Present Status and Perspectives of SHE Syntheses at RIKEN GARIS

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for the SHE synthesis collaboration at GARIS

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   ^{248}Cm(^{23}Na,5n)^{266}Bh
2. **Future plans of SHE syntheses at RIKEN**

1. Production and decay studies of RIs for SHE chemistry

Coupling SHE chemistry to a recoil separator

Breakthroughs in SHE chemistry

- **Chemical experiments under low background condition**
- **Stable and high gas-jet transport yields**
- **New chemical reactions**

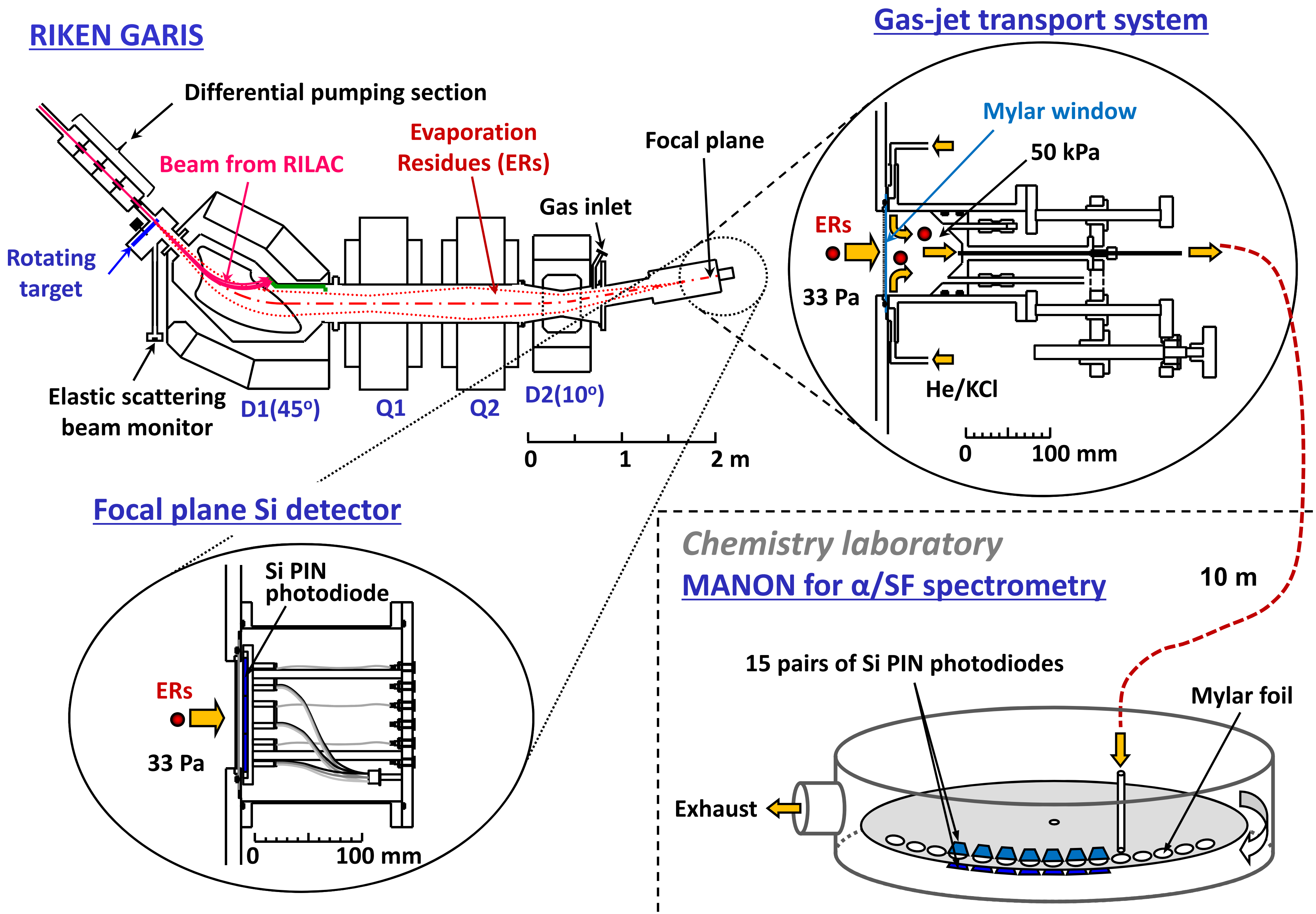
Development of a gas-jet transport system coupled to GARIS

- ^{169}**Tm(**^{40}**Ar,3*n*)**^{206}**Fr**; ^{208}**Pb(**^{40}**Ar,3*n*)**^{245}**Fm** [JNRS **8**, 55 (2007); EPJD **45**, 81 (2007)]
- ^{238}**U(**^{22}**Ne,5*n*)**^{255}**No** [JNRS **9**, 27 (2008)]

Production and decay studies of SHE RIs for chemical studies

- ^{248}**Cm(**^{18}**O,5*n*)**^{261}**Rf**^{a,b} [Chem. Lett. **38**, 426 (2009); PRC **83**, 034602 (2011)]
- ^{248}**Cm(**^{19}**F,5*n*)**^{262}**Db** [PRC **89**, 024618 (2014)]
- ^{248}**Cm(**^{22}**Ne,5*n*)**^{265}**Sg**^{a,b} [PRC **85**, 024611 (2012)] → $Sg(CO)_6$ chemistry
- ^{248}**Cm(**^{23}**Na,5*n*)**^{266}**Bh** [This work]

Experimental setup



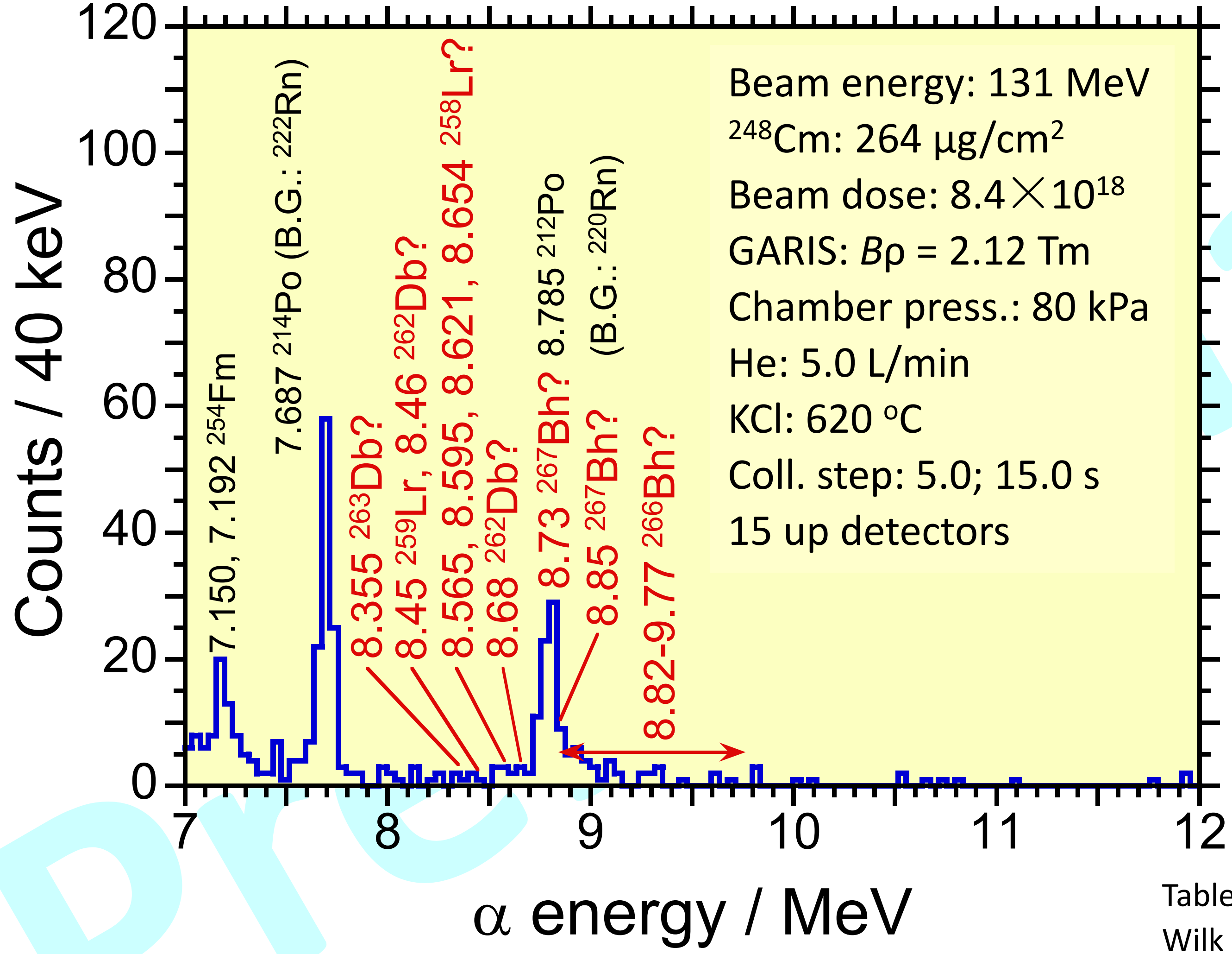
Experimental conditions

Nuclide	^{266}Bh ($T_{1/2}$ = 1.20 s[1)])	^{267}Bh ($T_{1/2}$ = 13.7 s[1)])
Reaction	^{248}Cm(^{23}Na,5*n*)	^{248}Cm(^{23}Na,4*n*)
Cross section (pb)	~50 (5*n* + 4*n*)? [2)]	
Beam energy, $E_{lab.}$ (MeV)	131	
Beam intensity (pμA)	3	
$^{248}Cm_2O_3$ thickness (μg/cm^2)	290; 250	
Magnetic rigidity (Tm)	2.12	
GARIS He (Pa)	33	
RTC Mylar window (μm)	0.7	
Honeycomb grid (%)	78	
Gas-jet He (kPa)	80	
Chamber depth (mm)	20	
He flow rate (L/min)	5.0	
KCl generator (^{o}C)	620	
Step interval of MANON (s)	5.0; 8.5; 15.0	

1) Wilk *et al.*, PRL **85**, 2697 (2000).; Eichler *et al.*, Nature **407**, 63 (2000).; Morita *et al.*, JSPS **81**, 103210 (2012).; Qin *et al.*, Nucl. Phys. Rev. **23**, 400 (2006).

2) Morira *et al.*, JPSJ **78**, 064201 (2009).

α-particle spectrum



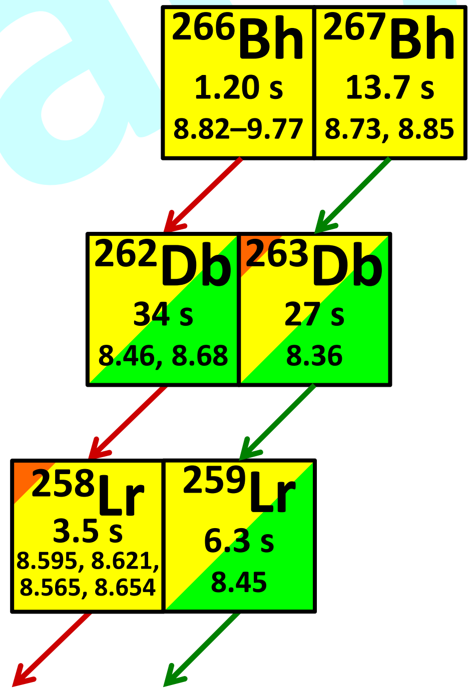


Table of Isotopes, 8th ed. (1996).
Wilk *et al.*, PRL **85**, 2697 (2000).
Eichler *et al.*, Nature **407**, 63 (2000).
Qin *et al.*, Nucl. Phys. Rev. **23**, 400 (2006).
Morita et al., JSPS **78**, 064201 (2009).
Morita *et al.*, JSPS **81**, 103210 (2012).
Haba *et al.*, PRC **89**, 024618 (2014).

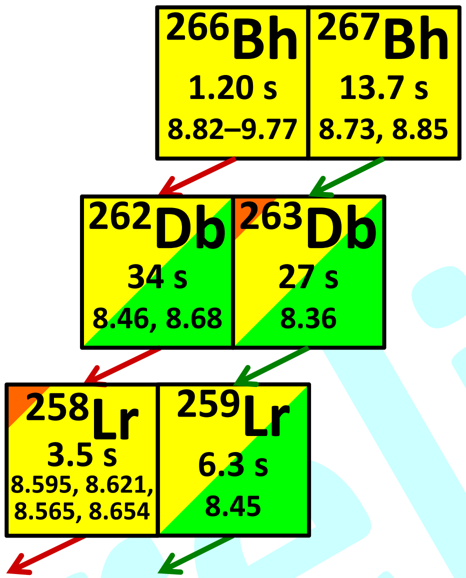
Search for α-α/SF correlations

$E_{\alpha 1}$ = 8.00–10.00 MeV

$E_{\alpha 2;\, \alpha 3}$ = 8.00–8.73 MeV

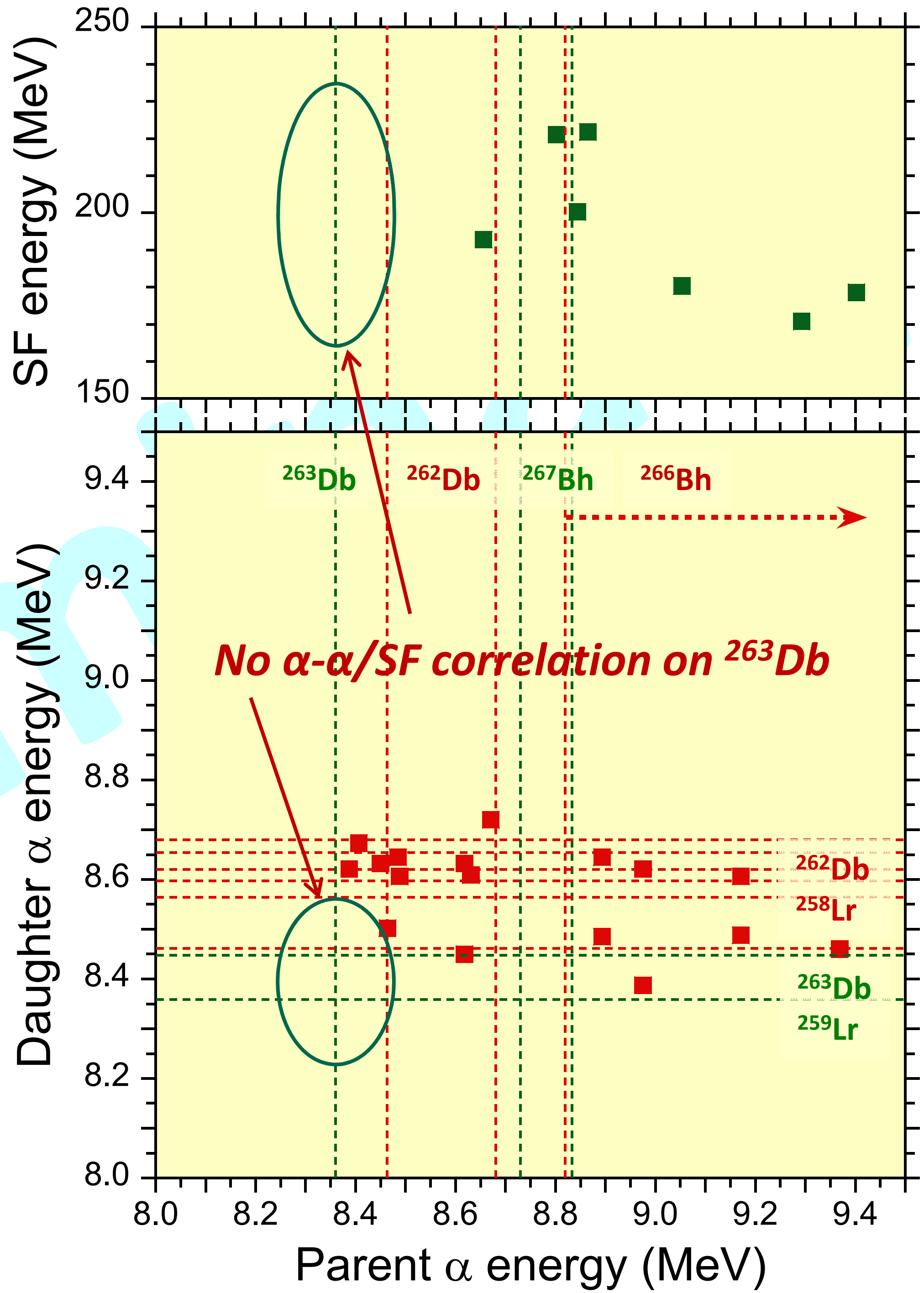
$E_{SF} \geq$ 50 MeV; Si top & bottom coin.

$\Delta T \leq$ 340 s [= 10 $T_{1/2}$(^{262}Db)]



No. of the observed correlations

	Observed	Random
α-α-α	4	< 0.01
α-α	5	< 0.82
α-SF	7	< 0.06

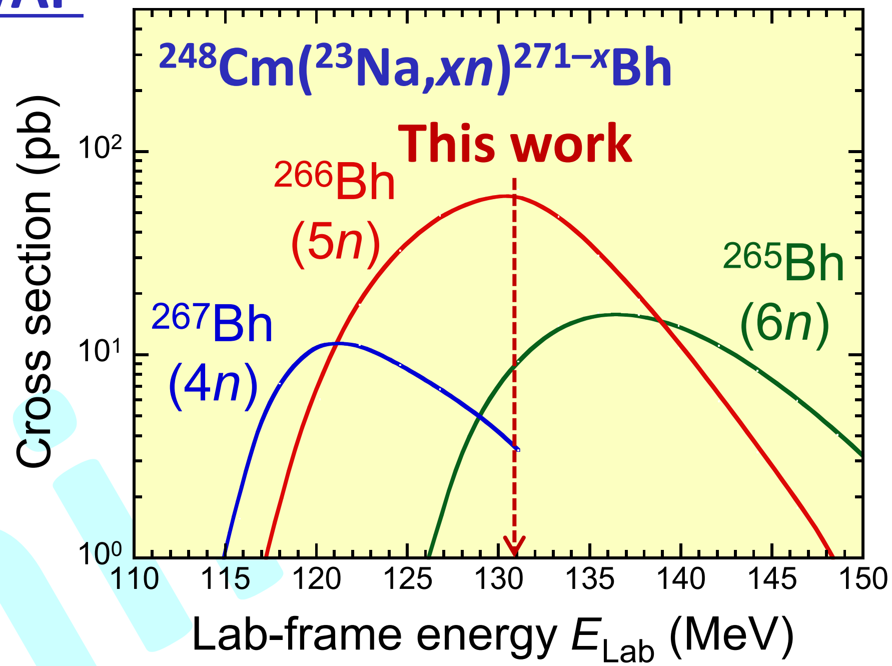


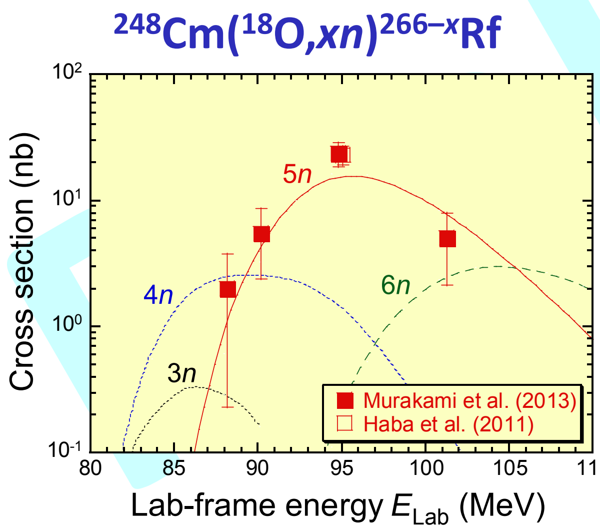
Excitation function calculated by HIVAP

Reisdorf and Schädel, ZPA **343**, 47 (1992).
Nishio *et al.*, PRL **93**, 162701 (2004).
Nishio *et al.*, PRC **82**, 024611 (2010).

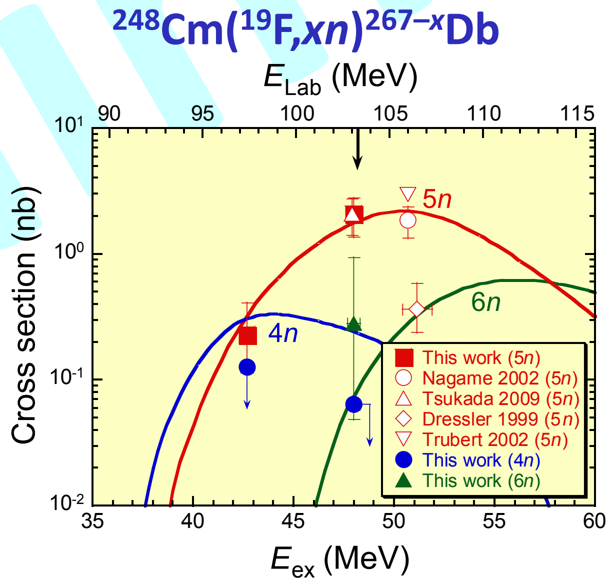
- **For $^{248}Cm(^{23}Na,xn)^{271-x}Bh$, σ(5*n*) is 60 pb, and σ(4*n*) is more than one order of magnitude smaller than σ(5*n*).**

→ Most of the observed events in this work can be assigned to ^{266}Bh.

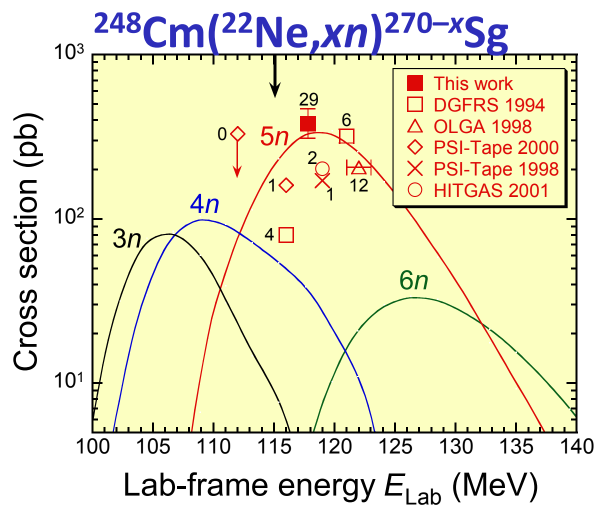




Haba et al., PRC **83**, 034602 (2011).
Murakami et al., PRC **88**, 024618 (2013).



Haba et al., PRC **89**, 024618 (2014).



Haba et al., PRC **85**, 024611 (2012).

Decay properties of ^{266}Bh

- **E_α of ^{266}Bh spread widely in E_α = 8.62–9.40 MeV.**
- **$T_{1/2} = 10.7^{+4.2}_{-2.4}$ s in this work is longer than those of ^{266}Bh in the literatures.**

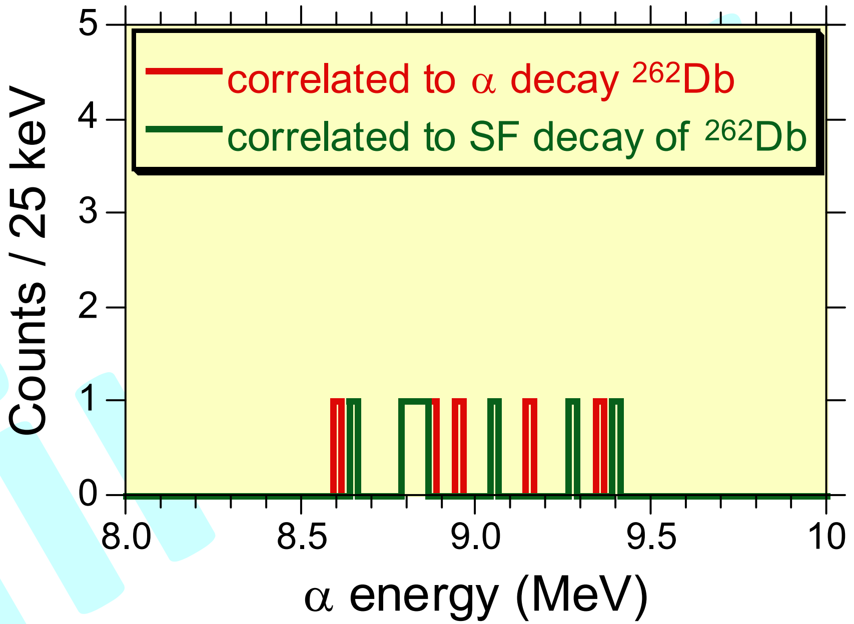
Nuclide	This work		Refs. [1–4]	
	N	$T_{1/2}$ [s]	N	$T_{1/2}$ [s]
^{266}Bh	**12**	**$10.7^{+4.2}_{-2.4}$**	8	**$1.20^{+0.66}_{-0.31}$**
^{267}Bh			11	**$13.7^{+5.9}_{-3.2}$**

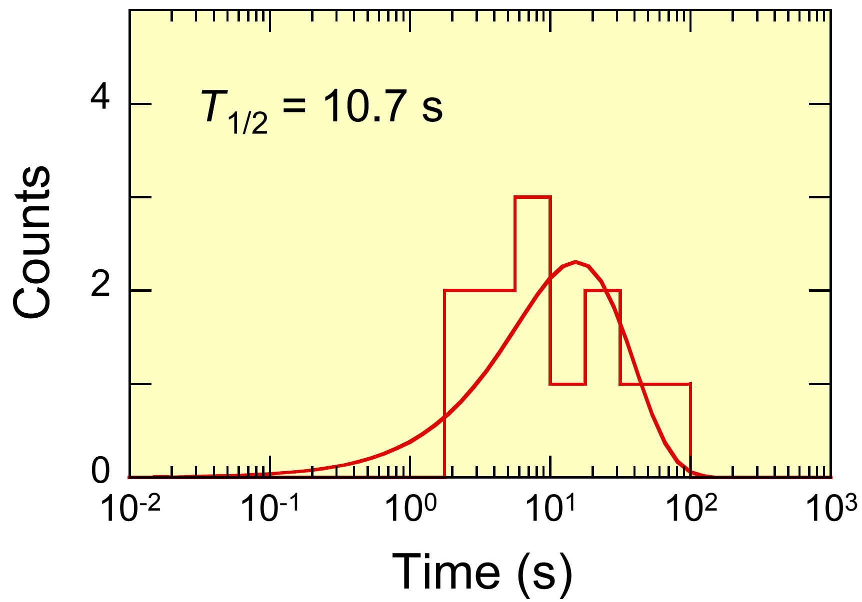
[1] ^{249}Bk(^{22}Ne,5;4n)^{266,267}Bh (N = 1, 5): Wilk *et al.*, PRL **85**, 2697 (2000).
[2] ^{249}Bk(^{22}Ne,4n)^{267}Bh (N = 6): Eichler *et al.*, Nature **407**, 63 (2000).
[3] ^{243}Am(^{26}Mg,3n)^{266}Bh (N = 4): Qin *et al.*, Nucl. Phys. Rev. **23**, 400 (2006).
[4] ^{209}Bi(^{70}Zn,n)^{278}113 → ^{266}Bh (N = 3): Morita *et al.*, JPSJ **81**, 103201 (2012).

- **Existence of an isomeric state in ^{266}Bh?**

→ Further investigation of ^{267}Bh at a lower beam energy

- **The longer half-life of ^{266}Bh is good for Bh chemistry in the future.**





Excitation function for ^{248}Cm(^{23}Na,5n)^{266}Bh

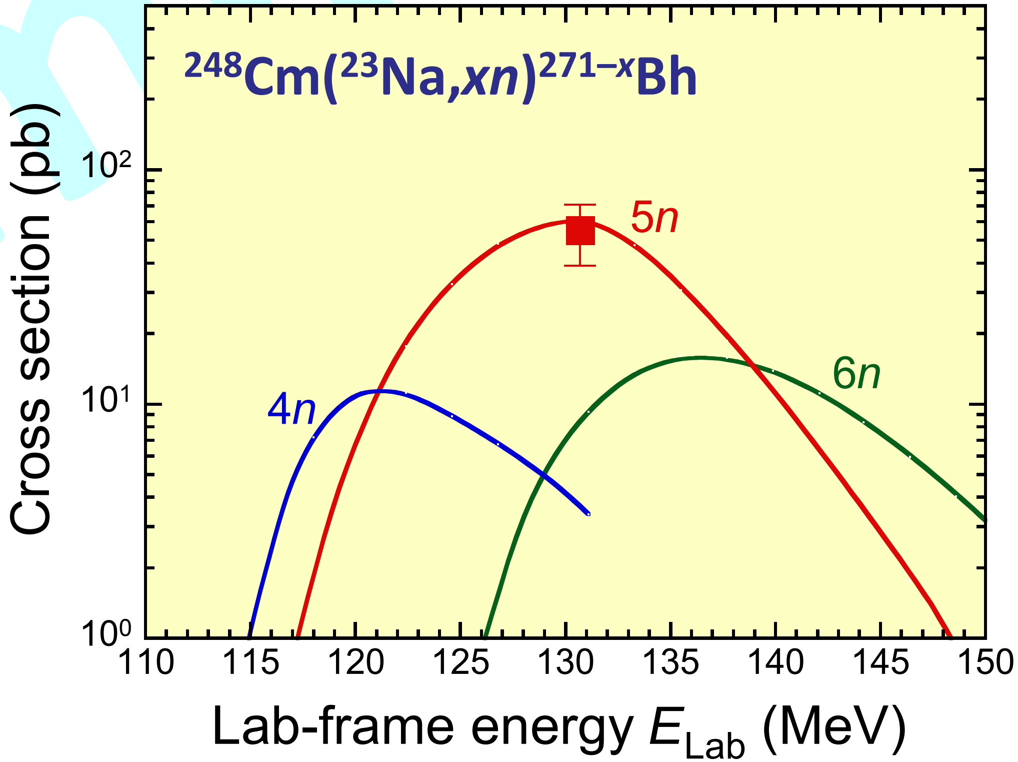
Reaction	Cross section at 131 MeV	Reaction*	Cross sections* at 117/123 MeV
^{248}Cm(^{23}Na,5n)^{266}Bh	**55±16 pb**	^{249}Bk(^{22}Ne,5n)^{266}Bh	-/25–250 pb
		^{249}Bk(^{22}Ne,4n)^{267}Bh	$58^{+33}_{-15}/96^{+55}_{-25}$ pb

*Wilk *et al.*, PRL **85**, 2697 (2000).

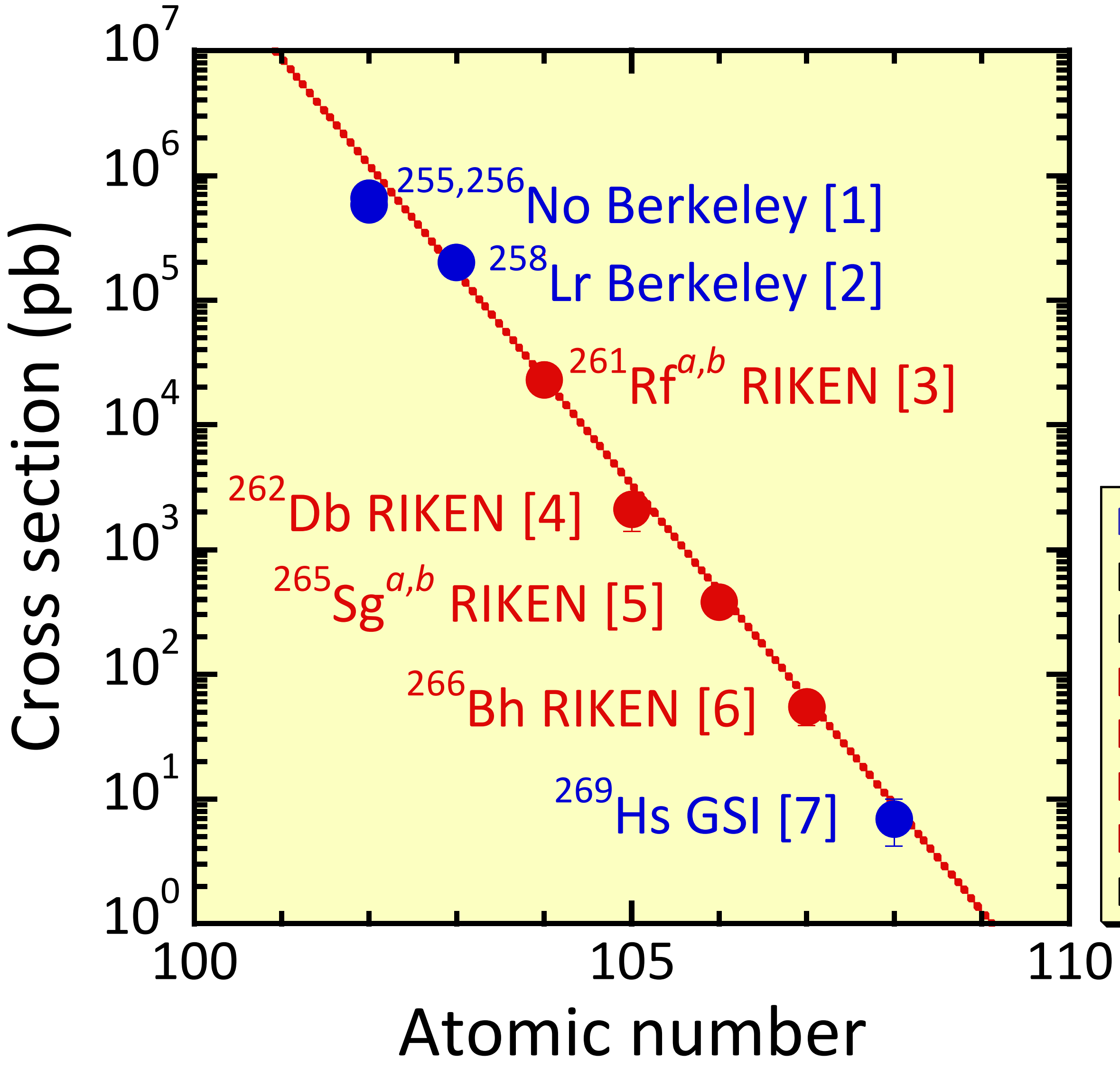
Assumptions

- $T_{1/2}$(^{266}Bh) = 10.7 s
- SF branch of ^{266}Bh: b_{SF} = 0%
- GARIS transmission: 15%
- Gas-jet transport efficiency: 50%
- Gas-jet transport time: 2.7 s

- **The ^{248}Cm(^{23}Na,5n)^{266}Bh cross section is comparable to the ^{249}Bk(^{22}Ne,5;4n)^{266,267}Bh.**
- **HIVAP reproduces the ^{248}Cm(^{23}Na,5n)^{266}Bh cross section.**



Cross section systematics for the $^{248}Cm(X,5n)$ reactions



References

[1] Sikkeland *et al.*, PL **172**, 1232 (1968).

[2] Eskola *et al.*, PRC **4**, 632 (1971).

[3] Haba *et al.*, PRC **83**, 034602 (2011);

[4] Haba *et al.*, PRC **89**, 024618 (2014).

[5] Haba *et al.*, PRC **85**, 024611 (2012).

[6] This work

[7] Dvorak *et al.*, PRL **100**, 132503 (2008).

2. Future plans of SHE syntheses at RIKEN

Chemistry using preseparated $^{261}Rf^{a}$, ^{262}Db, $^{265}Sg^{a,b}$, and ^{266}Bh

- $^{248}Cm(^{23}Na,xn)^{271-x}Bh$ (in progress)
- Aqueous chemistry of Sg and Bh by solvent extraction with LS
  Development of a rapid solvent extraction apparatus coupled to GARIS
  → TASCA15 contribution by Y. Komori
- Gas chemistry of organometallic compounds of SHEs
  → Assessing the thermal stability of $Sg(CO)_6$ (R. Eichler and Ch. E. Düllmann)

Syntheses of the heaviest SHEs

- $^{248}Cm(^{50}Ti,xn)^{298-x}118$ (Feb.–Mar., 2016)
  ☑ ^{50}Ti-MIVOC with $Cp^{*50}TiMe_3$ from Univ. Strasbourg
    → Acceleration test in Jun., 2015: 0.5 pμA on target; 0.22 mg/h
  ☐ 9 mg of ^{248}Cm shipped to RIKEN from ORNL (Dec., 2015)
    → Preparation of ^{248}Cm rotating target (500-μg/cm^2; ϕ100 mm)
  ☐ GARIS II commissioning (Oct. 21–28, 2015 and Jan. 25–Feb. 15, 2016)
    → $^{238}U(^{48}Ca,xn)^{286-x}Cn$ and $^{248}Cm(^{48}Ca,xn)^{296-x}Lv$

Collaborators for the GARIS gas-jet experiment

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Thank you for your kind attention.