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

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Seventh Workshop on the Chemistry of the Heaviest Elements
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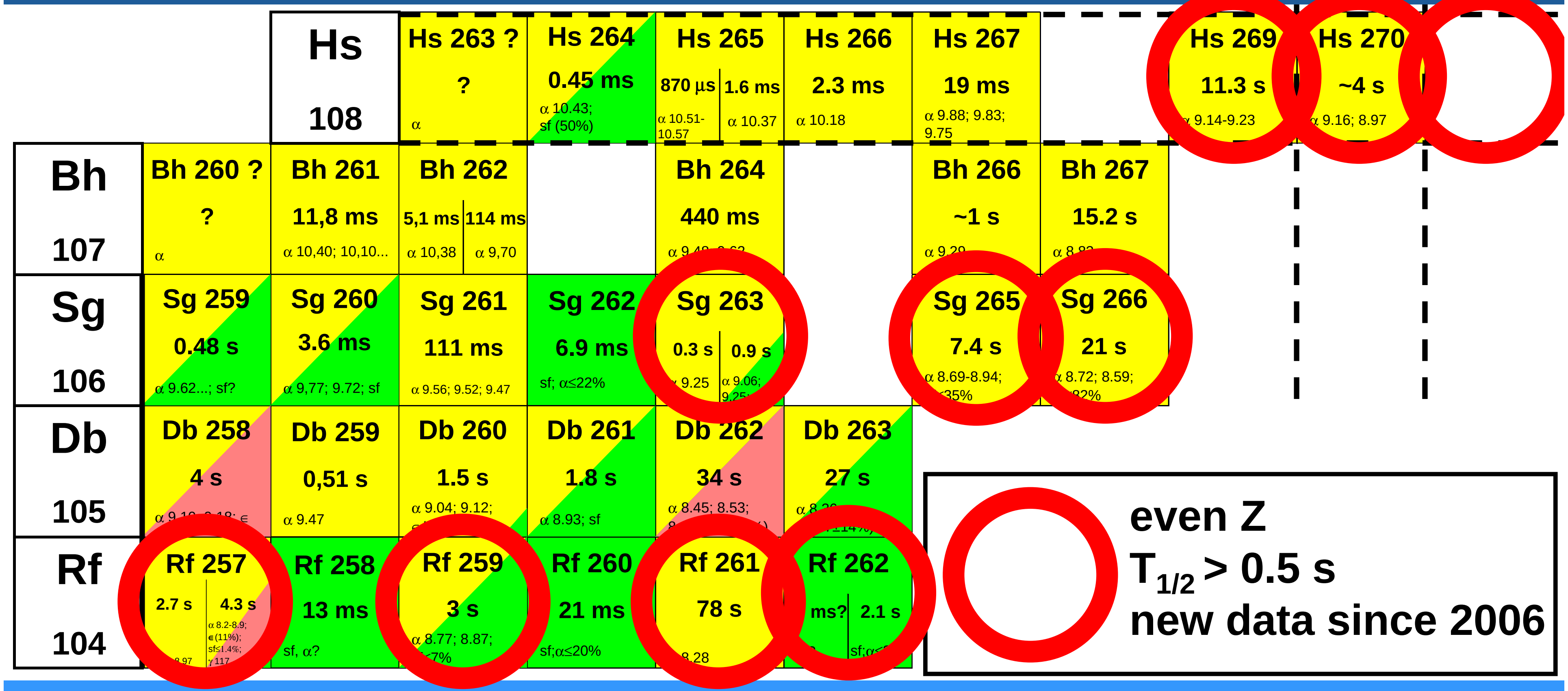
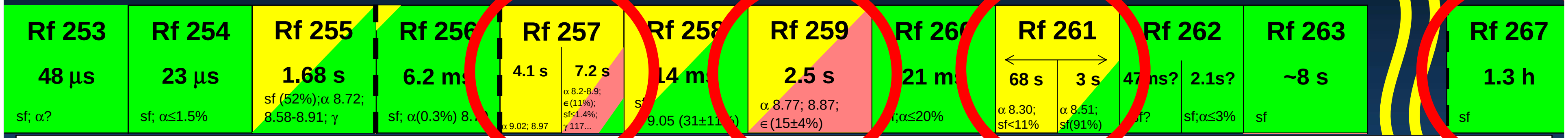
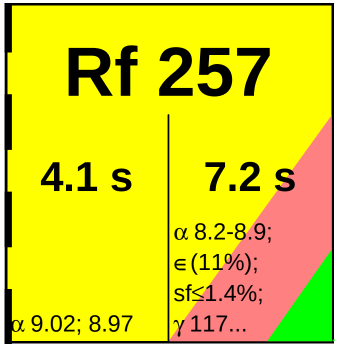
# Why such a talk???

## The chart of nuclides ~2001

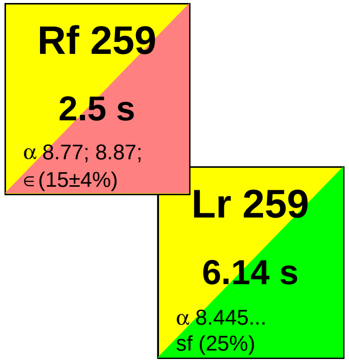


# Rutherfordium (Rf, Z=104)

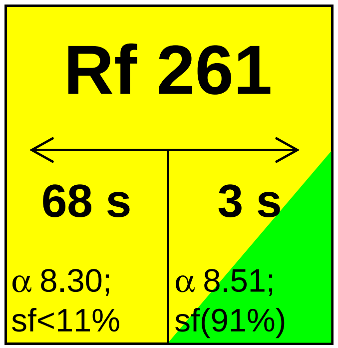



Mainly used in SISAK experiments




"SF branch in $^{259}$Rf" used in old Dubna chemistry studies, $b_{SF}$ never quantified.




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

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

Corroborated thru Hs chemistry (Dvorak et al.)

PHYSICAL REVIEW C **78**, 024605 (2008)

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

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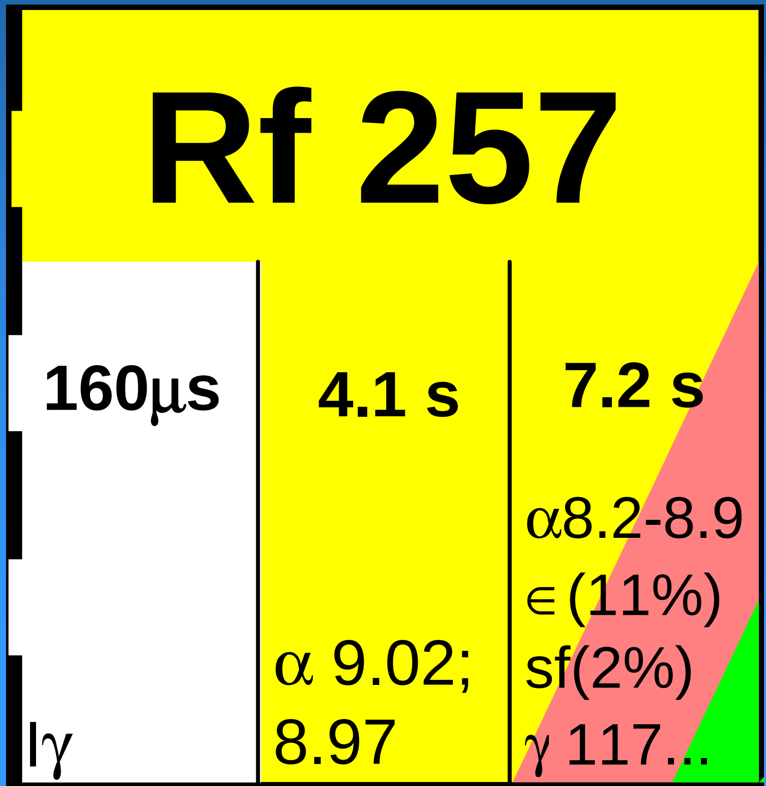
hed 25 August 2008)

**See also**
**Jeppesen et al., PRC 2009**
**Qian et al., PRC 2009**

# $^{257}$Rf: the classical SISAK Rf isotope




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.

PHYSICAL REVIEW C **77**, 034603 (2008)

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

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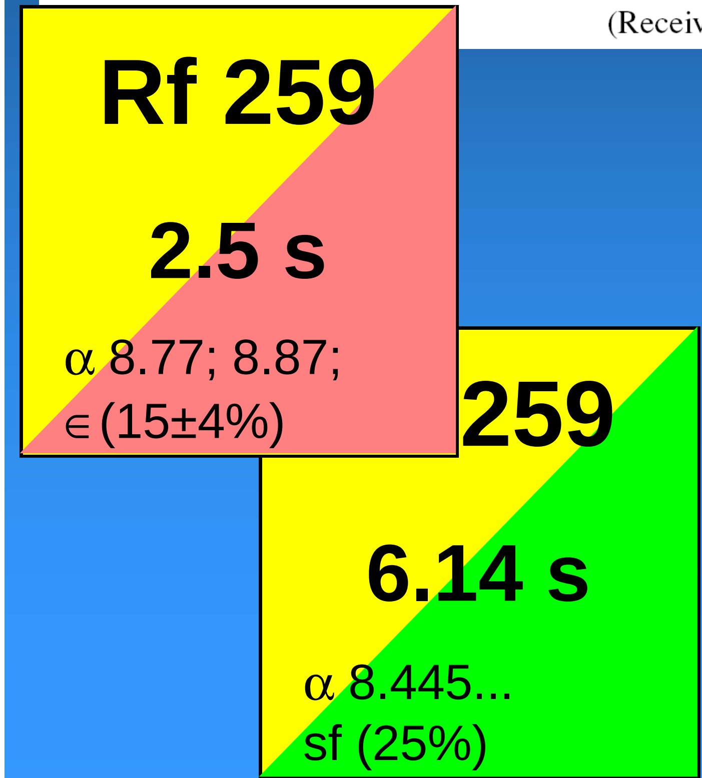
(Received 10 December 2007; published 7 March 2008)




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

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

**Status 2008 (BGS experiment):**
$b_{EC}$ ($^{259}$Rf) (15±4)% feeds $^{259}$Lr with $b_{SF}$ ~25%. This is able to explain all SF ascribed to "$^{259}$Rf" in that experiment.

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

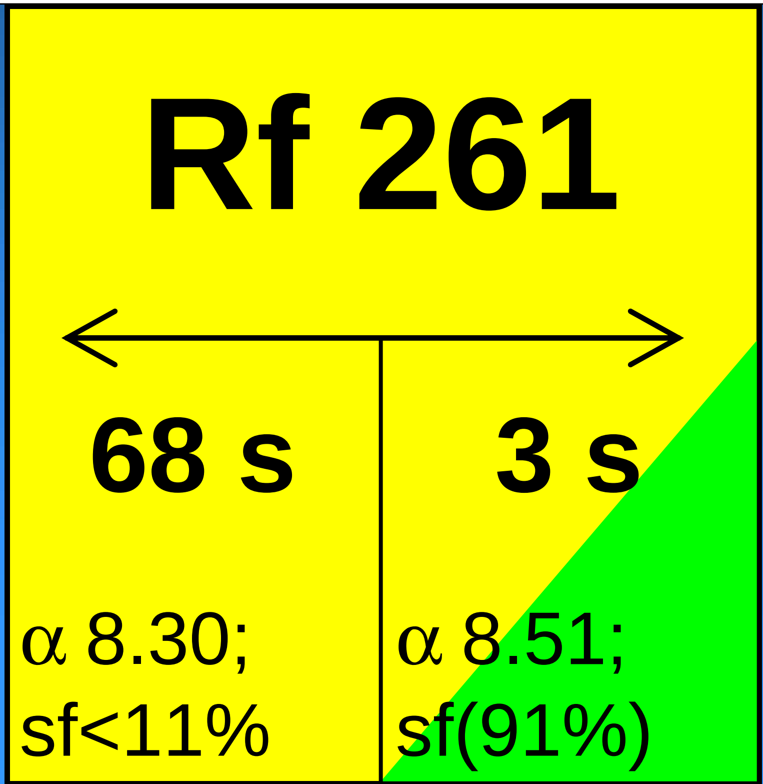
**$^{261}$Rf**: Known for decades: $^{261}$Rf ~1 min, $E_\alpha$ ~8.3 MeV, $b_{SF}$ < 11%

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

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

2008 spring: meta-analysis: exclusively following $\alpha$-decay of $^{265}$Sg

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




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;α≤3% |

Maybe $^{261b}$Rf

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

**Rf 267**

**1.3 h**

sf

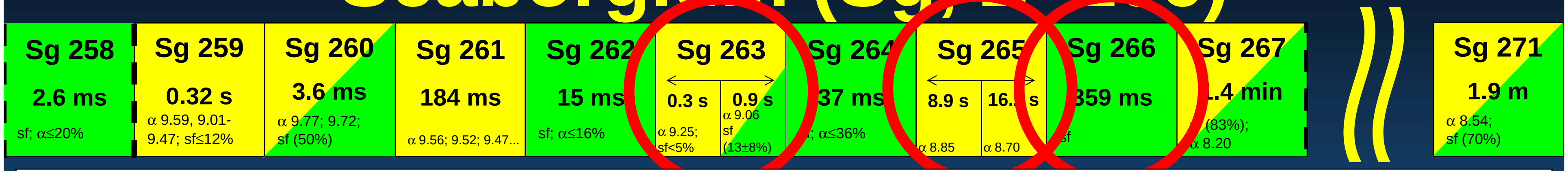
Endpoint from chains through $^{283}Cn$

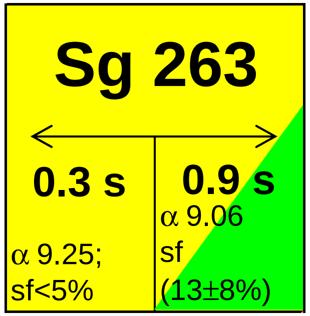
Tiny production rate

Long $T_{1/2}$

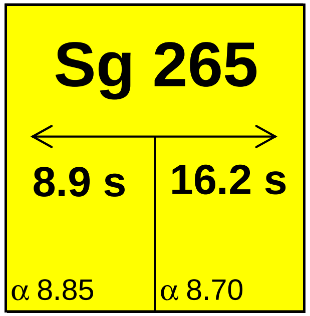
Not used for chemistry so far

# Seaborgium (Sg, Z=106)




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




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


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

PHYSICAL REVIEW C **74**, 044611 (2006)

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

K. E. Gregorich,[1] J. M. Gates,[1,2] Ch. E. Düllmann,[3] R. Sudowe,[1] S. L. Nelson,[1,2] M. A. Garcia,[1,2] I. Dragojević,[1,2] C. M. Folden III,[4] S. H. Neumann,[5] D. C. Hoffman,[1,2] and H. Nitsche[1,2]
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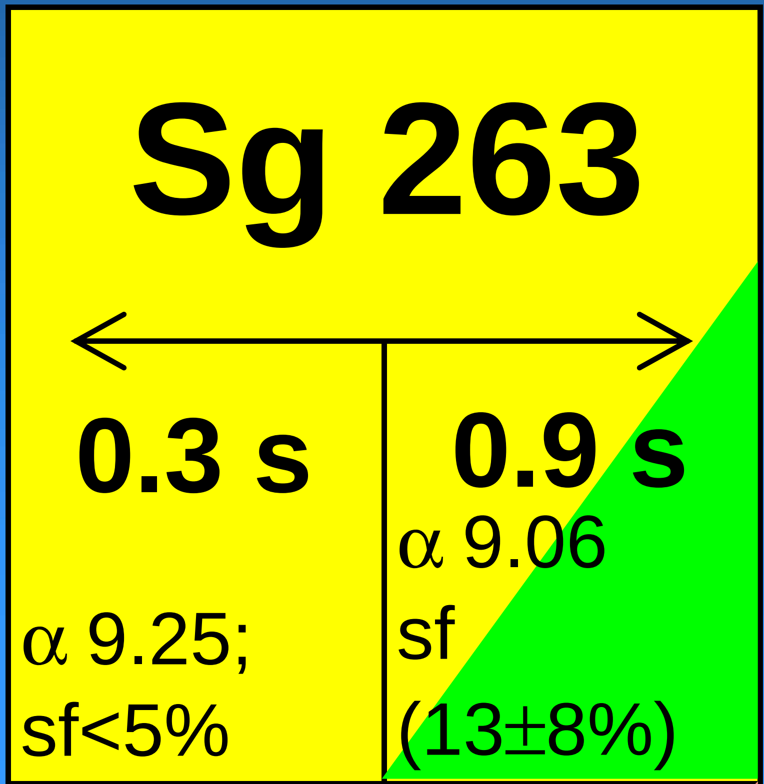
(Received 20 June 2006; published 23 October 2006)




**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

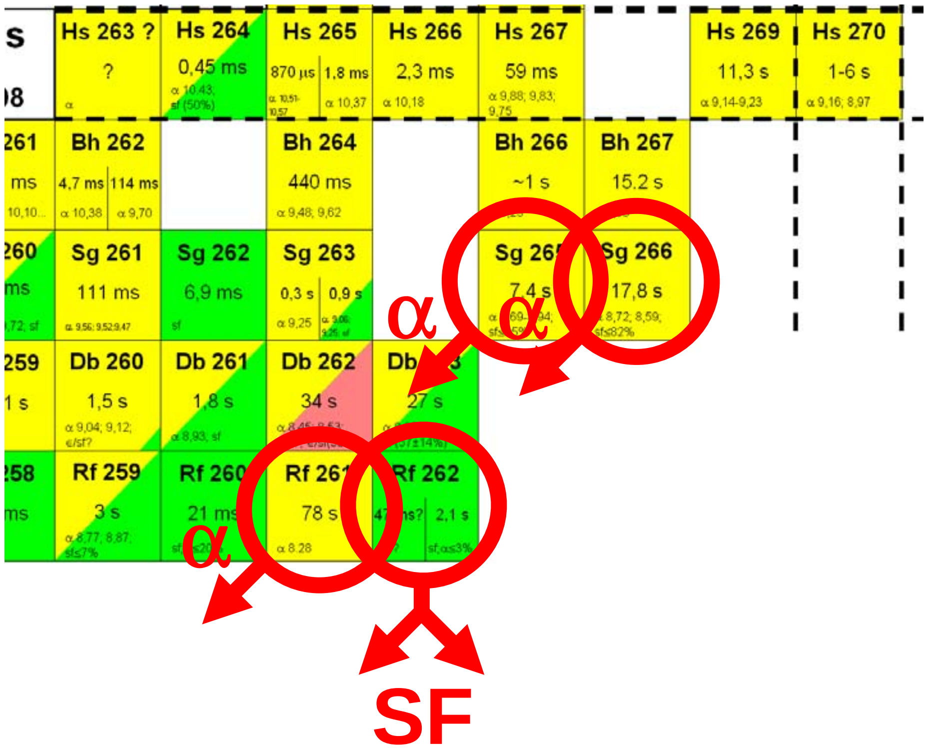
**→ chemical result questionable**

# $^{265,266}Sg$

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

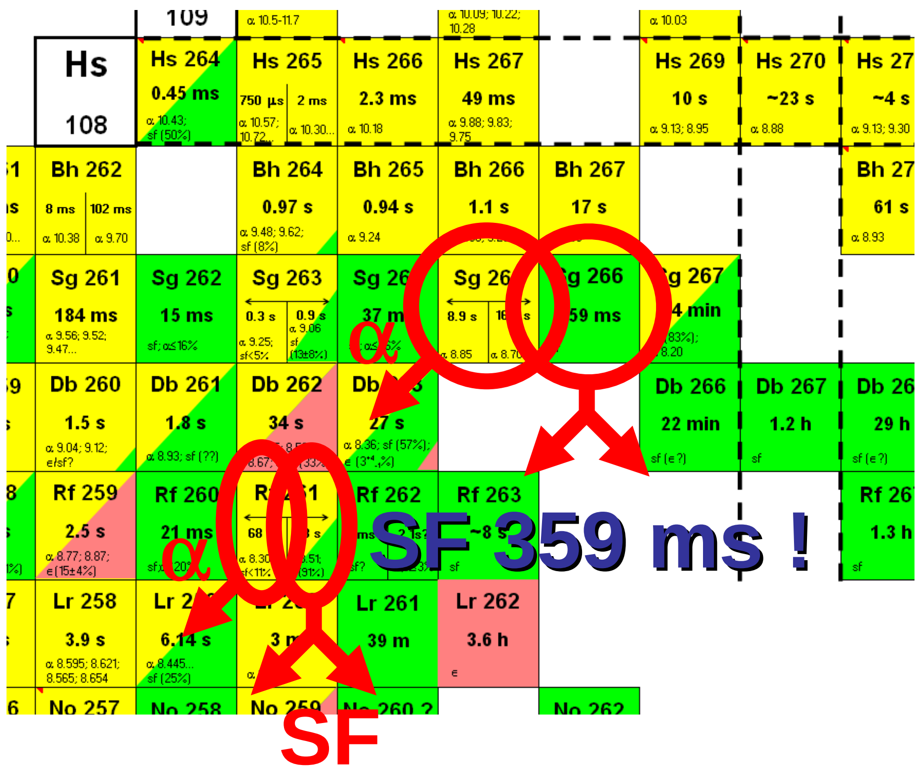
| Sg 265 | Sg 266 |
|---|---|
| 7.1 s | 17.8 s |
| α 8.69-8.94; sf≤35% | α 8.77; 8.52; sf≤82% |

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




2001

2007



PHYSICAL REVIEW C **77**, 064320 (2008)

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

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(Received 20 March 2008; published 26 June 2008)

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

**Sg 265**

**8.9 s** | **16.2 s**

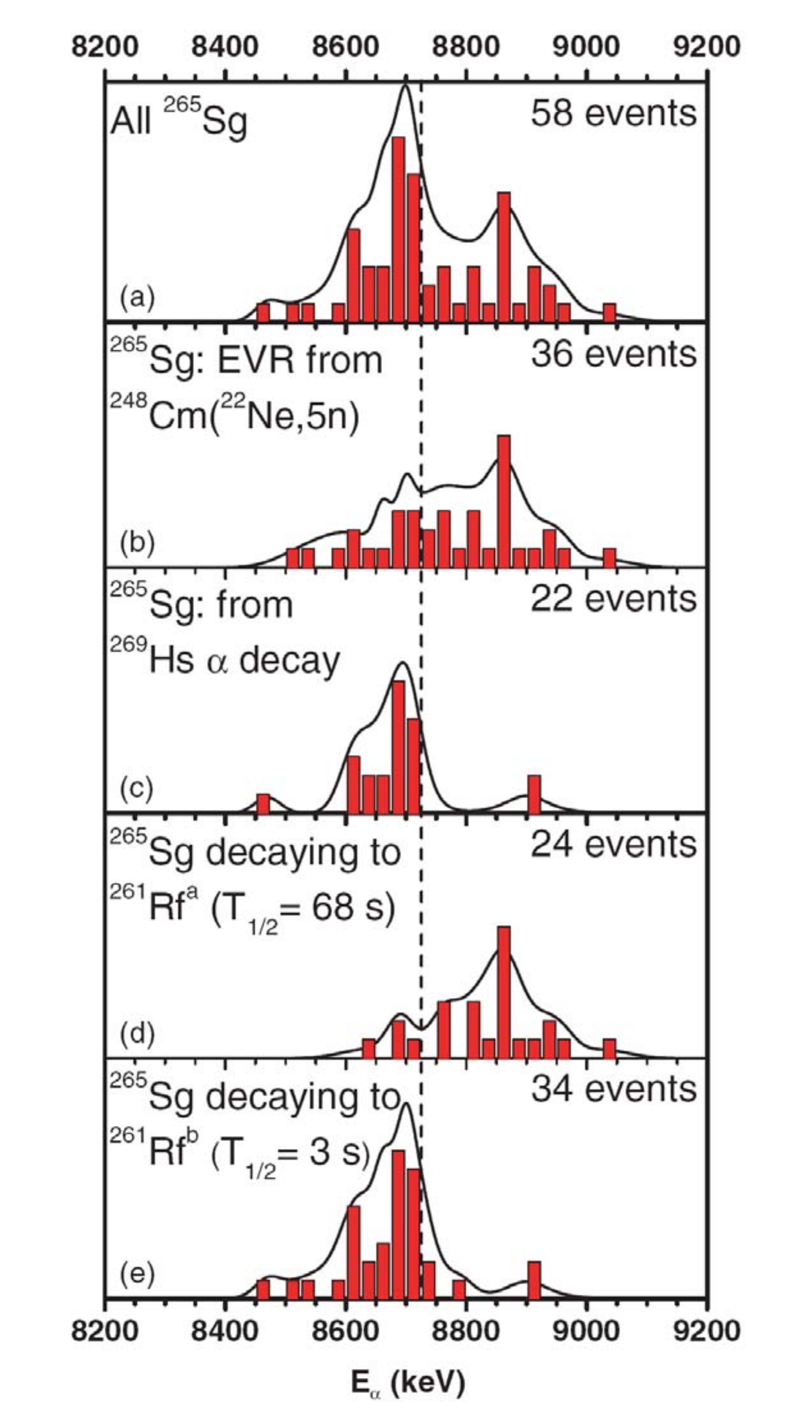
α 8.85 | α 8.70

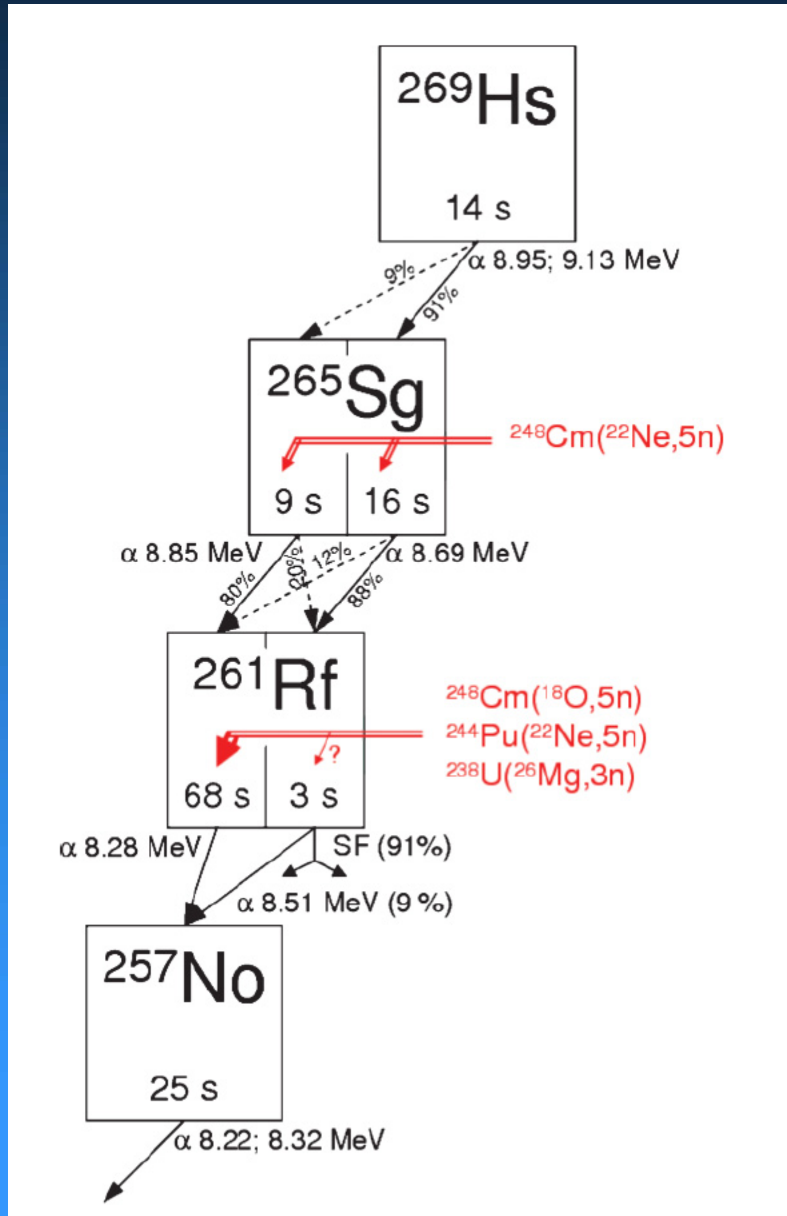
**Sg chemistry studies using "old" $^{265,266}Sg$ data**

| | # 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 $\varepsilon_{det}$ 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 $^{248}Cm(^{26}Mg,3\text{-}5n)^{269\text{-}271}Hs$


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 | Hs 264 | Hs 265 | | Hs 266 | Hs 267 | Hs 269 | Hs 270 | Hs 271 | Hs 275 |
|---|---|---|---|---|---|---|---|---|---|
| 0.65 ms | 0.45 ms | 0.3 ms | 1.9 ms | 2.3 ms | 49 ms | 10 s | ~23 s | ~4 s | 0.19 s |
| α 10.5-10.9 | α 10.43; sf (50%) | α 10.54 | α 10.31; 10.28... | α 10.18 | α 9.88; 9.83; 9.75 | α 9.13; 8.95 | α 8.88 | α 9.13; 9.30 | α 9.30 |

| Hs 269 | Hs 270 | Hs 271 |
|---|---|---|
| 10 s | ~23 s | ~4 s |
| α 9.13; 8.95 | α 8.88 | α 9.13; 9.30 |

**$^{270,271}$Hs discovered in chemistry experiments on the reaction: $^{248}$Cm($^{26}$Mg,3-5n)$^{269-271}$Hs**

**Alternative reactions that are under investigation:**

**$^{238}$U($^{36}$S,3-5n) and $^{226}$Ra($^{48}$Ca,3-5n)**

# 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:

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

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

Decay in adsorbed state:

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

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

Decay in implanted state:

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

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

→Influence of conversion $e^-$?

PRL **97,** 242501 (2006) PHYSICAL REVIEW LETTERS week ending 15 DECEMBER 2006

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

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uscript received 9 August 2006; published 14 December 2006)

**Hs 270**

**~23 s**

α 8.88

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

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

PRL **100,** 132503 (2008) PHYSICAL REVIEW LETTERS week ending 4 APRIL 2008

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

J. Dvorak,[1,*] W. Brüchle,[2] M. Chelnokov,[3] Ch. E. Düllmann,[2,4,5] Z. Dvorakova,[1,†] K. Eberhardt,[6] E. Jäger,[2] R. Krücken,[1] A. Kuznetsov,[3] Y. Nagame,[7] F. Nebel,[1] K. Nishio,[7] R. Perego,[1] Z. Qin,[2,8] M. Schädel,[2] B. Schausten,[2] E. Schimpf,[2] R. Schuber,[1] A. Semchenkov,[1,2] P. Thörle,[9] A. Türler,[1] M. Wegrzecki,[10] B. Wierczinski,[1] A. Yakushev,[1] and A. Yeremin[3]

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…October 2007; published 3 April 2008)

# Hs 271

# ~4 s

$\alpha$ 9.13; 9.30

Current $T_{1/2}$ estimated from $Q_\alpha$ 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: $T_{1/2}$~1.3 h)

Understanding of nuclear properties crucial for correct interpretation of chemistry experiments