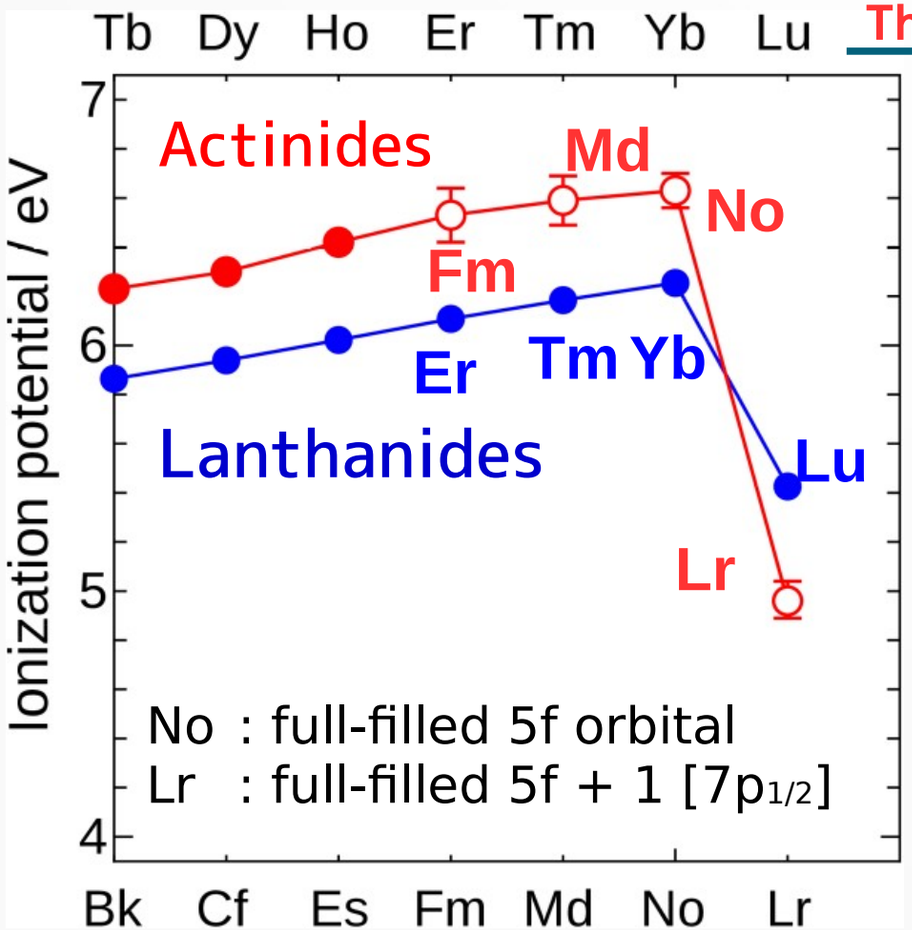
Effective $IP_1(IP_1^*)$ : $IP_1^* = IP_1 - kT \ln (Q_i/Q_o)$



# $IP_1$ of Heavy Actinides

| | Fm | Md | No | Lr |
|---|---|---|---|---|
| Sugar[1] | 6.50 | 6.58 | 6.65 | - |
| Exp. | < 6.76 [2] | - | 6.62621(5) [3] | 4.96±0.08[4] |
| This work | 6.53±0.11 | 6.59±0.10 | 6.63±0.08 | 4.96±0.05 |


[1] J. Sugar, J. Chem. Phys. **59** (1973) 788., J. Chem. Phys. **60**, (1974) 4103.
[2] M.Sewtz et al., PRL **90** (2003) 163002.
[3] Chhetri, P et al., PRL, **120** (2018) 263003.
[4] T.K.Sato et al., Nature **520** (2015) 209.


**We have successfully measured $IP_1$ values of Fm, Md and No using the surface ionization method. Lr $IP_1$ has been updated.**

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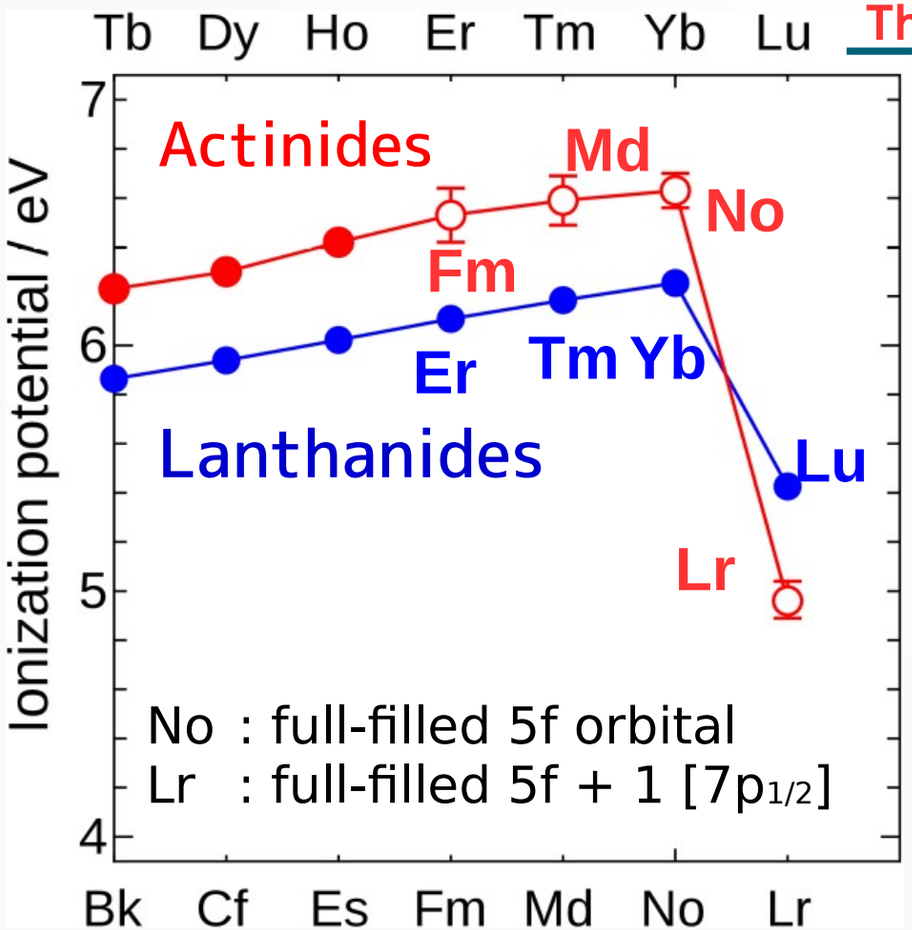


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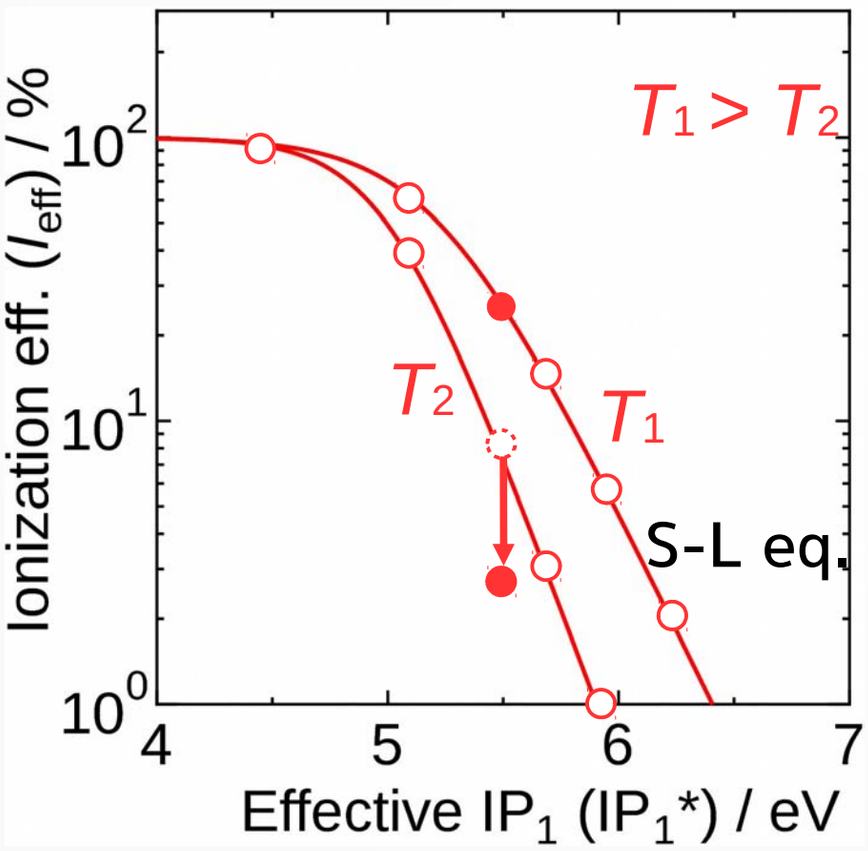
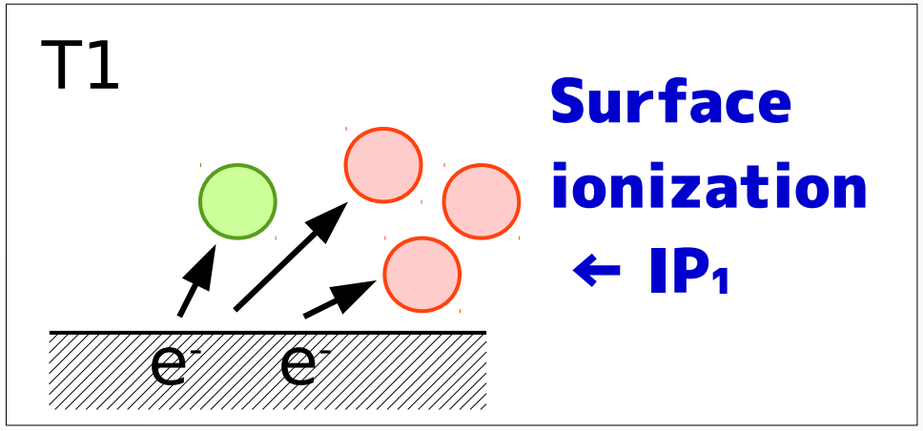
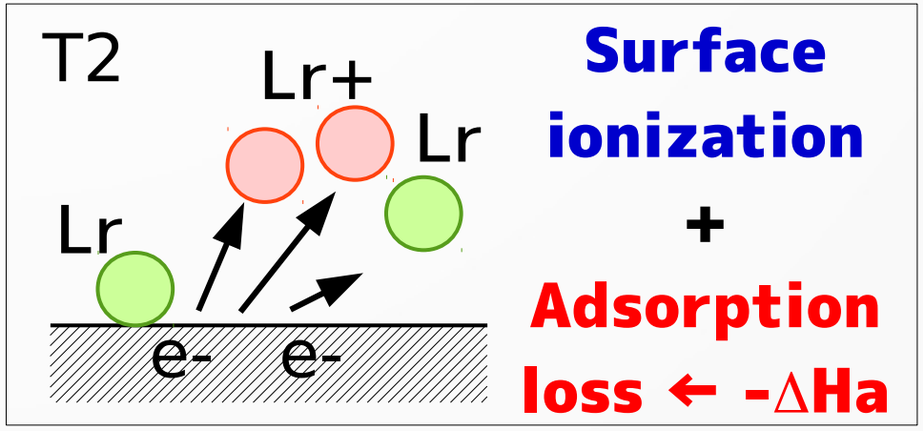
**→ Submitted to JACS**

# Adsorption of Lr atom



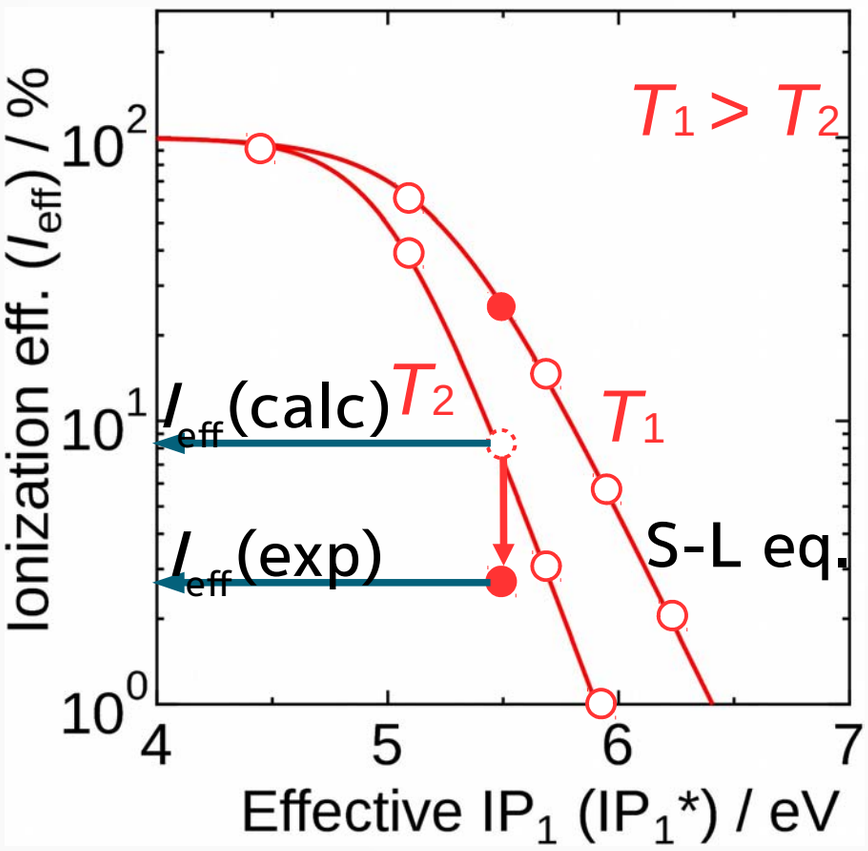



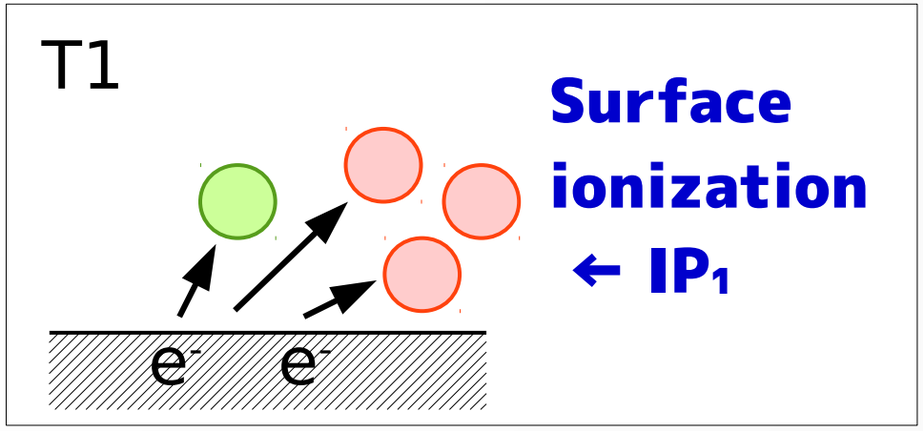



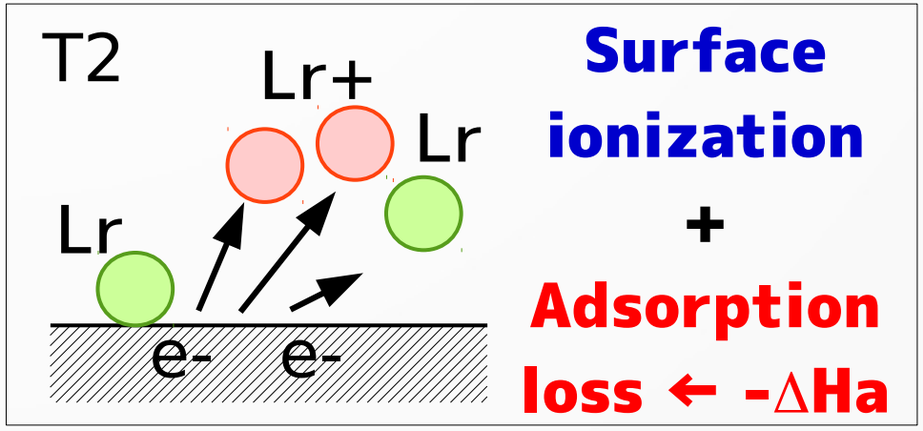

**Saha-Langmuir eq.**

$$I_{\mathrm{eff}} = \frac{N \exp\left((\phi - \mathrm{IP}_1^*)/kT\right)}{1 + N \exp\left((\phi - \mathrm{IP}_1^*)/kT\right)}$$

# Adsorption of Lr atom




$$R_{eff} = I_{eff}(exp)/I_{eff}(calc)$$

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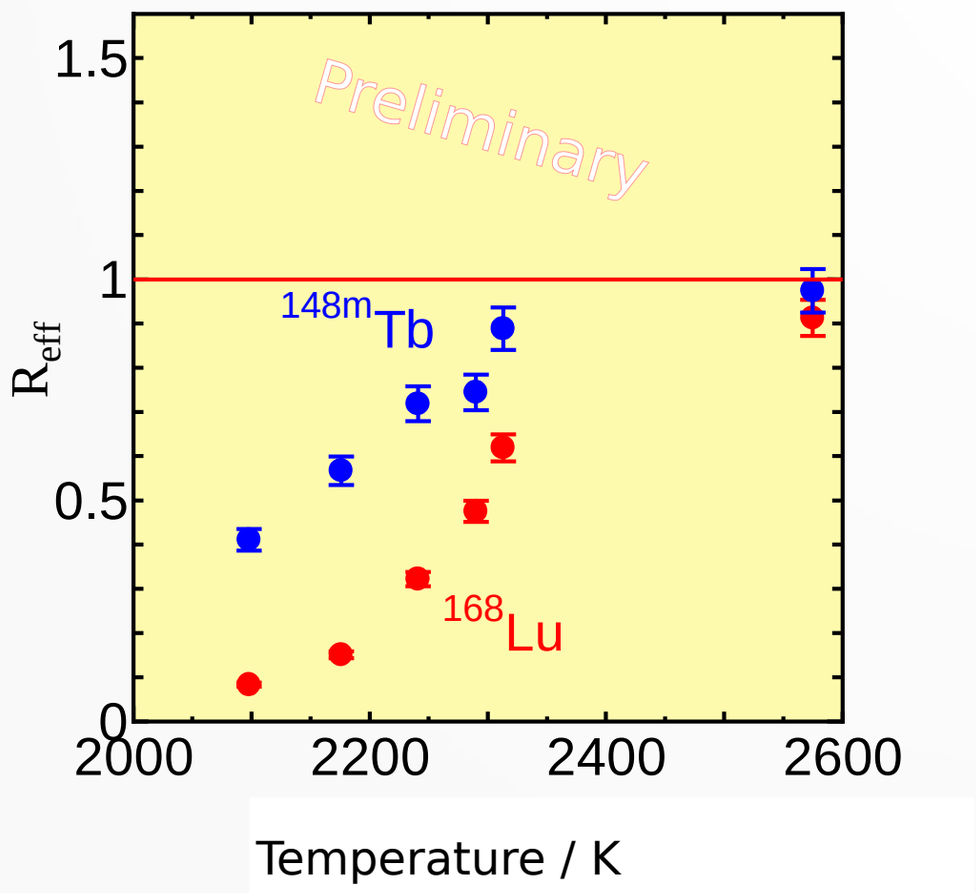
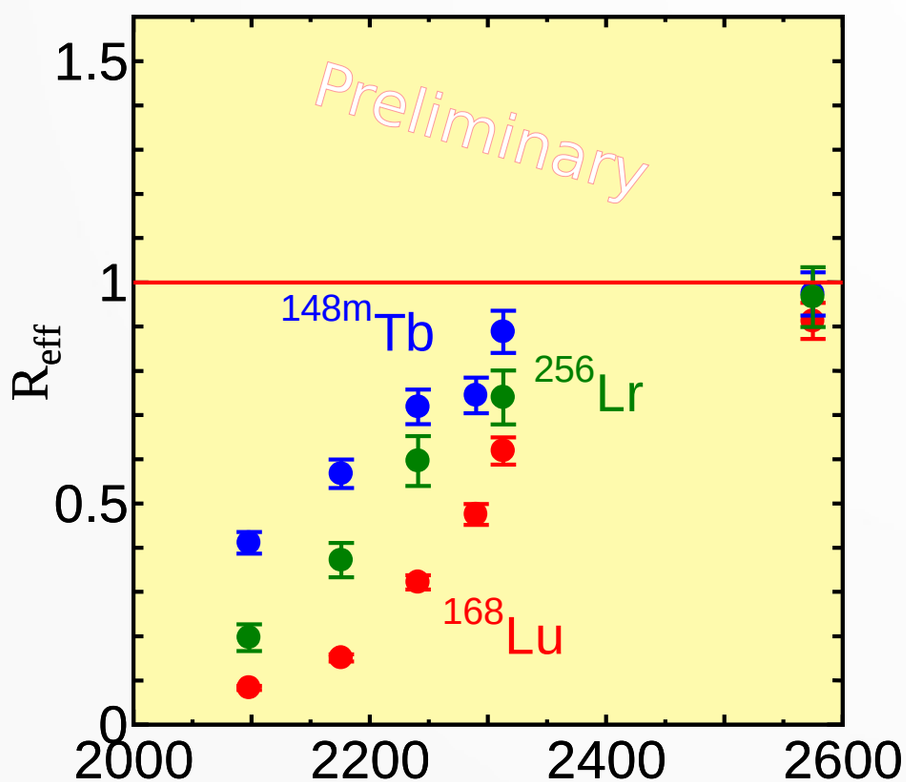



| Isotope | $T_{1/2}$ | - ΔHa/kJ mol$^{-1}$[1] |
|---|---|---|
| $^{148m}$Tb | 2.2 min | 578 |
| $^{168}$Lu | 5.5 min | 610 |

[1] R.Eichler, private comm.

# Adsorption of Lr atom




Temperature / K

Isotope : $^{256}$Lr ($T_{1/2}$ = 27 s)
Beam : $^{11}$B (67.9 MeV)
Target : $^{249}$Cf (260 μg/cm²)

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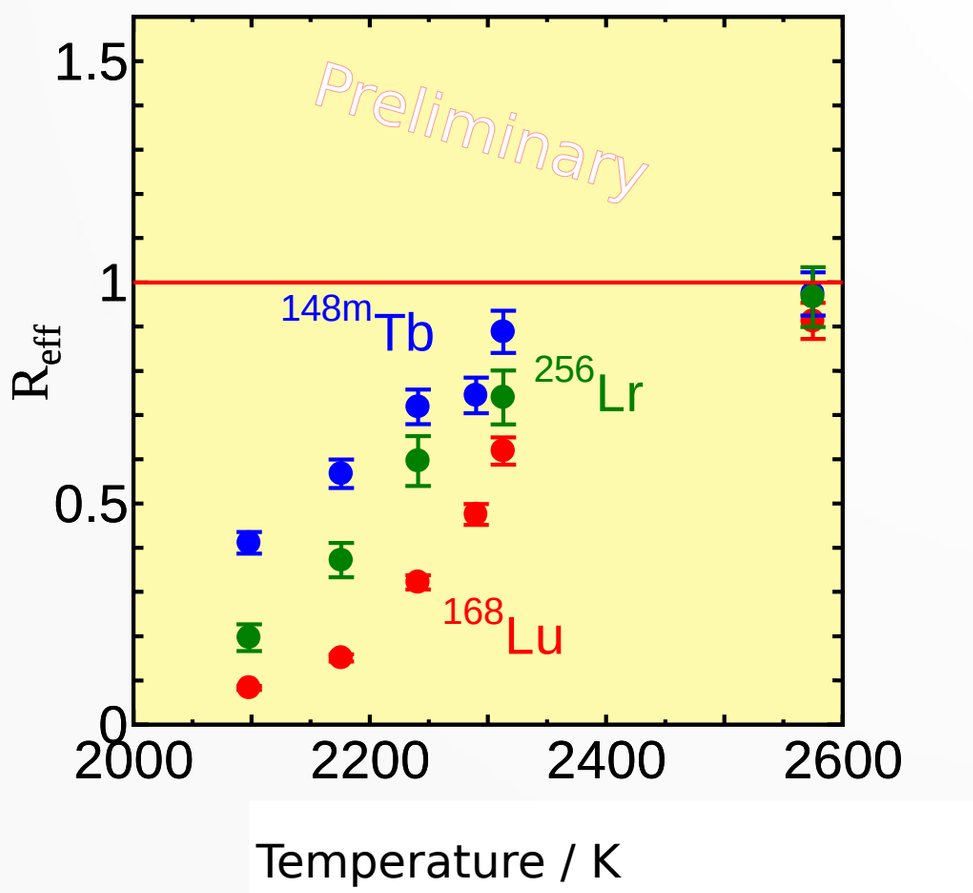


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< $^{256}$Lr (27 s)?

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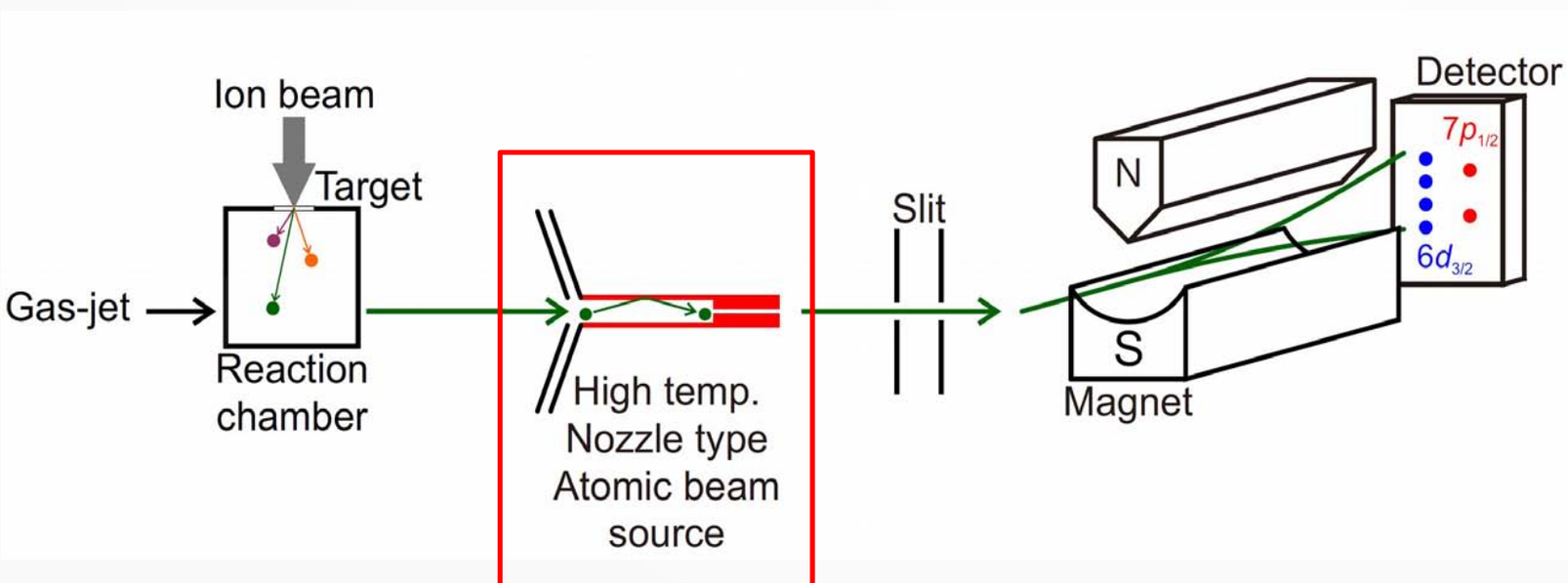
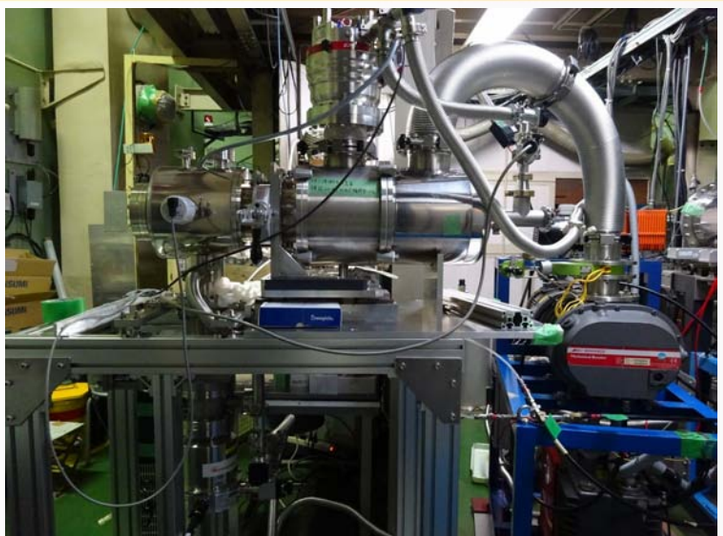
- ΔHa(Exp.) : Monte Carlo simulation (Zvara model + Surface ion.)
- ΔHa(Theory) : 535 kJ/mol (V. Pershina)

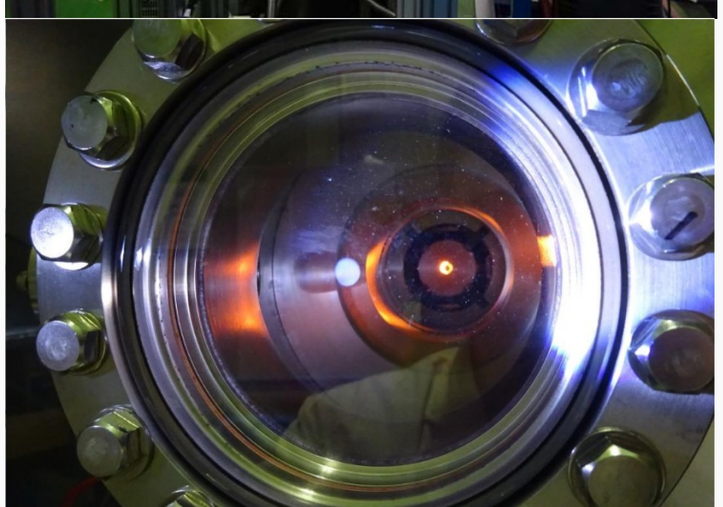
# Atomic Beam Source

**Atomic spin**

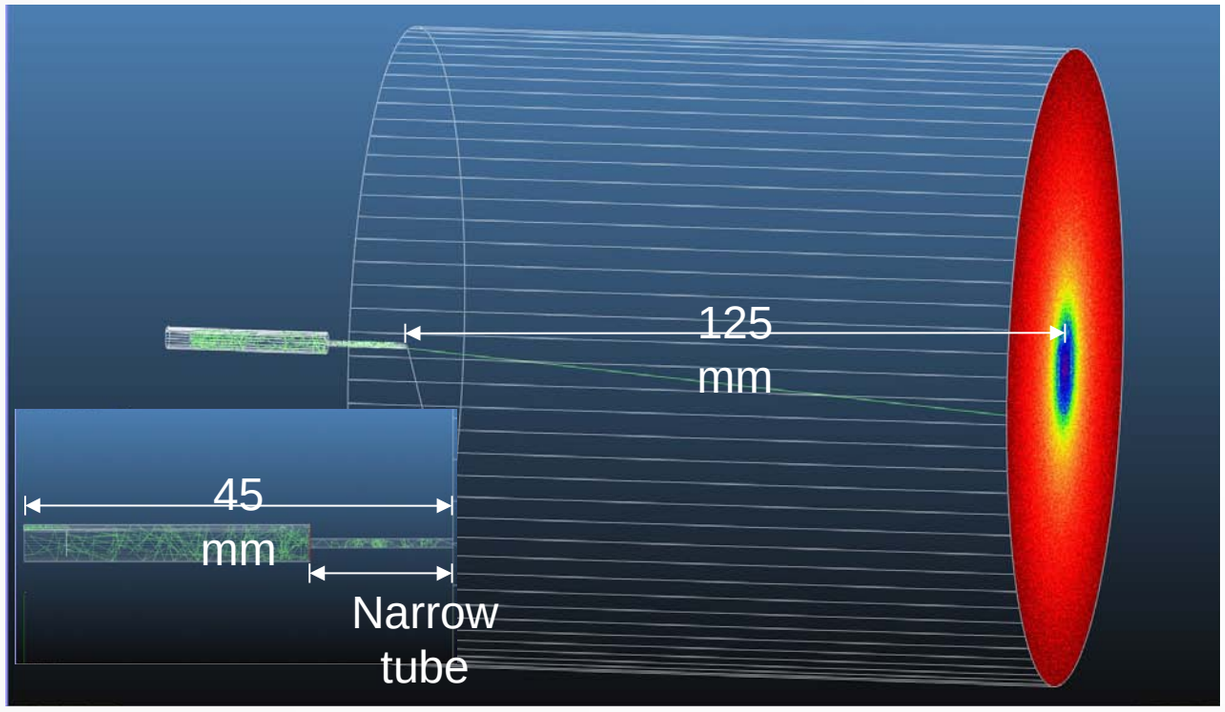
The electronic configuration of Lr atom can be confirmed directly by a determination of  the atomic spin.



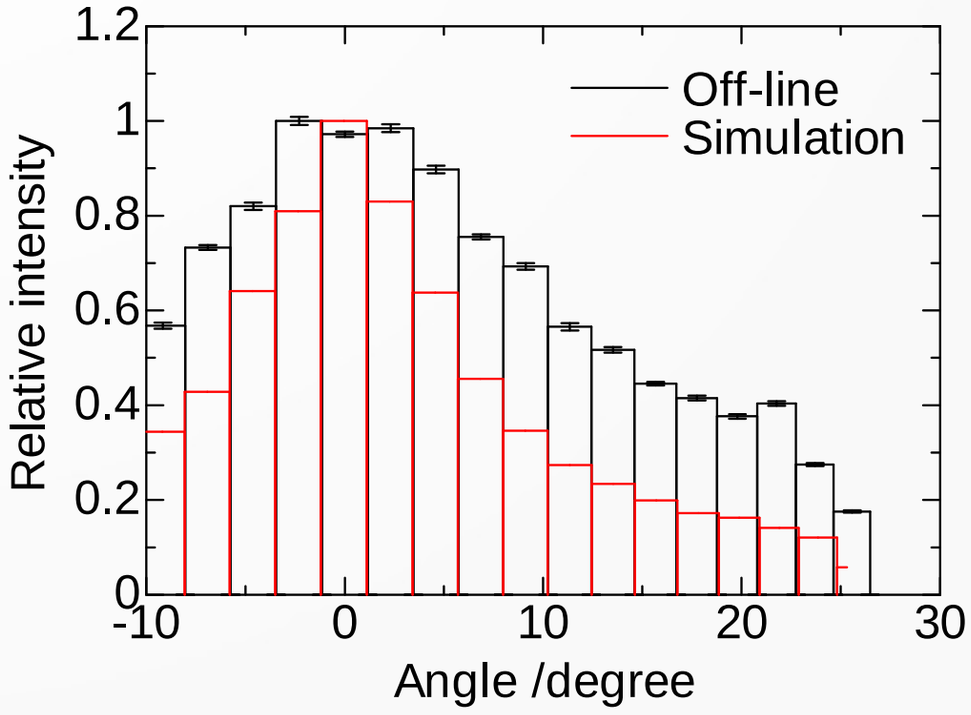


# Atomic Beam Source

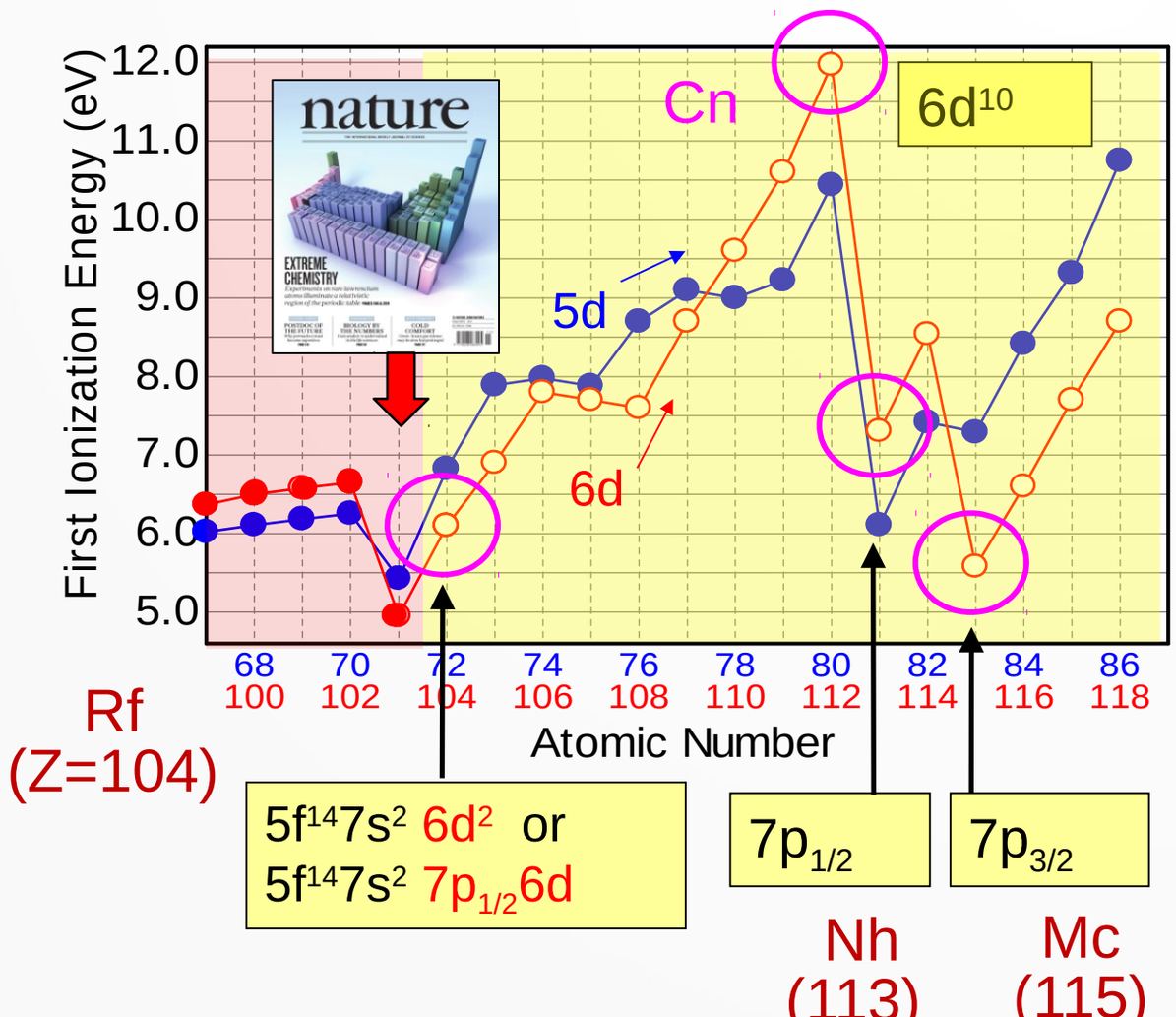



Beam: $CdI_2$

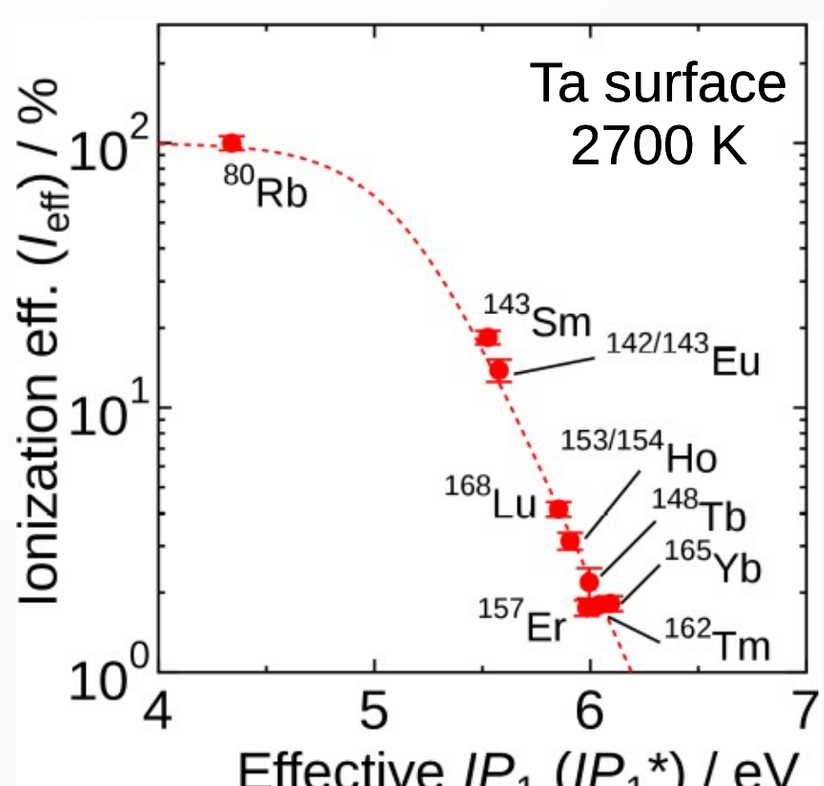
5mmφ at a distance 125mm
→ 0.01 %



# $IP_1$ of Z > 103

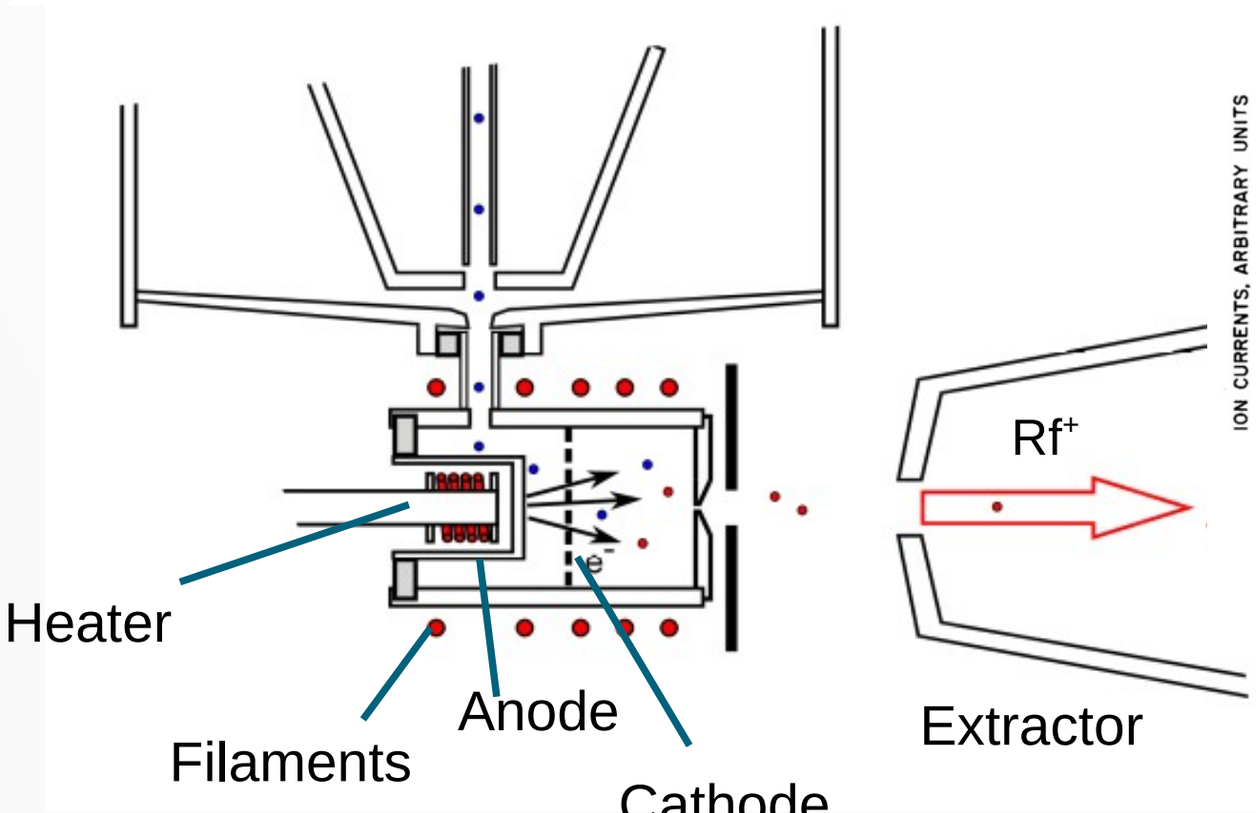


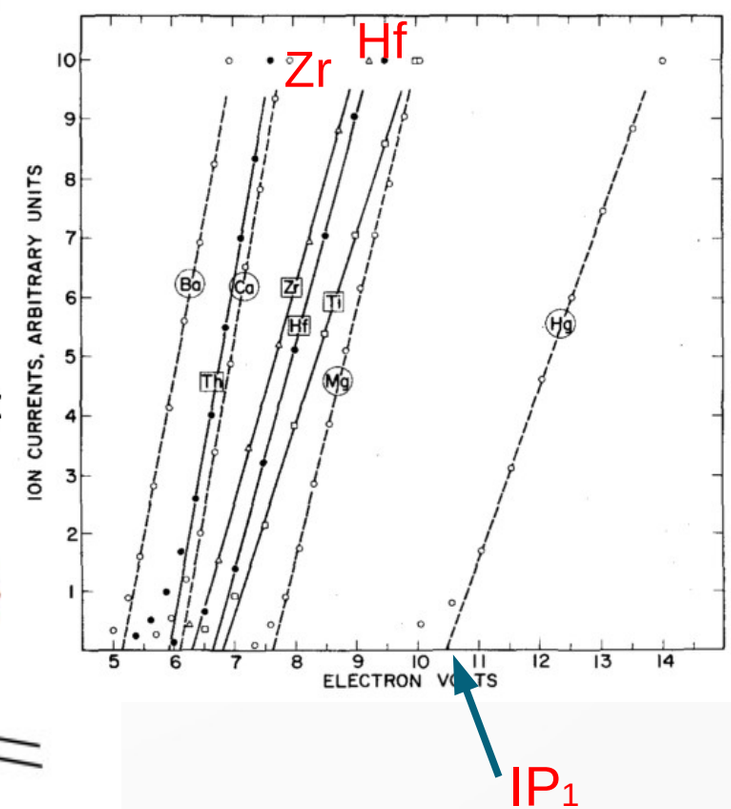

The surface ionization method cannot be applied to elements which $IP_1$ > 6 eV



# $IP_1$ of Z > 103

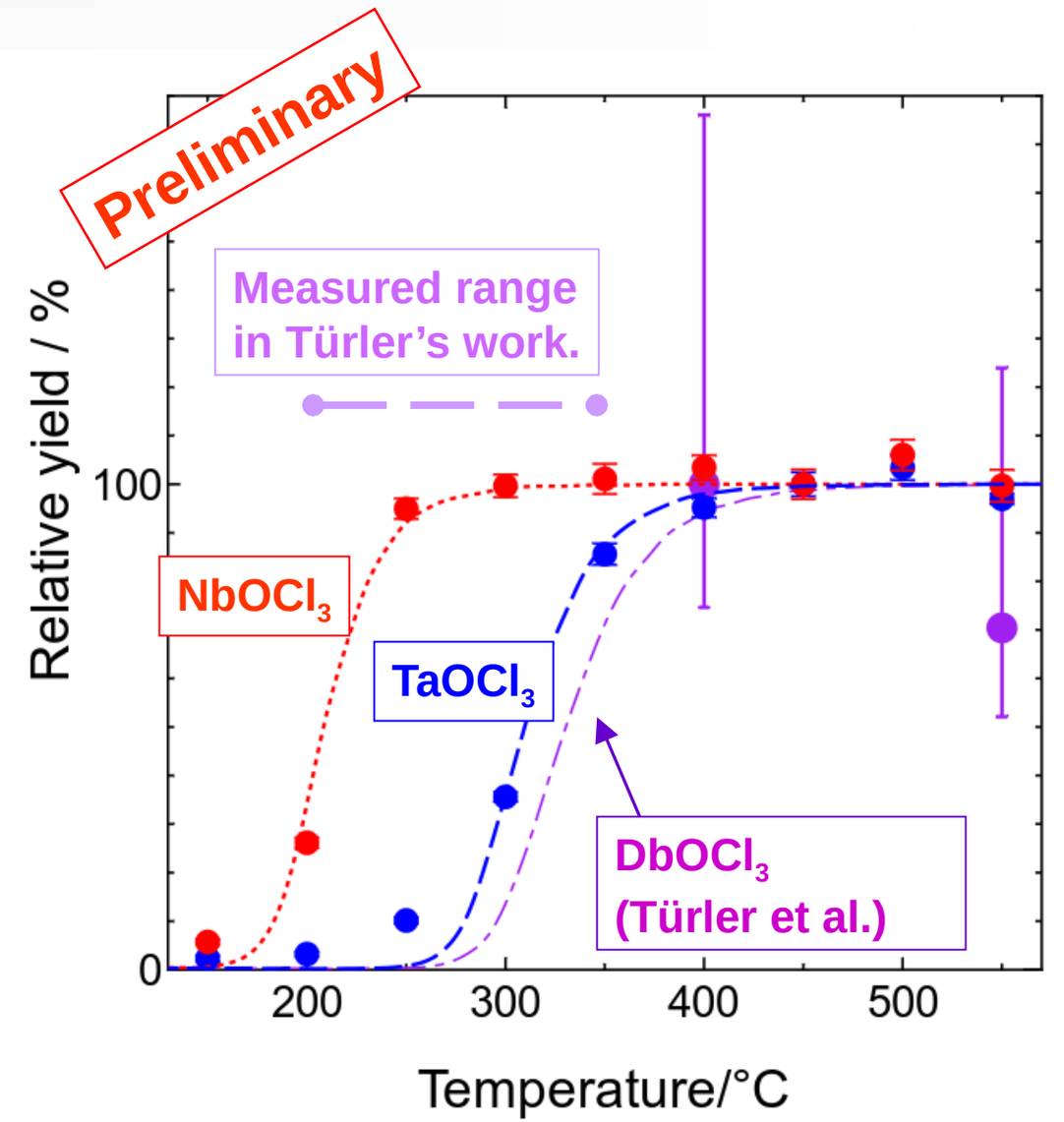
**$IP_1$ measurement > 103**

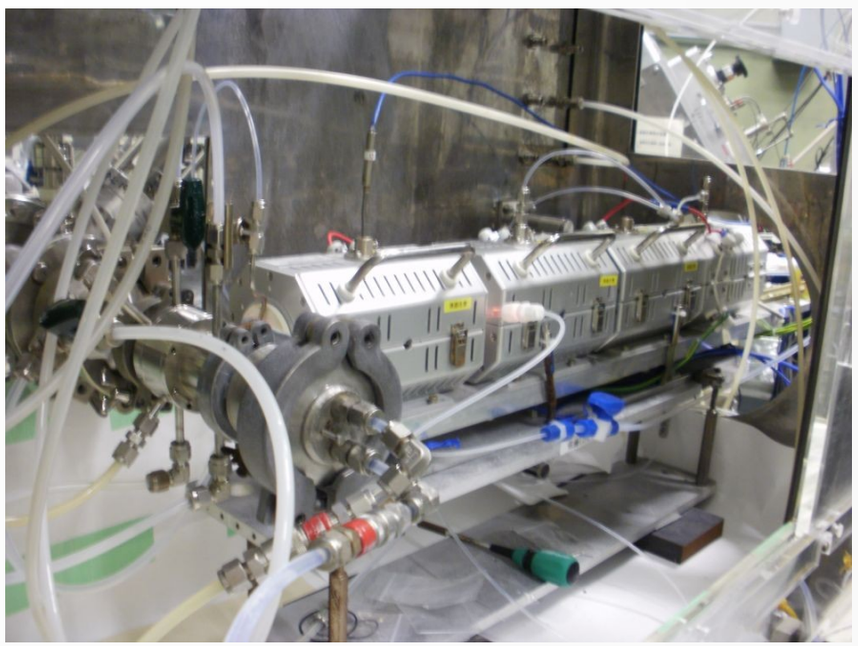



E.G.Rauh & J.Ackermann
J. Chem.Phys. 60 (1974) 1396.

# Volatility of Oxychlorides of Group 5

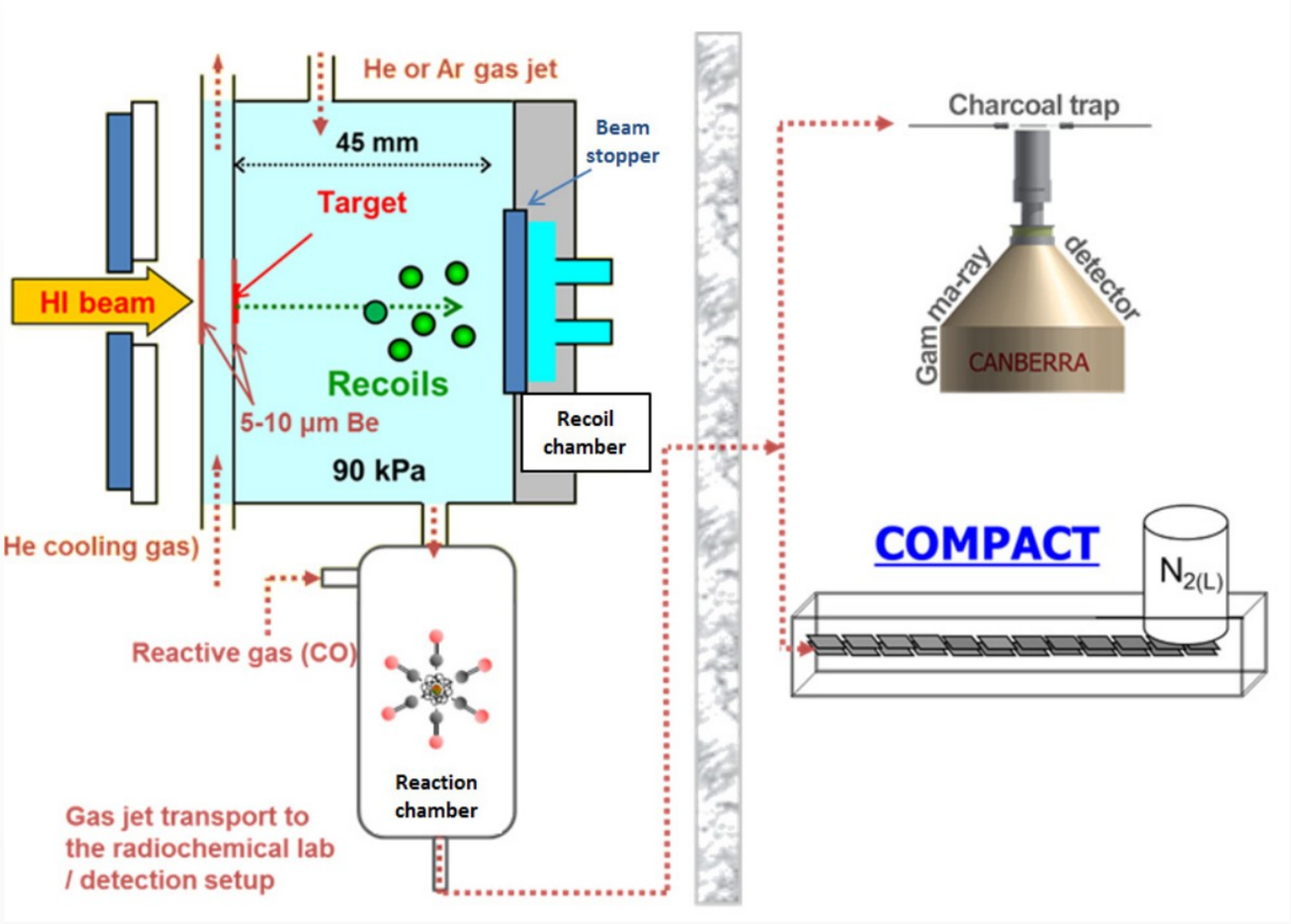


**Adsorption enthalpy :**
**-ΔHa (this work)**
**Nb : 105±3 kJ/mol**
**Ta : 126±2 kJ/mol**

# International collaboration

- In-situ production of M(CO)x / GSI
  - REIMEI budget
  - M(CO)x production w/o a separator
  - → Group 6~10



# JAEA Tandem Acc.(1982~)

The JAEA Tandem accelerator is one of the largest electrostatic accelerators in the world

| | |
|---|---|
| Terminal voltage | 2.5~18 MV |
| Pressure vessel | diameter, 8.3m; height, 26.6m<br>(Insulating gas: 6.7 kg/cm$^2$ of pure $SF_6$ gas) |
| Ion sources | 3 Negative ion-source<br>ECR ion-source (in high voltage terminal) |
| Typical beam current | 3 pμA (H), -1.0 pμA (Li – F), 0.1 pμA (Ar, Xe) |
| Target room | Five rooms, 10 beam lines |

# PAC

- 2 times / year  (May & Dec.)
- If you apply to next PAC (Dec.2018) and the application is approved, you can start the experiment after Feb. 2019.

More detailed information
→ https://ttandem.jaea.go.jp/index-eng.html
Or google “JAEA tandem”

# Summary

- $IP_1$ of heavy actinides : finished
- Adsorption behavior of Lr atom : almost finished
- Development of atomic beam source : on-going
- $IP_1$ of Element (Z>103) : planning
- Oxychlorides of Group 5 elements : on-going

# Thank you very much for your kind attention!!

Grant-in-Aid for Scientific Research