

Decay properties of "chemistry isotopes" of light even- Z transactinides

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Why such a talk???

The chart of nuclides ~2001

		Hs	Hs 263 ?	Hs 264	Hs 265	Hs 266	Hs 267	Hs 269	Hs 270
		108	?	0.45 ms α 10.43; sf (50%)	870 μ s 1.6 ms α 10.51-10.57 α 10.37	2.3 ms α 10.18	19 ms α 9.88; 9.83; 9.75	11.3 s α 9.14-9.23	~4 s α 9.16; 8.97
Bh	Bh 260 ?	Bh 261	Bh 262		Bh 264		Bh 266	Bh 267	
107	?	11,8 ms α 10,40; 10,10...	5,1 ms 114 ms α 10,38 α 9,70		440 ms α 9,48; 8,62		~1 s α 9,20	15.2 s α 8,82	
Sg	Sg 259	Sg 260	Sg 261	Sg 262	Sg 263		Sg 265	Sg 266	
106	0.48 s α 9.62...; sf?	3.6 ms α 9.77; 9.72; sf	111 ms α 9.56; 9.52; 9.47	6.9 ms sf; α \leq 22%	0.3 s 0.9 s α 9.25 α 9.06; 9.25		7.4 s α 8.69-8.94; 35%	21 s α 8.72; 8.59; 32%	
Db	Db 258	Db 259	Db 260	Db 261	Db 262	Db 263			
105	4 s α 9.10; 8.48; ϵ	0,51 s α 9.47	1.5 s α 9.04; 9.12; 8.97	1.8 s α 8.93; sf	34 s α 8.45; 8.53; 8.28	27 s α 8.20; 8.14			
Rf	Rf 257	Rf 258	Rf 259	Rf 260	Rf 261	Rf 262			
104	2.7 s 4.3 s α 8.2-8.9; ϵ (11%); sf; α 1.4%; 7.87 7.117	13 ms sf, α ?	3 s α 8.77; 8.87; 7%	21 ms sf; α \leq 20%	78 s 8.28	ms? 2.1 s sf; α \leq 20%			

even Z
 $T_{1/2} > 0.5$ s
 new data since 2006

Rutherfordium (Rf, Z=104)

Rf 253 48 μ s sf; α ?	Rf 254 23 μ s sf; $\alpha \leq 1.5\%$	Rf 255 1.68 s sf (52%); α 8.72; 8.58-8.91; γ	Rf 256 6.2 ms sf; α (0.3%) 8.72	Rf 257 4.1 s 7.2 s α 8.2-8.9; ϵ (11%); sf $\leq 1.4\%$; γ 117...	Rf 258 14 ms sf; α 9.02; 8.97	Rf 259 2.5 s α 8.77; 8.87; ϵ (15 \pm 4%)	Rf 260 21 ms sf; $\alpha \leq 20\%$	Rf 261 68 s 3 s α 8.30; sf < 11% α 8.51; sf (91%)	Rf 262 47 ns? 2.1s? sf; $\alpha \leq 3\%$	Rf 263 ~8 s sf	Rf 267 1.3 h sf
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Rf 257	
4.1 s	7.2 s
α 9.02; 8.97	α 8.2-8.9; ϵ (11%); sf $\leq 1.4\%$; γ 117...

Mainly used in SISAK experiments

Rf 259 2.5 s α 8.77; 8.87; ϵ (15 \pm 4%)	Lr 259 6.14 s α 8.445... sf (25%)
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"SF branch in ^{259}Rf " used in old Dubna chemistry studies, b_{SF} never quantified.

Rf 261	
68 s	3 s
α 8.30; sf < 11%	α 8.51; sf (91%)

Classical Rf chemistry isotope. Long-lived isomer $^{261\text{a}}\text{Rf}$ discovered in 1970 (Ghiorso et al.)

Indication for short-lived isomer $^{261\text{b}}\text{Rf}$ in 1996 at SHIP (Hofmann et al.), in decay from $^{277}\text{112}$.

Corroborated thru Hs chemistry (Dvorak et al.)

Influence of projectile neutron number in the $^{208}\text{Pb}(^{48}\text{Ti}, n)^{255}\text{Rf}$ and $^{208}\text{Pb}(^{50}\text{Ti}, n)^{257}\text{Rf}$ reactions

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See also

Jeppesen et al., PRC 2009

Qian et al., PRC 2009

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^{257}Rf : the classical SISAK Rf isotope

Rf 257

160 μs	4.1 s	7.2 s
	α 9.02; 8.97	α 8.2-8.9 ϵ (11%) sf(2%) γ 117...
Iγ		

Experiment at the BGS measured $T_{1/2}$ of the two relevant states for chemistry experiments.

Isomeric production ratio and "apparent $T_{1/2}$ " not reported.

Synthesis of rutherfordium isotopes in the $^{238}\text{U}(^{26}\text{Mg}, xn)^{264-x}\text{Rf}$ reaction and study of their decay properties

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Rf 259

2.5 s

α 8.77; 8.87;
 \in (15 \pm 4%)

259

6.14 s

α 8.445...
sf (25%)

IUPAC/IUPAP TWG in 1993: some credit on discovery of Rf to Dubna based on "observation of SF from ^{259}Rf ".

$b_{\text{SF}}(^{259}\text{Rf})$ was never measured directly.

Status 2008 (BGS experiment):

$b_{\text{EC}}(^{259}\text{Rf})$ (15 \pm 4)% feeds ^{259}Lr with $b_{\text{SF}} \sim 25\%$. This is able to explain all SF ascribed to " ^{259}Rf " in that experiment.

Apparent b_{SF} in ^{259}Rf : $\sim 4\%$

^{261}Rf : Known for decades: $^{261}\text{Rf} \sim 1$ min, $E_\alpha \sim 8.3$ MeV, $b_{\text{SF}} < 11\%$

1996 / 2000 (SHIP): short SF / 8.5 MeV α terminate $^{277}\text{112}$ decay chains

2001- : chemistry experiments with $^{26}\text{Mg} + ^{248}\text{Cm} \rightarrow ^{274}\text{Hs}^*$ reveal existence of short-lived isomer which decays mostly by SF.

2008 spring: meta-analysis: exclusively following α -decay of ^{265}Sg

2008 summer: observation of $^{261\text{b}}\text{Rf}$ as EVR from $^{244}\text{Pu}(^{22}\text{Ne}, 5\text{n})$ at TASCA

Rf 261



68 s

3 s

α 8.30;
sf < 11%

α 8.51;
sf(91%)

In the Düllmann/Türler PRC (2008) on ^{265}Sg , the references are messed up.
Contact me if you are confused!

The puzzle seems solved.

Rf 262

47ms?

2.1s?

sf?

sf; $\alpha \leq 3\%$

Maybe ^{261b}Rf

Maybe superposition
of SF isomers and
190-ms ^{262}Rf

Rf 267

1.3 h

sf

Endpoint from chains
through ^{283}Cn

Tiny production rate

Long $T_{1/2}$

Not used for
chemistry so far

Seaborgium (Sg, Z=106)

Sg 258 2.6 ms sf; $\alpha \leq 20\%$	Sg 259 0.32 s α 9.59, 9.01-9.47; sf $\leq 12\%$	Sg 260 3.6 ms α 9.77; 9.72; sf (50%)	Sg 261 184 ms α 9.56; 9.52; 9.47...	Sg 262 15 ms sf; $\alpha \leq 16\%$	Sg 263 0.3 s 0.9 s α 9.25; sf $< 5\%$ α 9.06 (13 \pm 8%)	Sg 264 37 ms α $\leq 36\%$	Sg 265 8.9 s 16.2 s α 8.85 α 8.70	Sg 266 359 ms sf; α 8.20 (83%)	Sg 267 1.4 min α 8.20 (83%)	Sg 271 1.9 m α 8.54; sf (70%)
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Sg 263	
← 0.3 s	0.9 s →
α 9.25; sf $< 5\%$	α 9.06 sf (13 \pm 8%)

SF ^{263}Sg used in thermochromatography experiments in Dubna

Sg 265	
← 8.9 s	16.2 s →
α 8.85	α 8.70

Long (~10 yrs) believed to decay with $T_{1/2} \sim 7\text{s}$. Existence of two isomers recently inferred indirectly.

Sg 266
360 ms
sf

Long believed to be a ~20-s α -particle emitting isotope. No more...

New isotope ^{264}Sg and decay properties of $^{262-264}\text{Sg}$

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Sg 263



0.3 s

0.9 s

α 9.25;
sf < 5%

α 9.06

sf

(13 ± 8%)

Used in TC studies of Sg in Dubna
(Zvara *et al.*, RCA 81 (1998) 179)

^{263}Sg detection: count SF tracks in SiO_2

b_{SF} not available before this paper, now measured to 13% (sum of both isomers). Using this, known σ , and efficiencies as given by Zvara *et al.*, only about 50% of observed SF tracks can be explained

→ chemical result questionable

265,266Sg

Knowledge until ~2006 (thus used like that in ALL Sg chemistry studies so far!):

Sg 265	Sg 266
7.1 s	17.8 s
α 8.69-8.94; sf \leq 35%	α 8.77; 8.52; sf \leq 82%

α - α -chains were assigned to ^{265}Sg , α -SF-chains to ^{266}Sg .
The short-lived $^{261\text{b}}\text{Rf}$ with significant SF was still unknown!

S	Hs 263 ?	Hs 264	Hs 265	Hs 266	Hs 267	Hs 269	Hs 270
108	?	0.45 ms α 10.43; sf (50%)	870 μs α 10.51; 9.57	1.8 ms α 10.37	2.3 ms α 10.18	59 ms α 9.88; 9.83; 9.75	11.3 s α 9.14-9.23
261	Bh 262		Bh 264		Bh 266	Bh 267	
ms	4.7 ms 114 ms α 10.38 α 9.70		440 ms α 9.48; 9.62		~1 s	15.2 s	
260	Sg 261	Sg 262	Sg 263	Sg 265	Sg 266		
ms	111 ms α 9.56; 9.52; 9.47	6.9 ms sf	0.3 s 0.9 s α 9.25 α 9.06; 9.04	7.4 s α 8.94; 8.91; 8.87; 8.59; sf \leq 82%	17.8 s α 8.72; 8.59; sf \leq 82%		
259	Db 260	Db 261	Db 262	Db 263			
1 s	1.5 s α 9.04; 9.12; e/sf?	1.8 s α 8.93; sf	34 s α 8.45; 8.43; e/sf	27 s α 8.14; 8.13; e/sf			
258	Rf 259	Rf 260	Rf 261	Rf 262			
ms	3 s α 8.77; 8.87; sf \leq 7%	21 ms sf	78 s α 8.28	47 ms? 2.1 s sf \leq 3%			

2001

SF

2007

S	Hs	Hs 264	Hs 265	Hs 266	Hs 267	Hs 269	Hs 270	Hs 271
108		0.45 ms α 10.43; sf (50%)	750 μs α 10.57; 10.72	2 ms α 10.30...	2.3 ms α 10.18	49 ms α 9.88; 9.83; 9.75	10 s α 9.13; 8.95	~23 s α 8.88
261	Bh 262		Bh 264	Bh 265	Bh 266	Bh 267		Bh 271
ms	4.7 ms 102 ms α 10.38 α 9.70		0.97 s α 9.48; 9.62; sf (8%)	0.94 s α 9.24	1.1 s	17 s		61 s α 8.93
260	Sg 261	Sg 262	Sg 263	Sg 265	Sg 266	Sg 267		
ms	184 ms α 9.56; 9.52; 9.47...	15 ms sf; α 9.16%	0.3 s 0.9 s α 9.25; sf (5%); α 9.06; sf (33%)	37 ms α 8.93; sf (33%)	8.9 s 16 s α 8.85; α 8.70	59 ms sf	4 min sf	
259	Db 260	Db 261	Db 262	Db 263	Db 266	Db 267	Db 268	
s	1.5 s α 9.04; 9.12; e/sf?	1.8 s α 8.93; sf (??)	34 s α 8.45; 8.43; e/sf	27 s α 8.14; 8.13; e/sf	22 min sf (e?)	1.2 h sf	29 h sf (e?)	
258	Rf 259	Rf 260	Rf 261	Rf 262	Rf 263		Rf 268	
ms	2.5 s α 8.77; 8.87; e (15 \pm 4%)	21 ms sf; α 8.20	68 ms 3 s α 8.30; α 8.51; sf (12%); α 8.30; α 8.51; sf (12%); α 8.30; α 8.51; sf (12%)	47 ms? 2.1 s sf \leq 3%	~8 s SF-359 ms!		1.3 h sf	
257	Lr 258	Lr 259	Lr 260	Lr 261	Lr 262			
s	3.9 s α 8.595; 8.621; 8.565; 8.654	6.14 s α 8.445...	3 m	39 m	3.6 h e			
256	No 257	No 258	No 259	No 260 ?	No 262			

SF

$^{248}\text{Cm}(^{22}\text{Ne}, xn)^{270-x}\text{Sg}$ reaction and the decay properties of ^{265}Sg reexamined

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Apparent $T_{1/2}$ from
 $^{248}\text{Cm}(^{22}\text{Ne}, 5n)$: **~10 s**

Sg 265



8.9 s

16.2 s

α 8.85

α 8.70

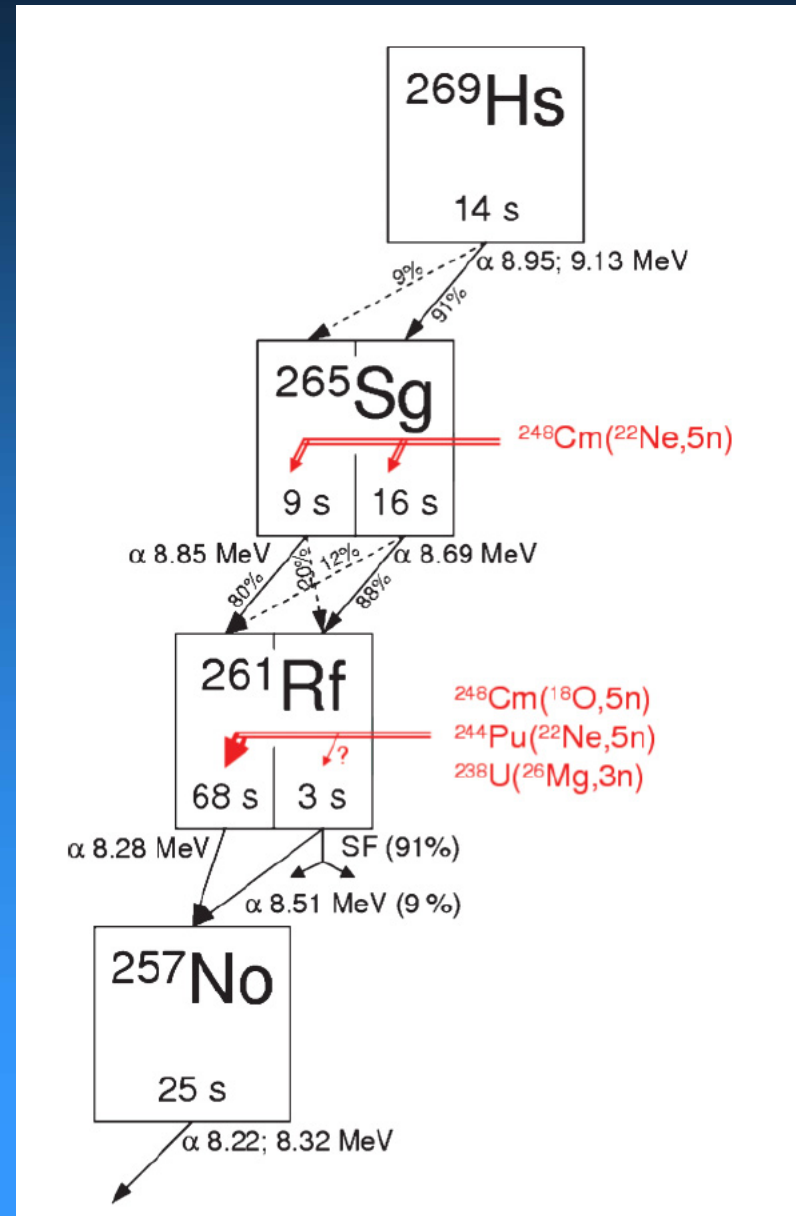
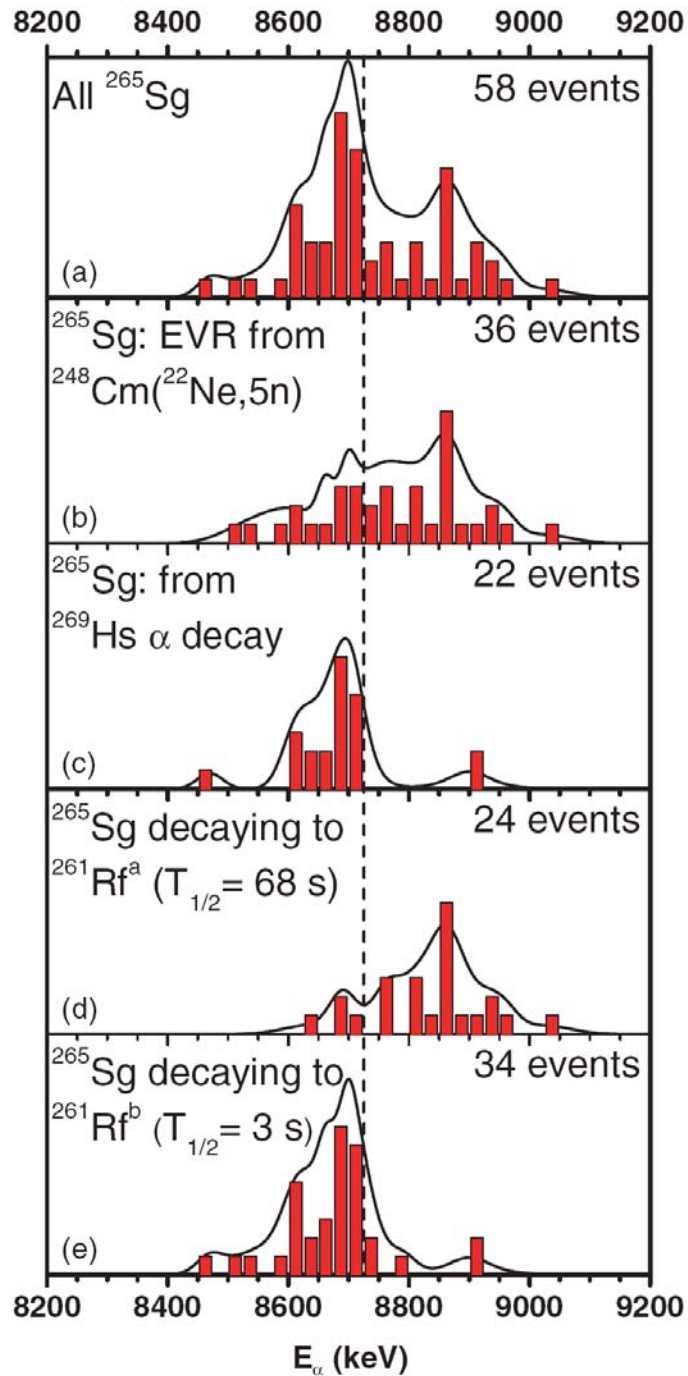
Sg chemistry studies using "old" $^{265,266}\text{Sg}$ data

of decay chains assigned to

	^{265}Sg	^{266}Sg
OLGA IC	17	2
HITGAS IC	0	2
ARCA 1	(3)	0
ARCA 2	0	0

Reexamination of ϵ_{det} for chains and of chemical conclusions may be warranted

Two states in ^{265}Sg



Long-lived ^{266}Sg ? No more...

Sg 266

360 ms

sf

Precipitates from studies of
 $^{248}\text{Cm}(^{26}\text{Mg},3-5\text{n})^{269-271}\text{Hs}$

Ch.E. Düllmann et al., Nature 2002

J. Dvorak et al., PRL 2006

J. Dvorak et al., PRL 2008

Hassium (Hs, Z=108)

Hs 263 0.65 ms α 10.5-10.9	Hs 264 0.45 ms α 10.43; sf (50%)	Hs 265 0.3 ms α 10.54	Hs 266 2.3 ms α 10.18	Hs 267 49 ms α 9.88; 9.83; 9.75	Hs 269 10 s α 9.13; 8.95	Hs 270 ~23 s α 8.88	Hs 271 ~4 s α 9.13; 9.30	Hs 275 0.19 s α 9.30
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Hs 269 10 s α 9.13; 8.95	Hs 270 ~23 s α 8.88	Hs 271 ~4 s α 9.13; 9.30
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$^{270,271}\text{Hs}$ discovered in chemistry experiments
on the reaction: $^{248}\text{Cm}(^{26}\text{Mg},3-5n)^{269-271}\text{Hs}$

Alternative reactions that are under investigation:



The classic Hs chemistry isotope (?)

Discovered n decay chains of $^{277}112$ at GSI (2x), later seen at RIKEN (2x)

Hs 269

10 s

α 9.13; 8.95

Current best values:

$$T_{1/2}: 9.7^{+9.7}_{-3.2} \text{ s}$$

K. Morita *et al.*, J. Phys. Soc. Jpn. 76 (2007) 043201

Decay in adsorbed state:

$$E_{\alpha}=9.13; 8.95 \text{ MeV}$$

J. Dvorak *et al.*, PRL 100 (2008) 132503

Decay in implanted state:

$$E_{\alpha}=9.24; 9.18 \text{ MeV}$$

K. Morita *et al.*, J. Phys. Soc. Jpn. 76 (2007) 043201

→Influence of conversion e^{-} ?

Doubly Magic Nucleus $^{270}_{108}\text{Hs}_{162}$

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*Manuscript received 9 August 2006; published 14 December 2006)

Hs 270

~23 s

α 8.88

Current $T_{1/2}$ estimated from
 Q_{α} according to
Parkhomenko et al. 2005

New half-life value should
precipitate from FLNR-TUM
experiment at DGFRS on
 $^{226}\text{Ra}(^{48}\text{Ca},4n)$

Observation of the $3n$ Evaporation Channel in the Complete Hot-Fusion Reaction $^{26}\text{Mg} + ^{248}\text{Cm}$ Leading to the New Superheavy Nuclide ^{271}Hs

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Hs 271

~4 s

α 9.13; 9.30

Current $T_{1/2}$ estimated from
 Q_α according to
Parkhomenko et al. 2005

Conclusion

Improved decay data is available for almost all isotopes with $T_{1/2} > 0.5$ s of Rf, Sg, and Hs

Implications for past experiments

Endpoints of "Dubna"-chains are very long-lived
(e.g., ^{267}Rf : $T_{1/2} \sim 1.3$ h)

Understanding of nuclear properties crucial for correct interpretation of chemistry experiments