Production of ^{265}Sg for chemical studies using the gas-jet transport system coupled to the RIKEN gas-filled recoil ion separator

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1. Introduction

RIKEN GARIS as a pre-separator for SHE chemistry

Breakthroughs in SHE chemistry

- **Chemical and physical experiments under low background condition**
- **Stable and high gas-jet transport efficiency**
- **New chemical systems that were not accessible before**

Development of a gas-jet transport system coupled to GARIS

[JNRS **8**, 55 (2007).; EPJD **45**, 81 (2007).; JNRS **9**, 27 (2008).]

→ Production of $^{261}Rf^{a,b}$ in the $^{248}Cm(^{18}O,5n)^{261}Rf^{a,b}$ reaction

[Chem. Lett. **38**, 426 (2009).; PRC **83**, 034602 (2011).]

<u>This work</u>

Aqueous chemistry of Sg at RIKEN

– based on successful collaboration on aqueous chemistry of Rf and Db at JAEA –

- **Production of ^{265}Sg and its homologues ^{173}W and ^{90}Mo**

$^{248}Cm(^{22}Ne,5n)^{265}Sg$

$^{nat}Gd(^{22}Ne,xn)^{173}W$ and $^{nat}Ge(^{22}Ne,xn)^{90}Mo$

- **Decay properties of $^{265}Sg^{a,b}$**

Previous decay studies of ^{265}Sg

Düllmann and Türler: PRC **77**, 064320 (2008).

^{248}Cm(^{22}Ne,5;4*n*)^{265,266}Sg: reanalysis → 36 events on ^{265}Sg^{a,b}

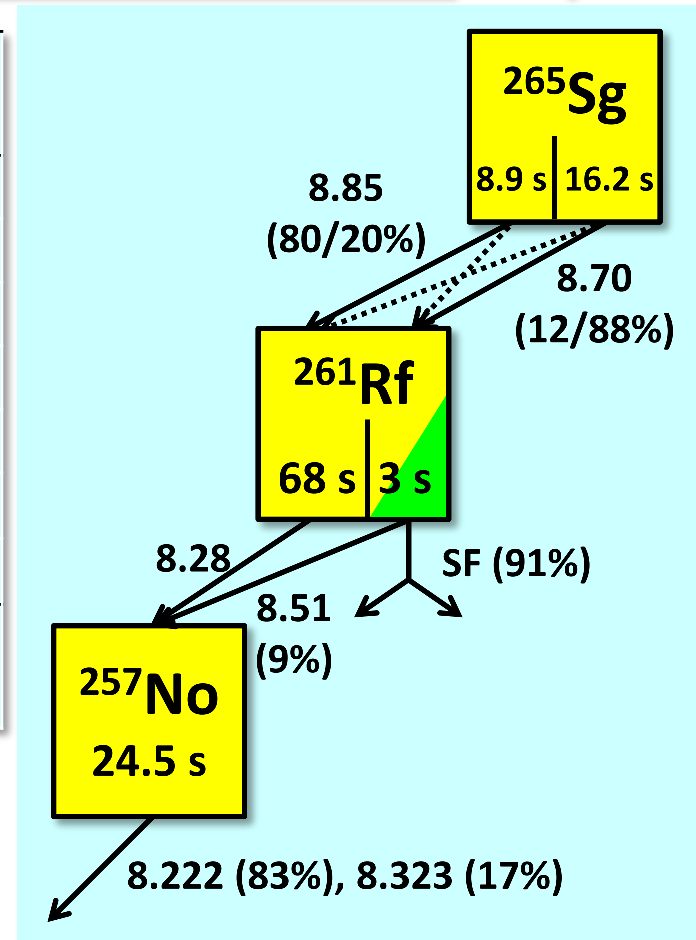
^{208}Pb(^{70}Zn,*n*)^{277}Cn: SHIP/GARIS + FPD → 4 events

^{248}Cm(^{26}Mg,5*n*)^{269}Hs: Gas-jet + COLD/CALLISTO/COMPACT → 20 events

Refs. ^{248}Cm(^{22}Ne,5*n*)^{265}Sg	Method	E_{beam}	No of. events	σ [pb]
Lazarev *et al.* (1994)	DGFRS	116	4[a)]	80
		121	6[a)]	320
Gregorich *et al.* (1996)	MG	121	3	
Türler *et al.* (1998,1999)	OLGA	121/123	19	206
Türler *et al.* (1998)	PSI Tape	119	1[b)]	78
Dressler *et al.* (2000)	PSI Tape	116	1[b)]	73
Hübener *et al.* (2001)	HITGAS	119	2[b)]	92

a) No $T_{1/2}$ data

b) Only sensitive to α-SF chains



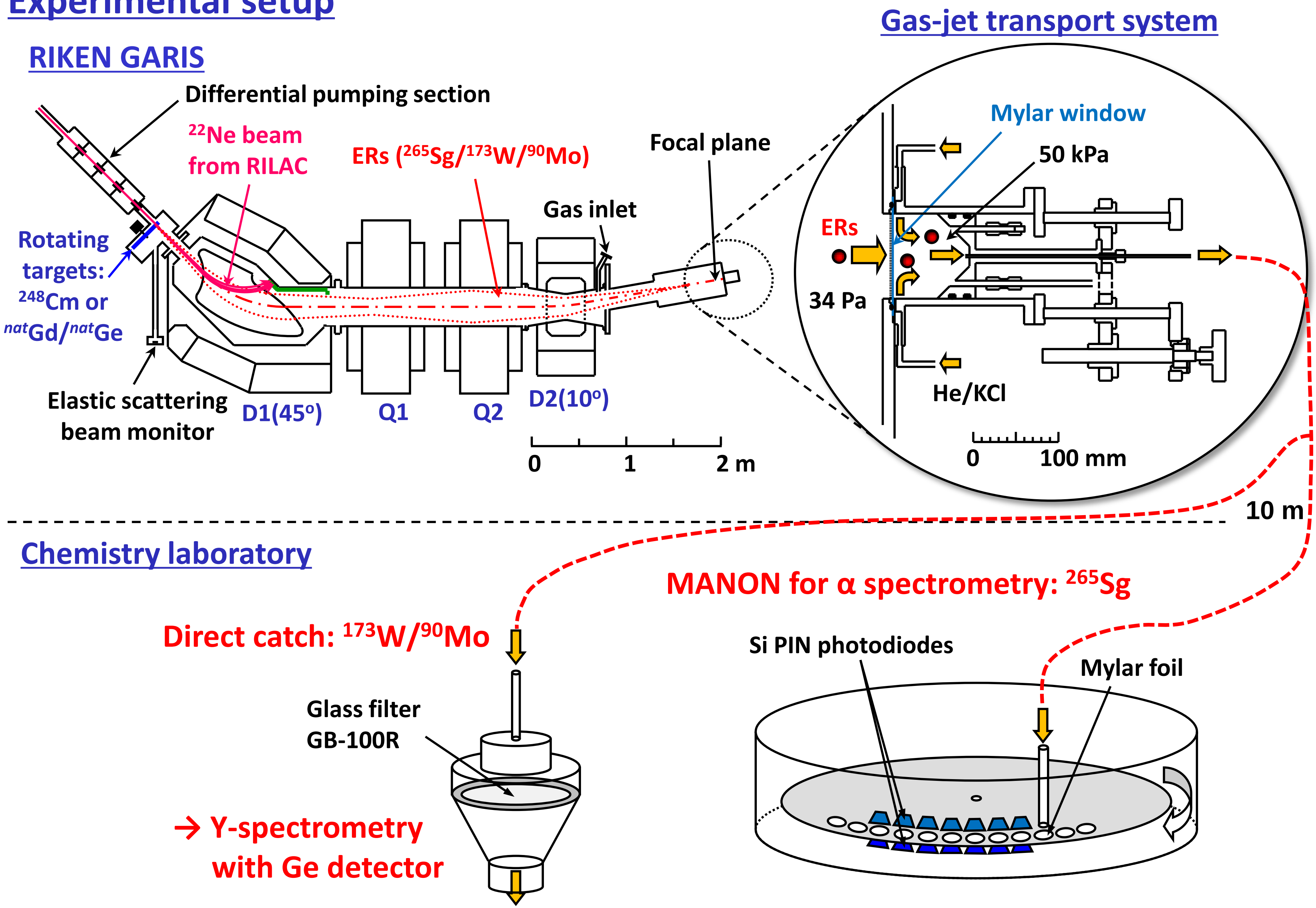
For future chemical studies with ^{265}Sg

Decay properties (E_α and $T_{1/2}$) and cross section ?

→ Systematic studies on ^{248}Cm(^{22}Ne,5*n*)^{265}Sg^{a,b}

2. Experimental

Experimental setup



Experimental conditions

Nuclide	$^{265}Sg^{a,b}$ (Z=106)	^{173}W (Z=74)	^{90}Mo (Z=42)
Half-life	8.9, 16.2 s*	7.6 min	5.67 h
Reaction	$^{248}Cm(^{22}Ne,5n)$	$^{nat}Gd(^{22}Ne,xn)$	$^{nat}Ge(^{22}Ne,xn)$
Beam energy (MeV)	118	←	←
Beam intensity (pμA)	4	←	0.25
Target (μg/cm^2) on 2-μm Ti	280/230 (Cm_2O_3)	340 (Gd_2O_3)	290 (Ge)
Recoil energy (MeV)	9.4	14.1	25.8
Magnetic rigidity (Tm)	1.73–2.16	1.50–1.93	0.985
GARIS He (Pa)	34	←	←
RTC Mylar window (μm)	0.65	←	←
Honeycomb grid (%)	84	←	←
Gas-jet He (kPa)	50	←	68
Chamber depth (mm)	40	100	100
He flow rate (L/min)	2.0/2.5	2.0	4.0
KCl generator (°C)	600/605	620	620
Aerosol collection (s)	20	120	300
α- or Y-spectrometry	MANON	Ge detector	Ge detector

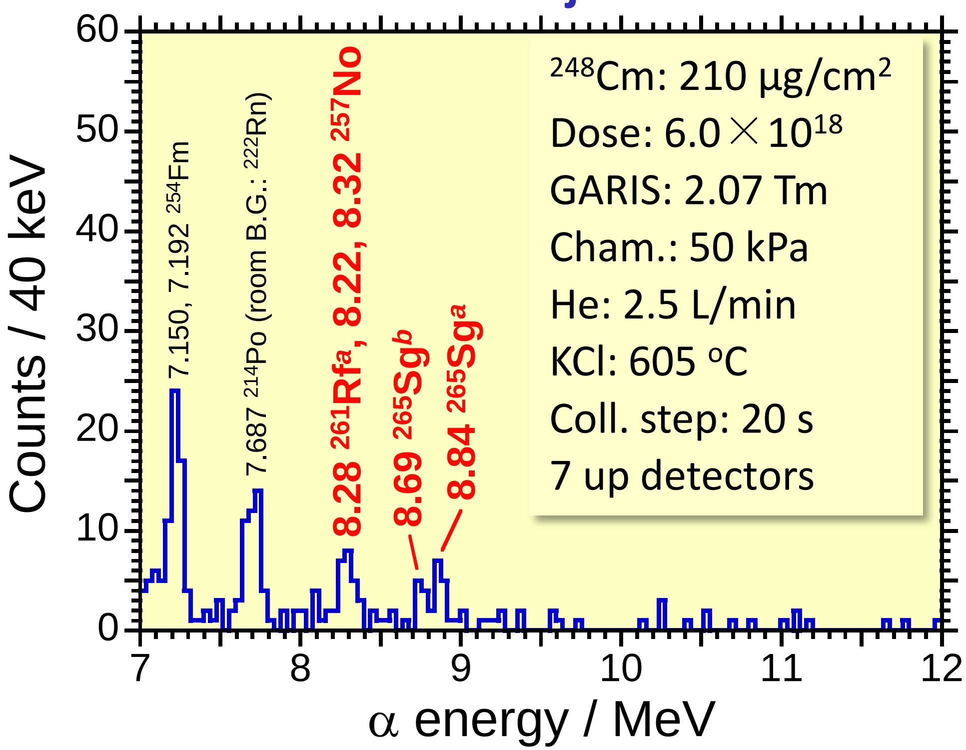
* Düllmann and Türler: PRC **77**, 064320 (2008).

3. Results and discussion

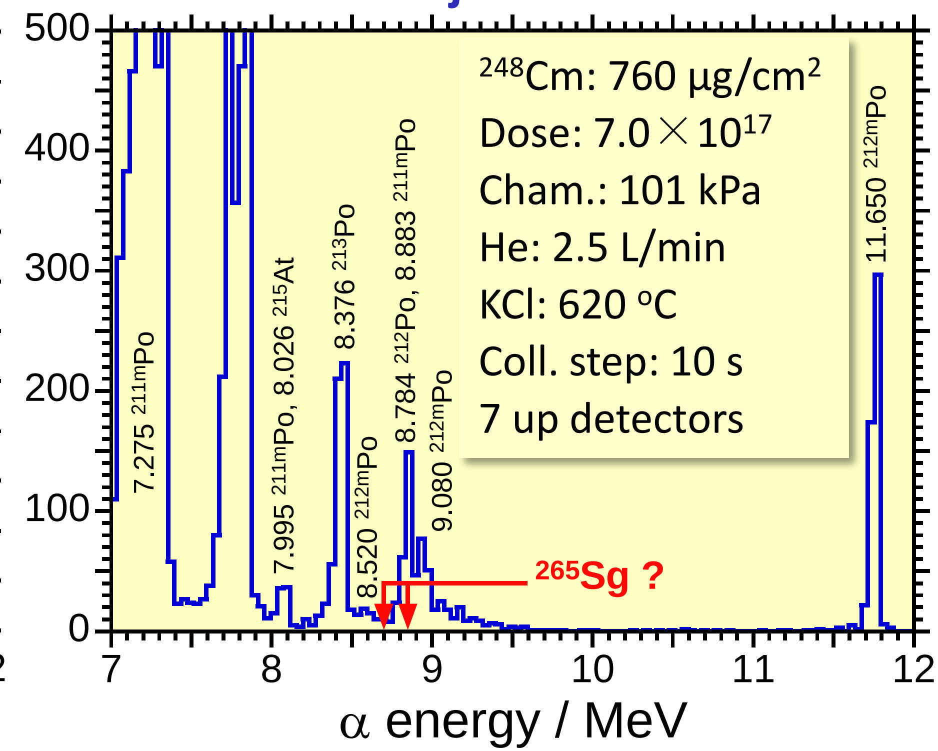
3.1. ^{248}Cm(^{22}Ne,5*n*)^{265}Sg

Beam time	Magnetic rigidity (Tm)	Beam dose (×10^{18})
Sep. 30–Oct. 6, 2008	1.73	2.07
	1.94	1.91
	2.16	1.57
	2.04	0.639
Sep. 19–23, 2009; July 16–20, 2010	2.07	11.2

RILAC + GARIS + Gas-jet + MANON



AVF + Gas-jet + MANON



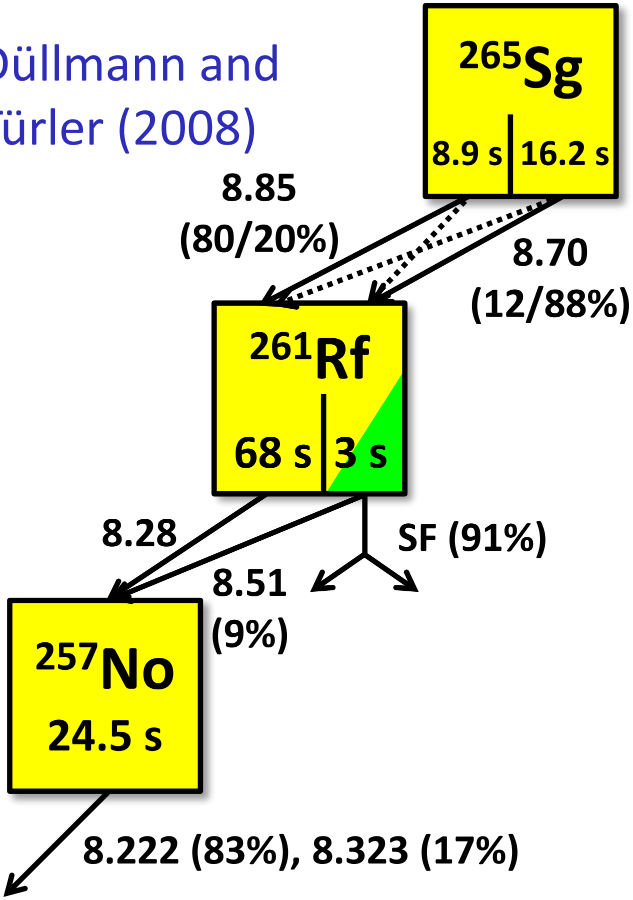
Search for α-α/α-SF correlations

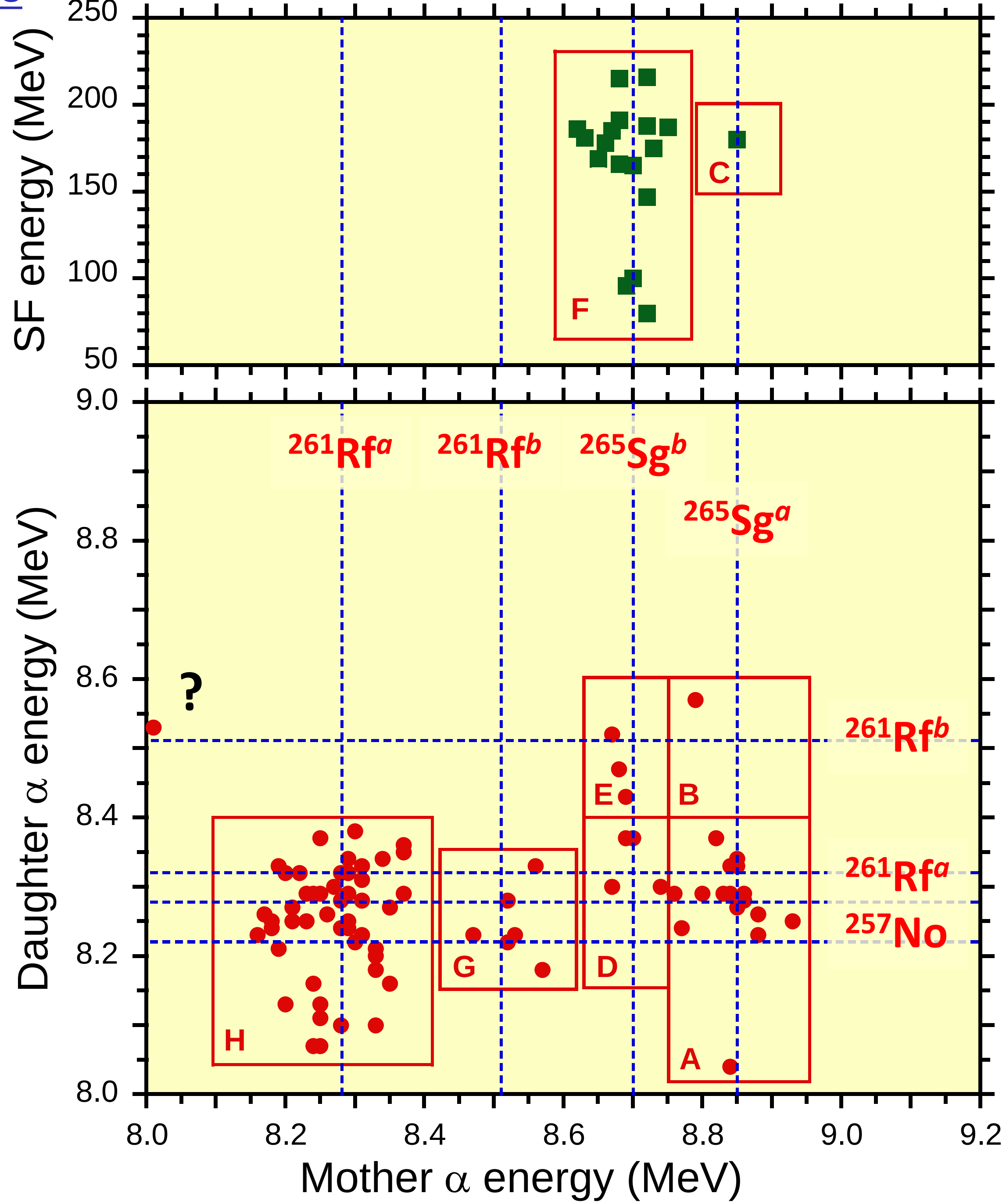
E_α = 8.0–9.0 MeV; $E_{SF} \geq 30$ MeV

ΔT = 226 s

	Observed	Random
α-α	**98**	< 5.3
α-α-α	**18**	< 0.1
α-SF	**18**	< 2.0

Düllmann and Türler (2008)

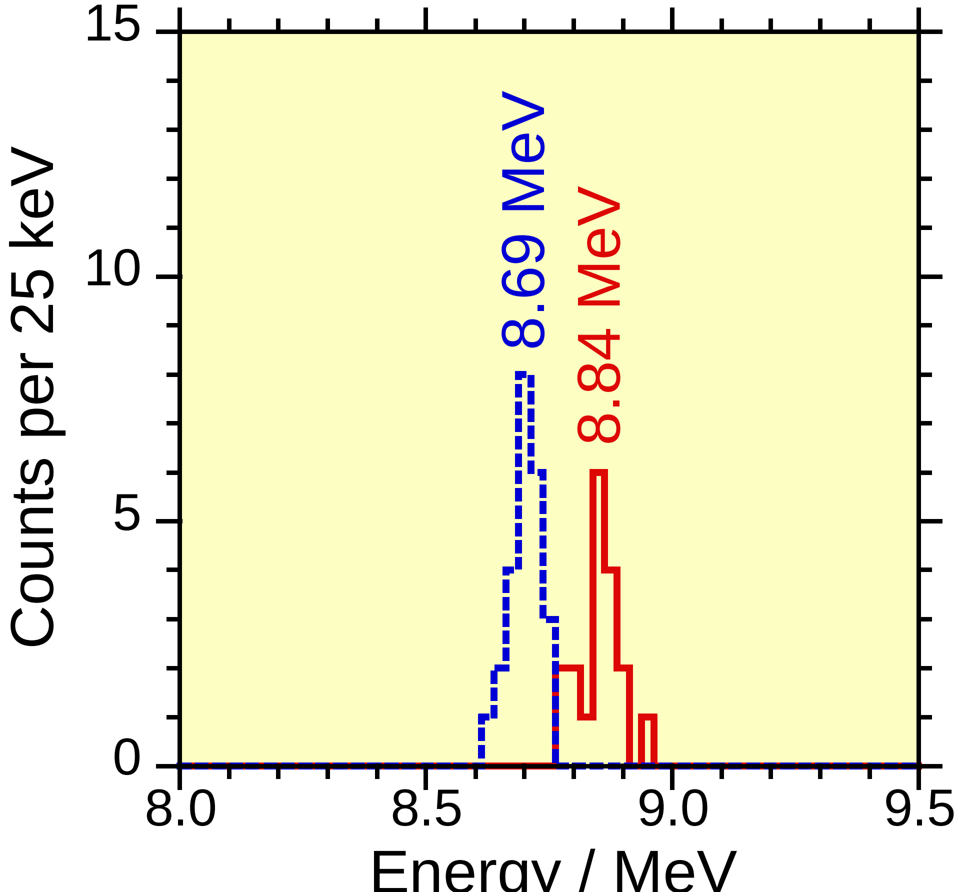




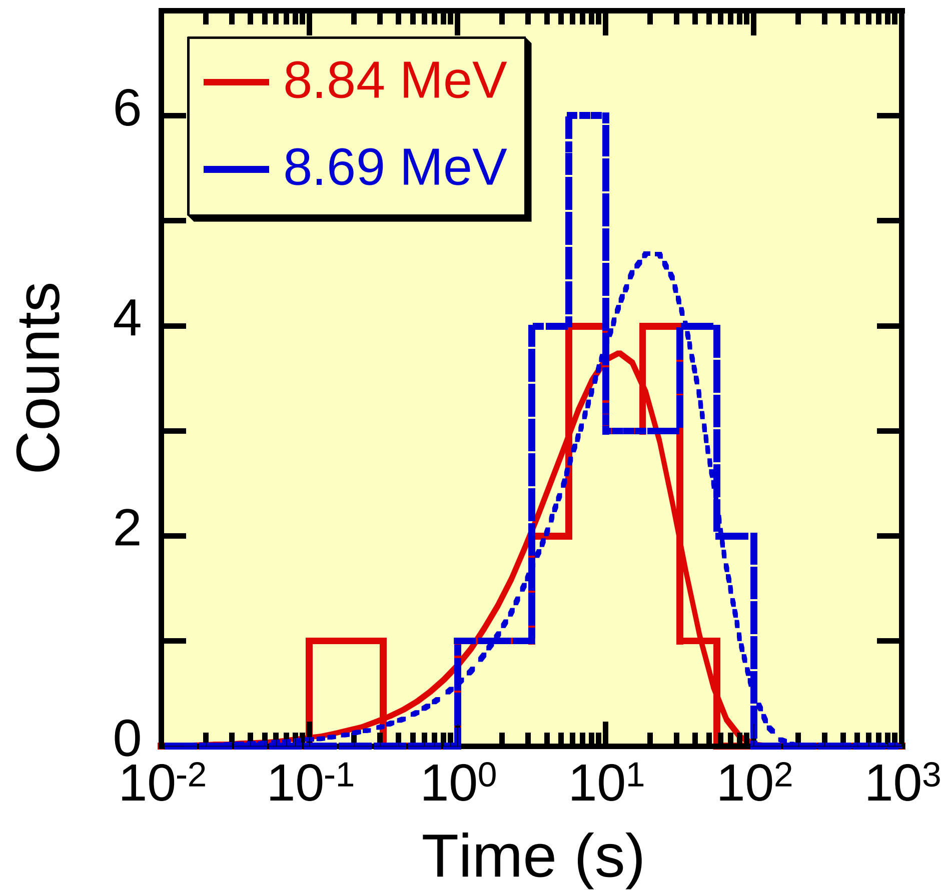
α energy and half-life of $^{265}Sg^{a,b}$

	This work				Düllmann and Türler (2008)		
	n	E_{α} [MeV]	$T_{1/2}$ [s]	b_{SF} [%]	n	E_{α} [MeV]	$T_{1/2}$ [s]
$^{265}Sg^{a}$	**18**	**8.84±0.05**	**$8.5^{+2.6}_{-1.6}$**	**< 50**	20	8.85	$8.9^{+2.7}_{-1.3}$
$^{265}Sg^{b}$	**24**	**8.69±0.05**	**$14.4^{+3.7}_{-2.5}$**	**< 51**	24	8.70	$16.2^{+4.7}_{-1.9}$

α spectrum of $^{265}Sg^{a,b}$



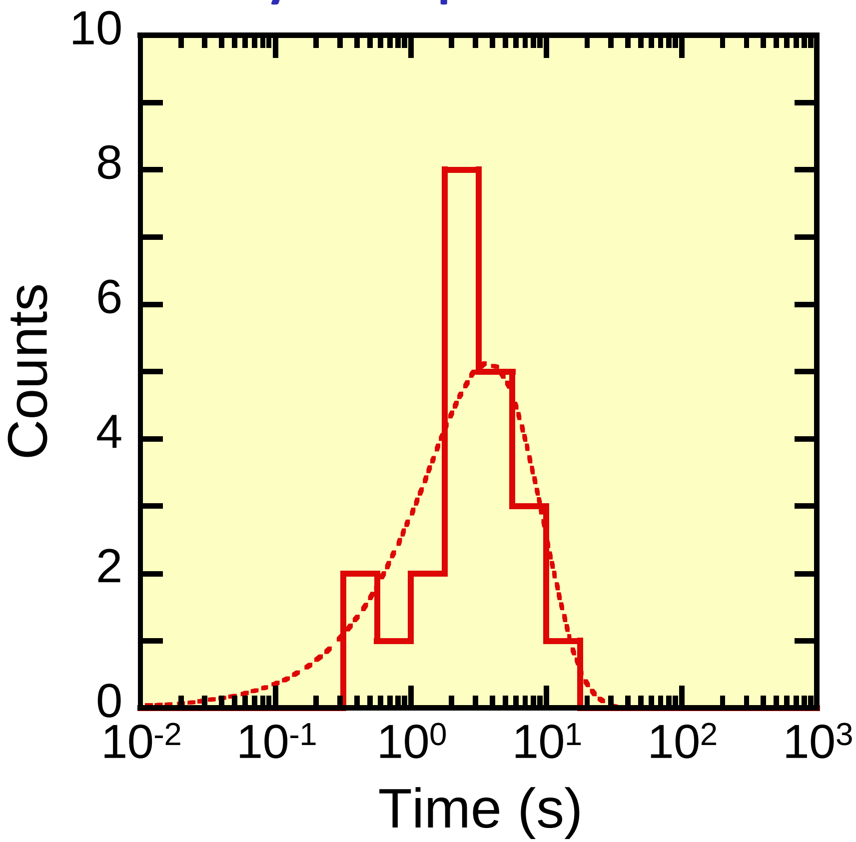
Decay time spectrum of $^{265}Sg^{a,b}$



α energy and half-life of $^{261}Rf^{a,b}$ and ^{257}No

	This work				References			
	n	E_α [MeV]	$T_{1/2}$ [s]	b_{SF} [%]	n	E_α [MeV]	$T_{1/2}$ [s]	b_{SF} [%]
$^{261}Rf^{a}$	**48**	**8.27±0.06**	**(33^{+12}_{-7})**		-	8.28±0.02[a]	68±3[b]	< 10[a]
$^{261}Rf^{b}$	**25**	**8.51±0.06**	**$2.6^{+0.7}_{-0.5}$**	**82±9**	88	8.52±0.05[d]	1.9±0.4[d]	73±6[d]
^{257}No	**54**	**8.07–8.38**	**23^{+4}_{-3}**		-	8.222, 8.323[c]	24.5±0.5[c]	

Decay time spectrum of $^{261}Rf^{b}$

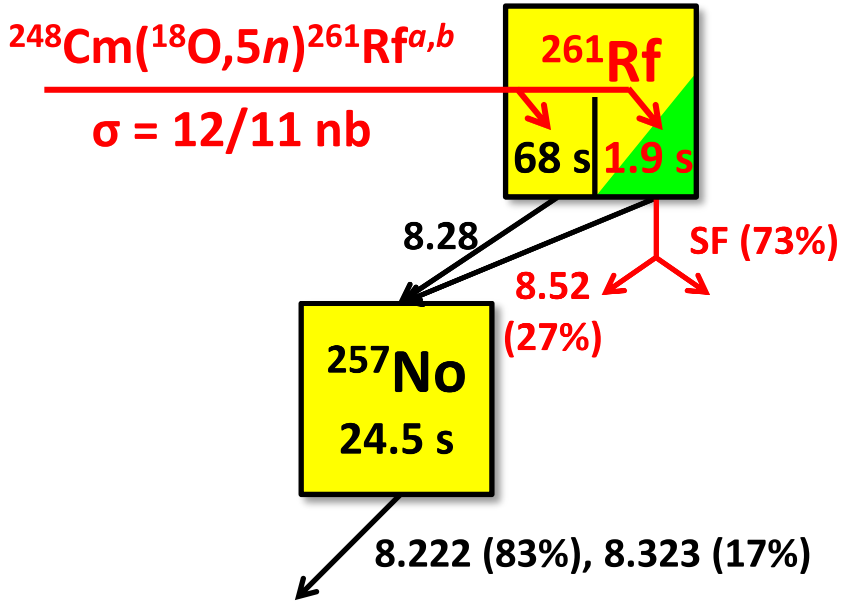


a) Table of Isotopes, 8th ed.

b) Asai, private communication.

c) Asai *et al.*, PRL **95**, 102502 (2005).

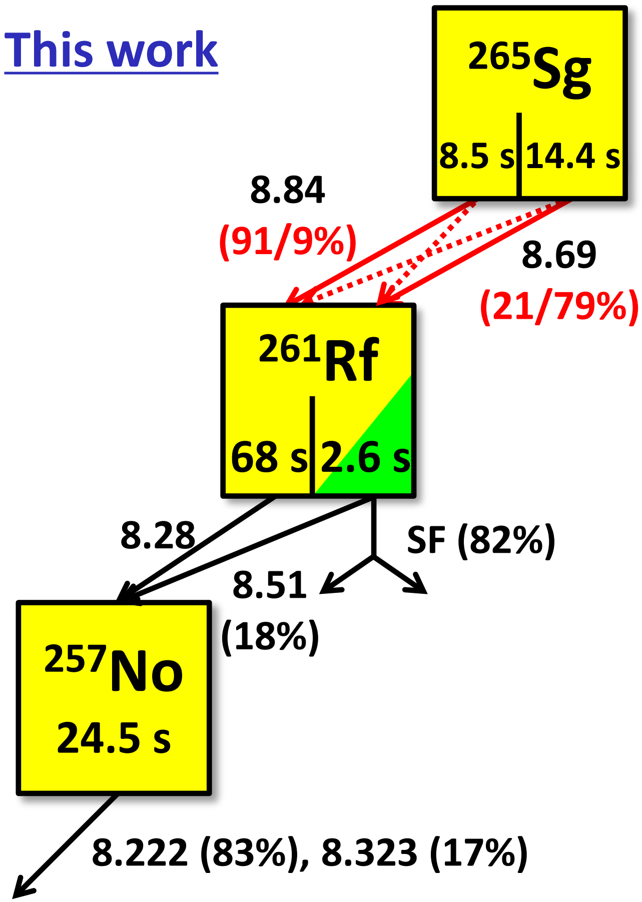
d) Haba *et al.*, PRC **83**, 034602 (2011).



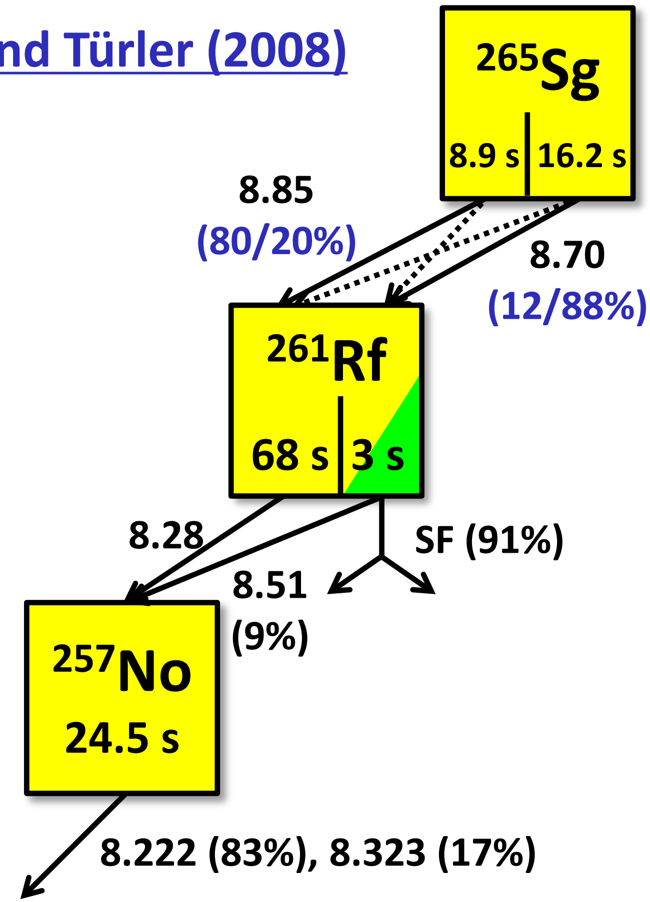
Decay patterns observed in the chain $^{265}Sg^{a,b}$ → $^{261}Rf^{a,b}$ → ^{257}No

^{265}Sg state	→	^{261}Rf state	No. of events (obs.)	No. of events (corr.)	Branching ratio [%] This work	Branching ratio [%] Düllmann and Türler (2008)
a	→	*a*	16	19.9	91	80
	→	*b*	2	2.0	9	20
b	→	*a*	4	5.1	21	12
	→	*b*	19	19.0	79	88

This work



Düllmann and Türler (2008)



Cross section

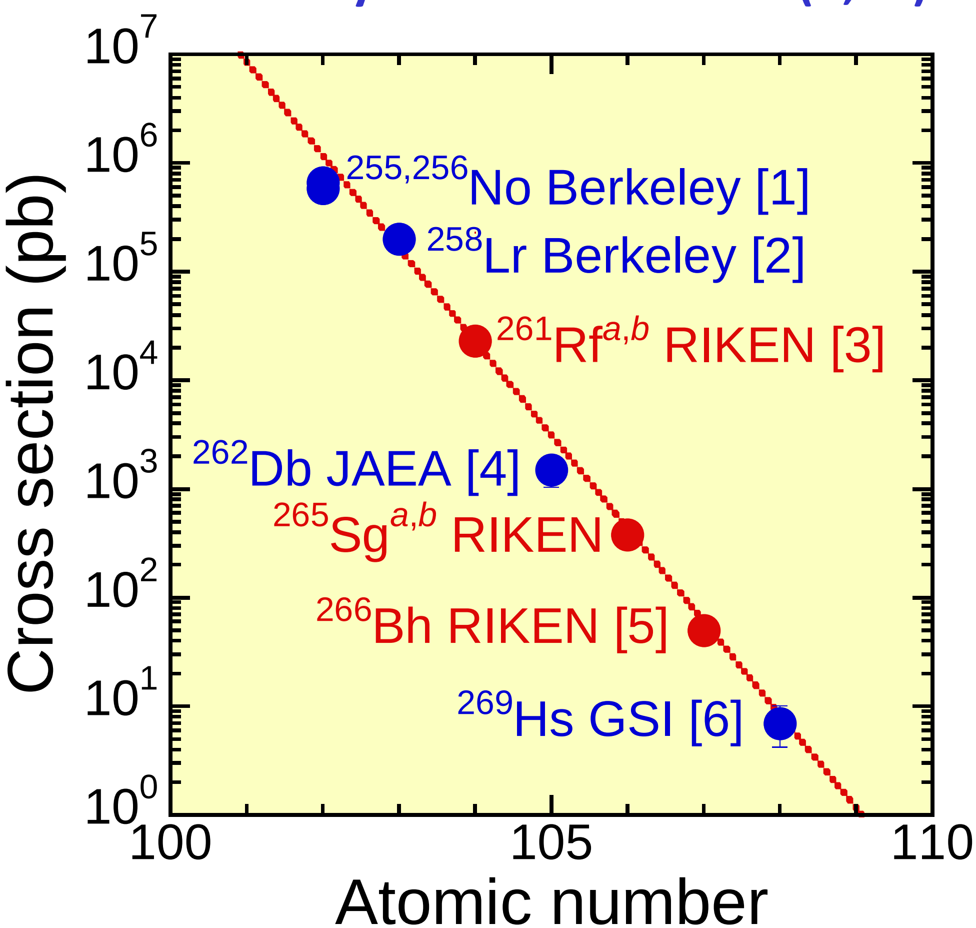
	Cross section at 118 MeV [pb]
$^{265}Sg^{a}$	180^{+80}_{-60}
$^{265}Sg^{b}$	200^{+60}_{-50}

$\sigma(^{265}Sg^{a+b}) = 380^{+90}_{-70}$ pb

$\sigma(^{265}Sg^{a})/\sigma(^{265}Sg^{b}) = 1.3 \pm 0.6$

Assumptions: GARIS eff. = 13%; gas-jet eff. = 50%; gas-jet transport time = 3 s

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



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).

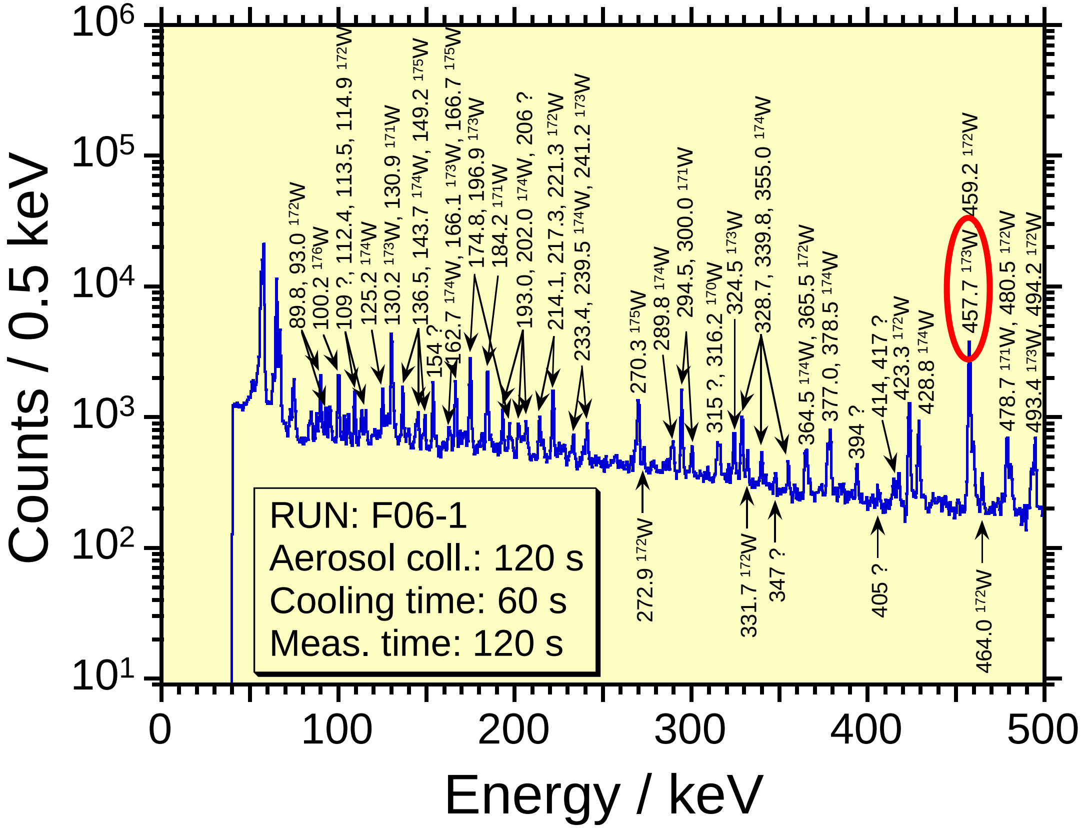
[4] Nagame *et al.*, JNRS **3**, 85 (2002).

[5] Morita *et al.*, JPSJ **78**, 064201 (2009).

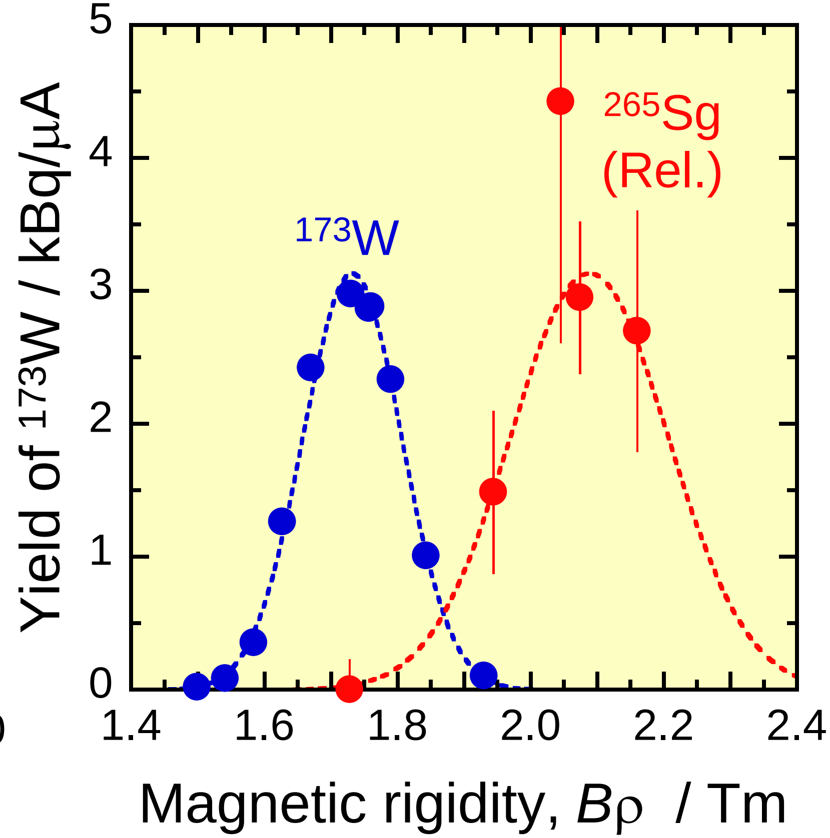
[6] Dvorak *et al.*, PRL **100**, 132503 (2008).

3.2. ^{nat}Gd(^{22}Ne,*xn*)^{173}W

γ-ray spectrum



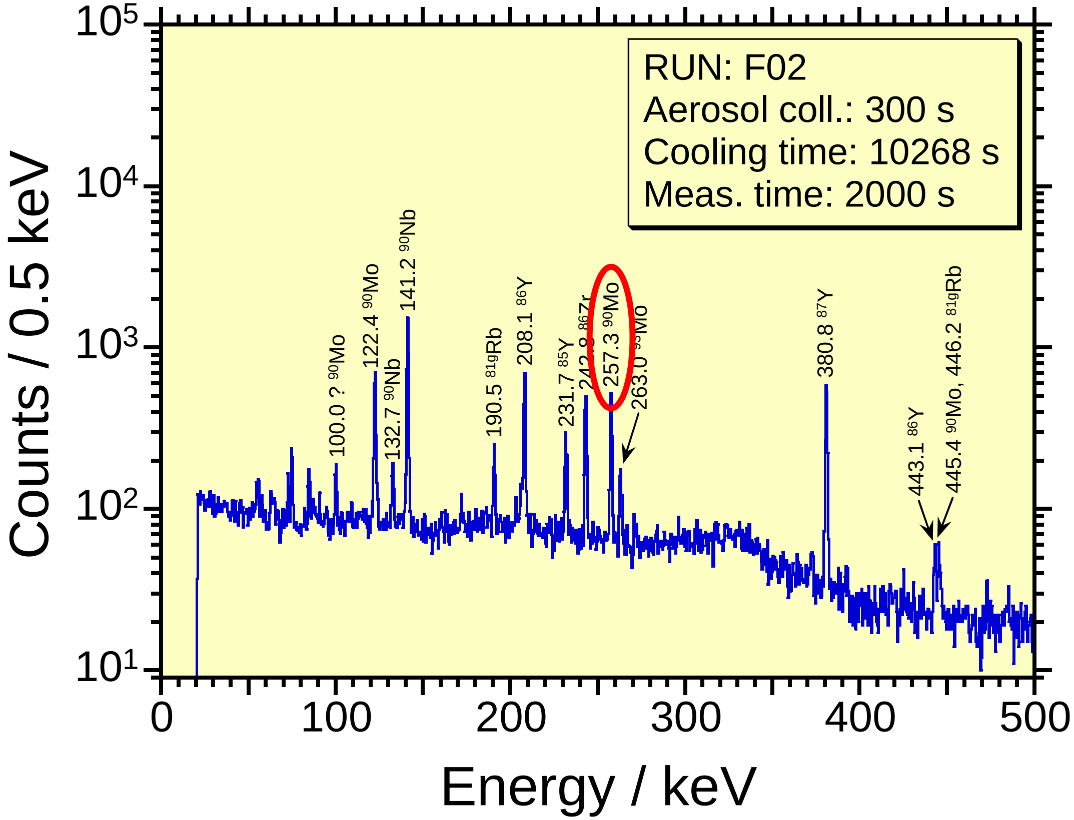
Yield of ^{173}W vs. *B*ρ



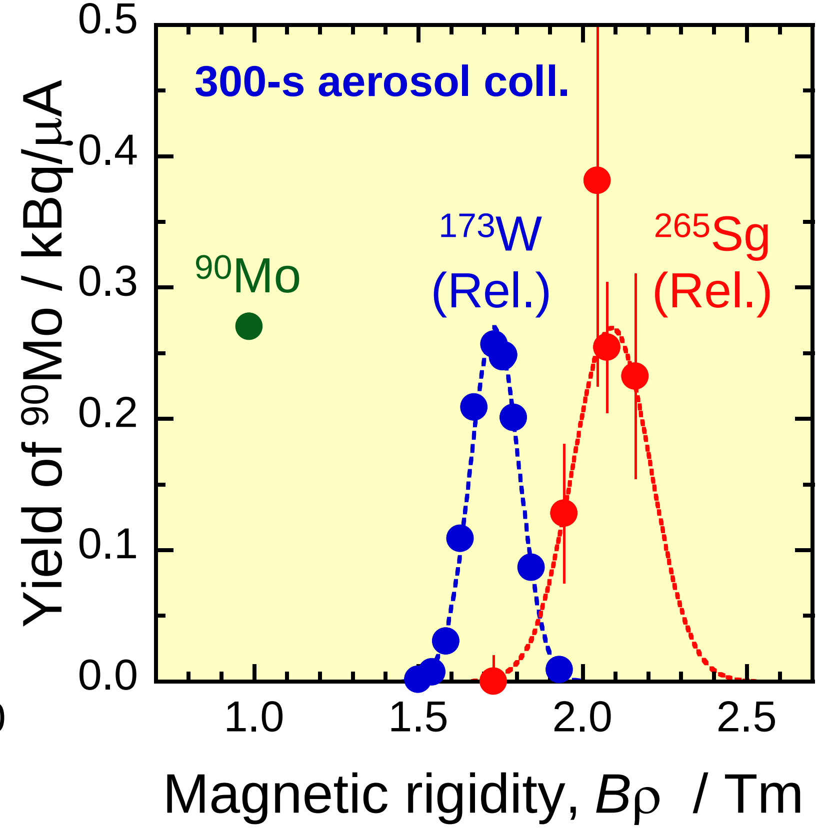
- ^{171}W ($T_{1/2}$ = 2.38 min), ^{172}W (6.6 min), **^{173}W (7.6 min)**, ^{174}W (31 min), ^{175}W (35.2 min), and ^{176}W (2.5 h)
- **B_ρ = 1.73 ± 0.01 Tm** and $\Delta B_\rho / B_\rho$ = 10.1 ± 0.3%
- Yield (Chem. Lab.): **3.1 kBq/μA** after 120-s aerosol collection
- Gas-jet eff.: **65 ± 1%**

3.3. $^{nat}Ge(^{22}Ne,xn)^{90}Mo$

γ-ray spectrum



Yield of ^{90}Mo vs. *B*ρ



- **^{90}Mo ($T_{1/2}$ = 5.67 h)**, ^{93}Mo, $^{90m,90g,89a,89b,88g,87m,87g,86g}Nb$, $^{89m,89g,87m,86,85g}Zr$, $^{89m,87m,86m,86g,85m,85g,84m}Y$, ^{83g}Sr, ^{81g}Rb, and ^{81m}Kr
- Yield (Chem. Lab.): **0.27 kBq/μA** after 300-s aerosol collection (0.985 Tm)
  (The optimum *B*ρ and the gas-jet efficiency will be measured in the future.)

4. Summary

- $^{265}Sg^{a,b}$ for chemical studies of Sg were produced in the $^{248}Cm(^{22}Ne,5n)$ reaction, and their decay properties were investigated using MANON under low background conditions attained by the GARIS gas-jet system.

- $^{265}Sg^{b}$ with $T_{1/2}$ = 14.4 s and σ = 200 pb is available for aqueous chemistry of Sg.

- The homologues of Sg, ^{173}W and ^{90}Mo, were produced in the $^{nat}Gd(^{22}Ne,xn)$ and $^{nat}Ge(^{22}Ne,xn)$ reactions, respectively.

→ ***We are ready for chemistry experiments of Sg together with its homologues!!***