Development of a surface ionizer for the first ionization potential measurement of Lr

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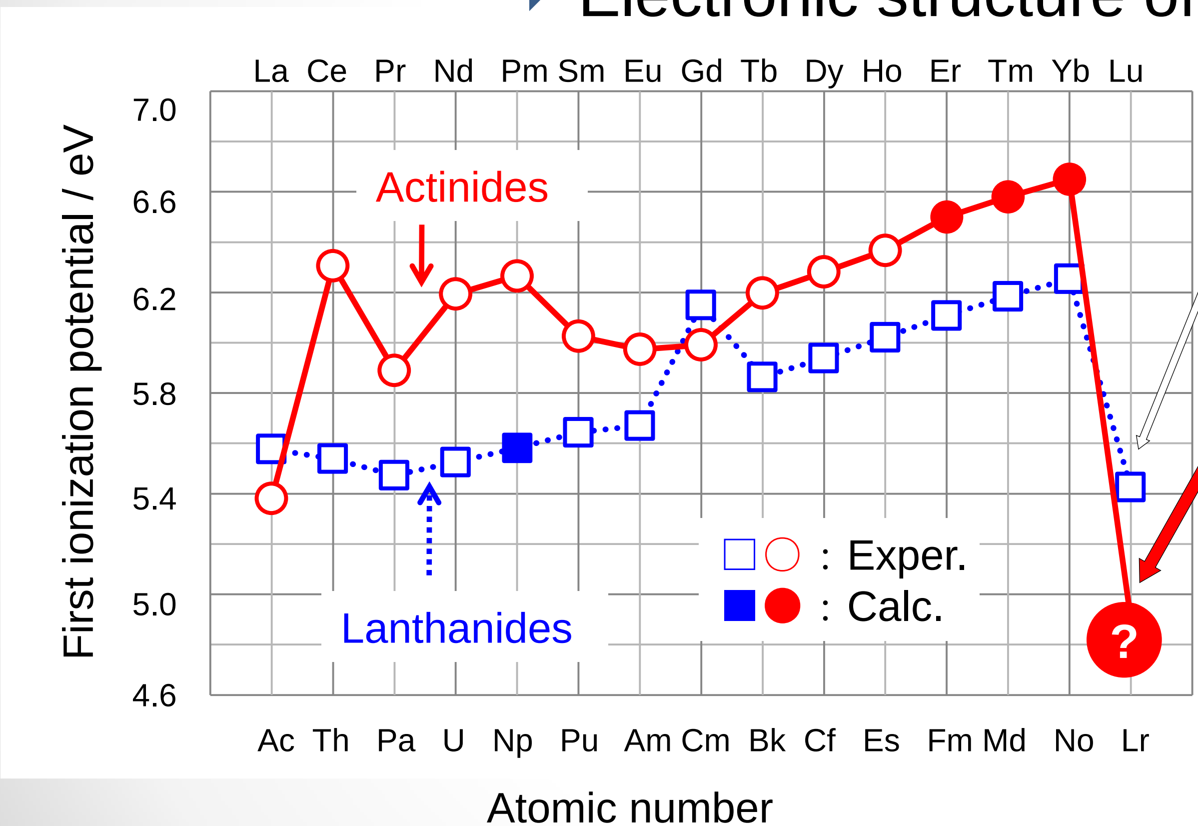
Contents

Background

The first ionization potential (IP) reflects the stability of an outermost electron.

➡ Electronic structure of heavy element atoms



Lu: [Xe]$4f^{14}6s^{2}\underline{5d}$

Lr: [Rn]$5f^{14}7s^{2}\underline{7p_{1/2}}$

4.89 eV [A. Borchevsky *et al.* (2007)]
4.78 eV [X. Cao and M. Dolg (2003)]
4.55 eV [W. Liu *et al.* (1998)]
4.31 eV [T. A. Carlson *et al.* (1970)]

Handbook of Chemistry and Physics (2006).
H. Bache *et al.* (2002).

Purpose: determine the first ionization potential of Lr

Experimental technique

Heavy elements with Z > 100

- Low production rates
- Short nuclear half-lives

} IPs must be measured on an atom-at-a-time scale.

We employed a surface ionization comparison technique.

G. R. Hertel, J. Chem. Phys. **48** (1968) 2053, and references therein.

Surface-ionization comparison technique

Saha-Langmuir equation

Ionization yield

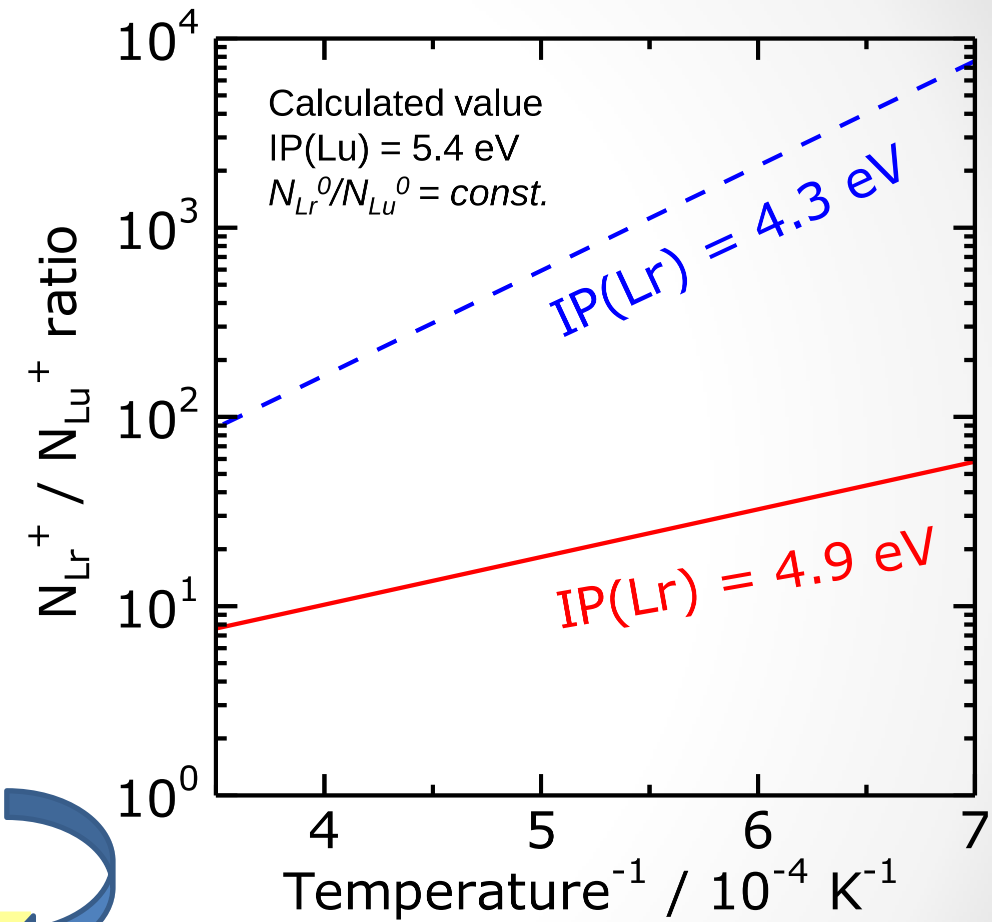
$$\begin{cases} \alpha_A = \dfrac{N_A^+}{N_A^0} = \exp\left(\dfrac{\varphi - IP_A}{kT}\right) \\ \alpha_B = \dfrac{N_B^+}{N_B^0} = \exp\left(\dfrac{\varphi - IP_B}{kT}\right) \end{cases}$$

N^+, N^0: Number of ions and neutral atoms.
φ: Work function of a surface material.
IP: IP of an atom of interest. k: Boltzmann constant. T: Surface temperature

Ratio of ionization yields

$$\frac{\alpha_A}{\alpha_B} = \frac{N_A^+/N_A^0}{N_B^+/N_B^0} = \exp\left(\frac{IP_B - IP_A}{k}\right)$$

$$\log\left(\frac{N_A^+}{N_B^+}\right) = \log\left(\frac{N_A^0}{N_B^0}\right) + \boxed{\frac{IP_B - IP_A}{k}} \times \frac{1}{T}$$

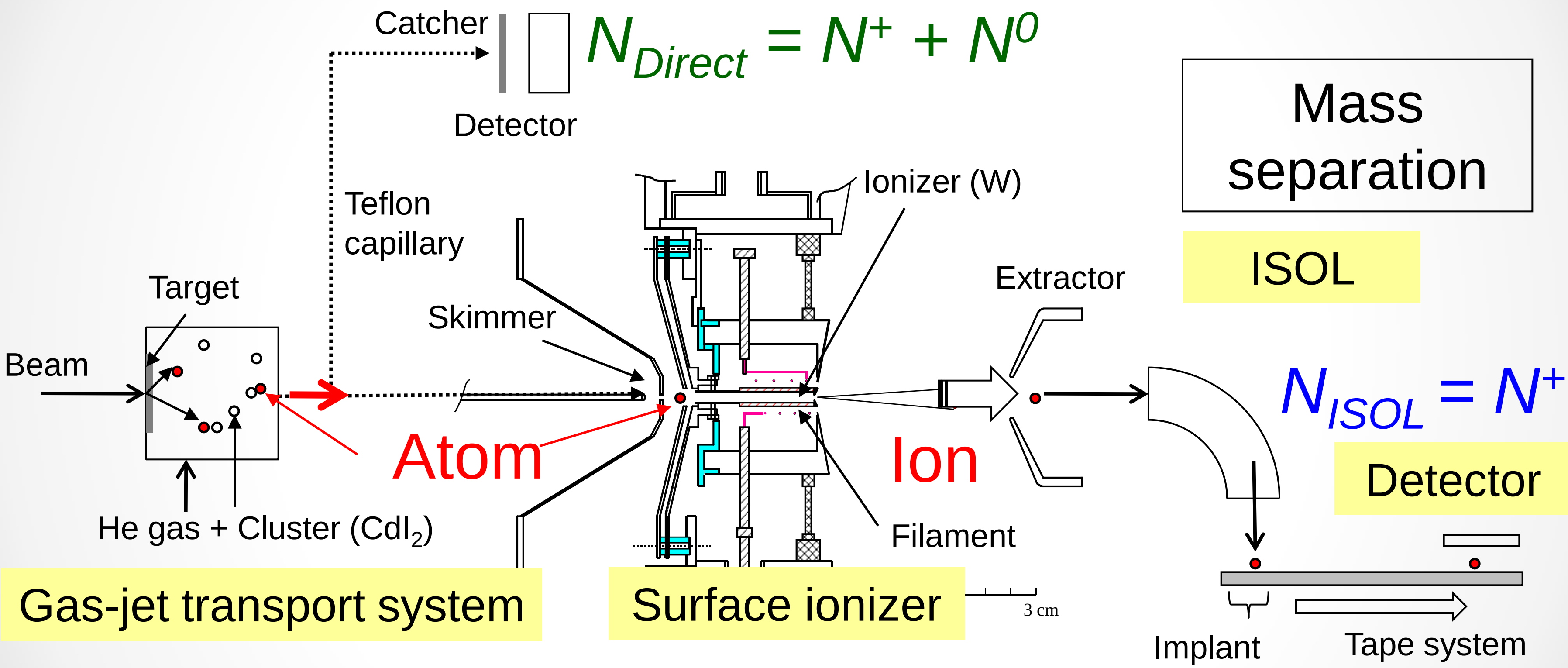


Difference between the IPs of the two elements

Experimental setup

Production yield measurement

JAEA Tandem accelerator facility



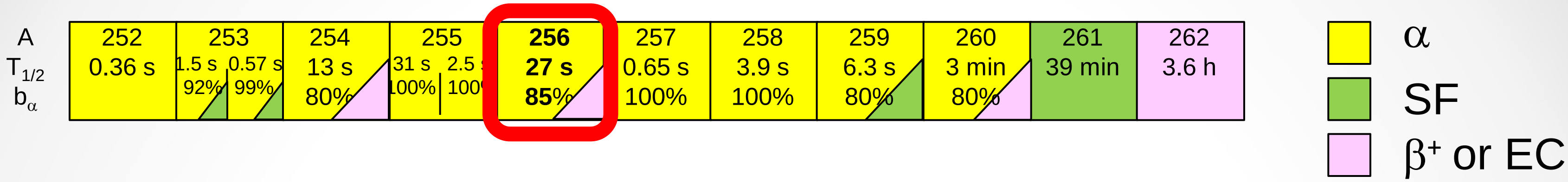
Production and transport of isotopes

Ionization

Ionic yield measurement

S. Ichikawa *et al.*, Nucl. Inst. and Meth. in Phys. Res. B **187** (2002) 548.

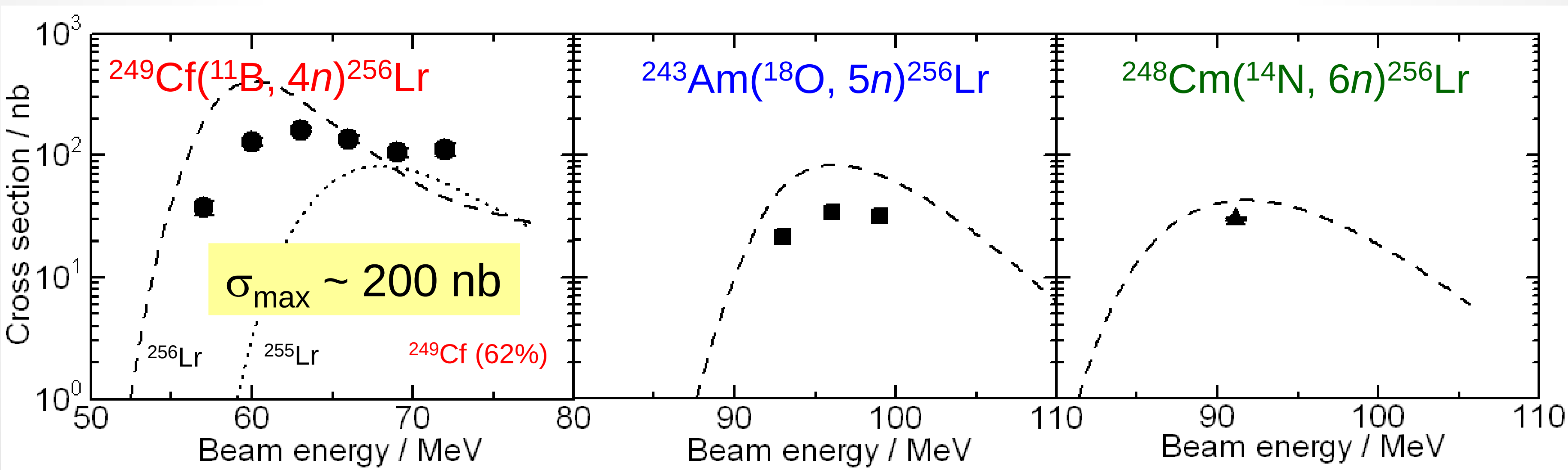
Production of ^{256}Lr



Relatively longer half-life (27 s)

Higher α-decay branching ratio (85%)

Excitation functions

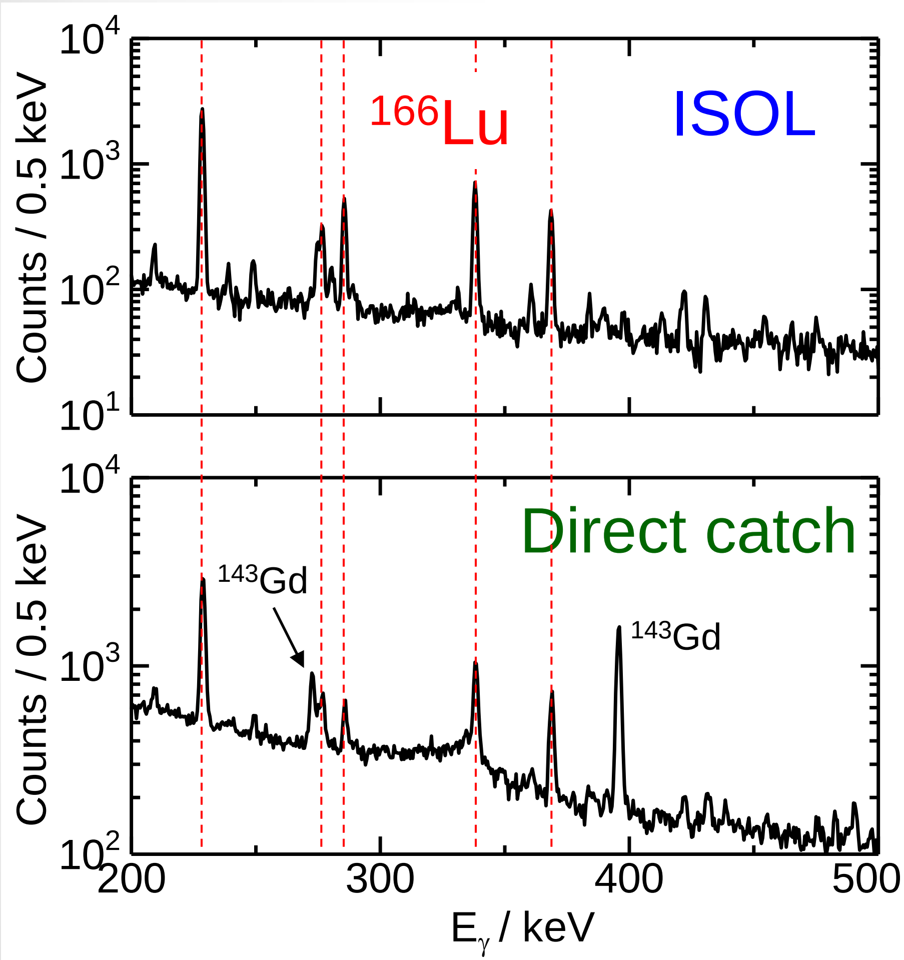


α-particle from $^{256}Lr^{+}$ ~ 300 events / day

Experimental condition

Beam	Targets	Produced isotopes
$^{11}B^{4+}$ 70 MeV	^{136}Ce, ^{nat}Pr, ^{nat}Tb	^{140}Pm, ^{143}Sm, $^{142\text{-}144}Eu$, ^{165}Yb
$^{12}C^{5+}$ 90 MeV	^{136}Ce, ^{nat}Pr, ^{nat}Tb	^{143}Sm, $^{143,145}Gd$, $^{148,149}Tb$, ^{166}Lu
$^{12}C^{5+}$ 90 MeV	^{142}Nd, ^{147}Sm, ^{nat}Eu	$^{149,150}Dy$, $^{154,155}Er$, $^{158,160}Tm$
$^{19}F^{7+}$ 122 MeV	$^{nat,144,149}Sm$	$^{159\text{-}168}Lu$

Ionization efficiency measurement



Ionization efficiency

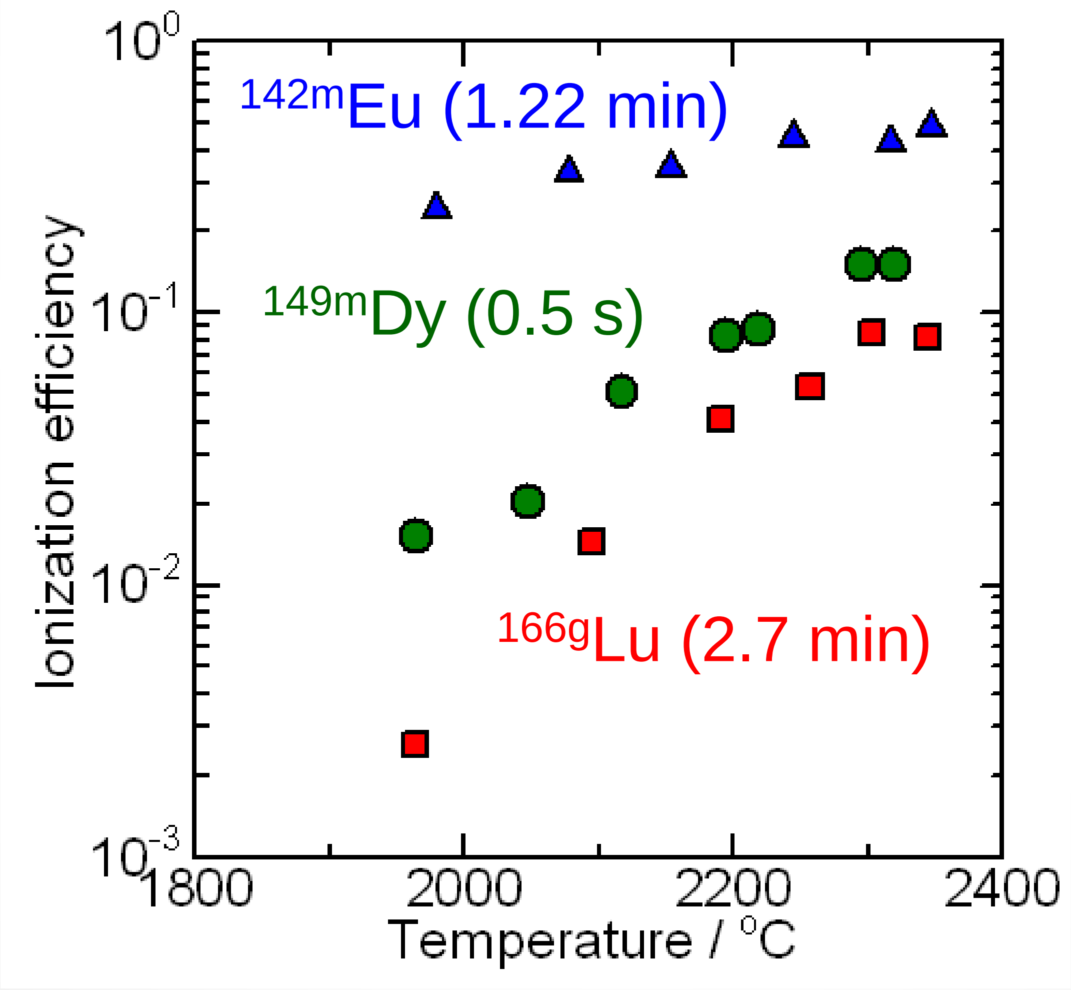
$$\beta = \frac{N_{ISOL}}{N_{Direct}} = \frac{N^+}{N^+ + N^0} = \frac{\alpha}{\alpha + 1}$$

Ion / atom ratio in the ionizer

$$\alpha = \frac{N^+}{N^0} = \frac{N_{ISOL}}{N_{Direct} - N_{ISOL}}$$

Ionization efficiency

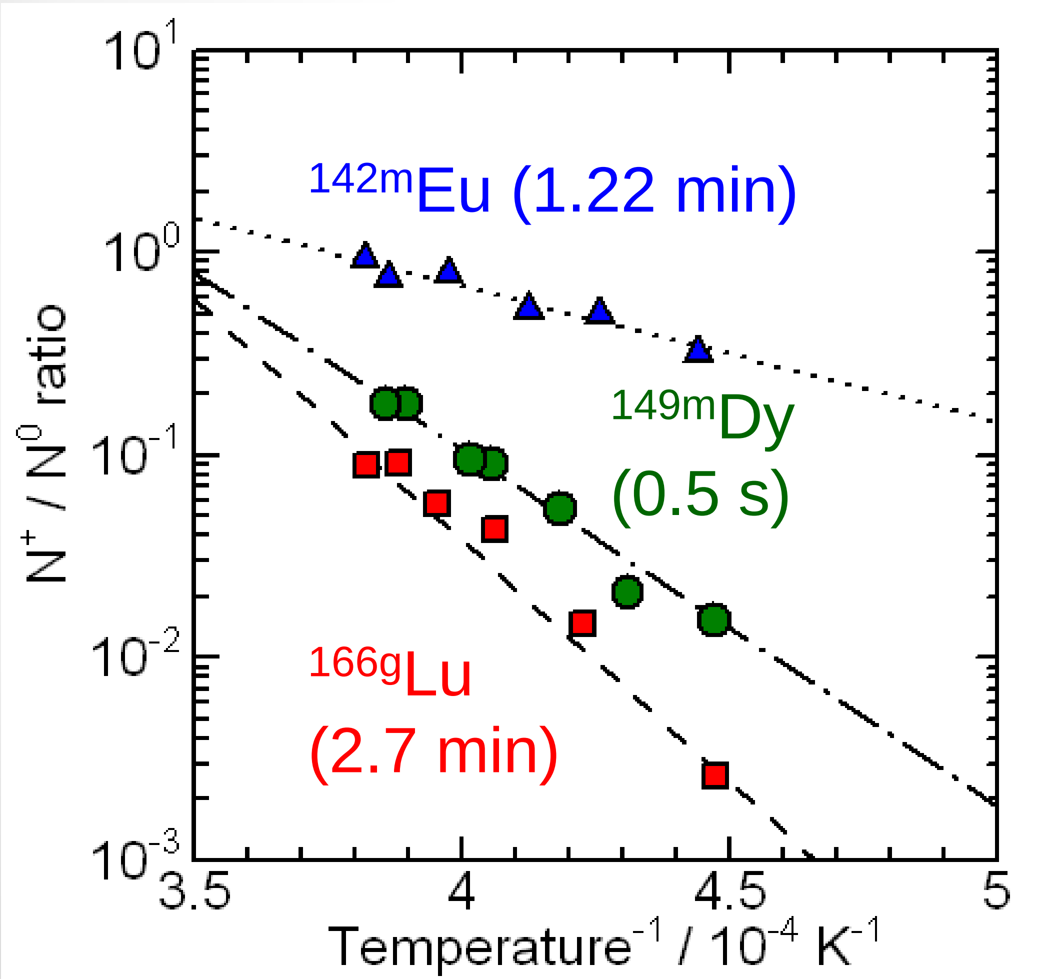
$$\beta = \frac{N_{ISOL}}{N_{Direct}} = \frac{N^+}{N^+ + N^0} = \frac{\alpha}{\alpha + 1}$$



Ion / atom ratio

$$\alpha = \frac{N^+}{N^0} = \frac{N_{ISOL}}{N_{Direct}\varepsilon_{ISOL} - N_{ISOL}}$$

$$\alpha = \frac{N^+}{N^0} = \exp\left(\frac{\varphi - IP}{kT}\right)$$



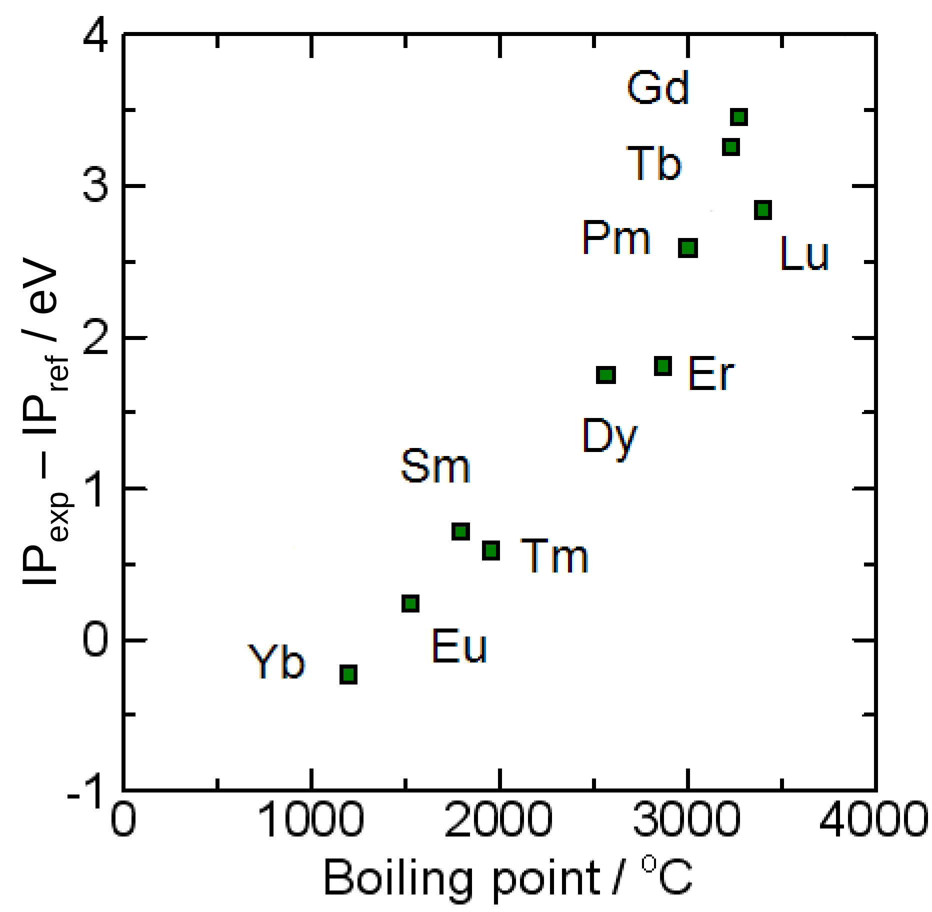
Compare with the Saha-Langmuir equation

$$\text{Slope} = \frac{\varphi - IP_{\exp}}{k}$$

$$IP_{exp} = \varphi - k \cdot \text{Slope}$$

Work function of W (5.42 eV)

Measured IP vs. B.P.



Obtained ionization efficiency of each lanthanide element is affected by

- Ionization potential
- Boiling point

To determine an IP, an effect of the boiling point has to be considered.

Summary

- We have developed a surface ionizer coupled to a gas-jet transport system at JAEA-ISOL.
- Temperature dependence of ionization efficiencies for lanthanides was measured.

Ionization efficiency { Saha-Langmuir equation / Parameter of the B.P.

Improvement of an ionizer ~~B.P.~~

→ Determine the IP of Lr

Thank you for your kind attention.