^{105}Ru data evaluation and experimentation

S. Lalkovski

22 April 2015

Agenda

ENSDF Activities

Evaluated

- **200:** F.Kondev and S.Lalkovski, NDS108 (2007) 1471
- **207:** F.Kondev and S.Lalkovski, NDS112 (2011) 707
- **112:** S.Lalkovski and F.Kondev, NDS124 (2015) 157

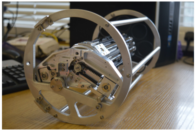
XUNDL

- **Cd:** 103-105
- **Ag:** 122-126
- **Pd:** 121
- **Rh:** 117

... being evaluated

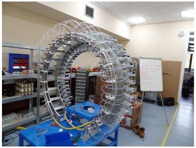
- **A=105:** In collaboration with J.Timar & F.Kondev
  evaluated: Sr, Y, Zr, Nb, Mo, Tc, Ru, Rh, Ag, In, Sn, Sb, Tl
  in process: Pd
  to be evaluated: Cd

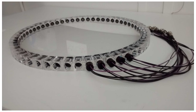
UKNUSTAR

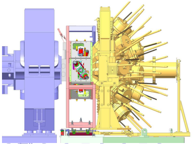


Work Packages

- R^3B
- HISPEC
- DESPEC







Historical overview

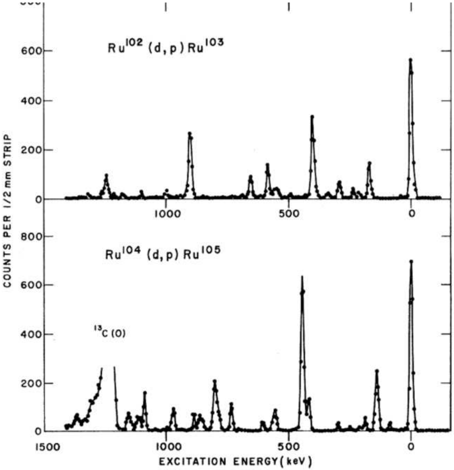
Z \ N	57	58	59	60	61	62	63	64	N
Z	103Pd 16.991 D ε: 100.00%	104Pd STABLE 11.14%	105Pd STABLE 22.33%	106Pd STABLE 27.33%	107Pd 6.5E+6 Y β-: 100.00%	108Pd STABLE 26.46%	109Pd 13.7012 H β-: 100.00%	110Pd STABLE 11.72%	111Pd 23.4 M β-: 100.00%
45	102Rh 207.3 D ε: 78.00% β-: 22.00%	103Rh STABLE 100%	104Rh 42.3 S β-: 99.55% ε: 0.45%	105Rh 35.36 H β-: 100.00%	106Rh 30.07 S β-: 100.00%	107Rh 21.7 M β-: 100.00%	108Rh 16.8 S β-: 100.00%	109Rh 80 S β-: 100.00%	110Rh 28.5 S β-: 100.00%
44	101Ru STABLE 17.06%	102Ru STABLE 31.55%	103Ru 39.247 D β-: 100.00%	104Ru STABLE 18.62%	105Ru 4.44 H β-: 100.00%	106Ru 371.8 D β-: 100.00%	107Ru 3.75 M β-: 100.00%	108Ru 4.55 M β-: 100.00%	109Ru 34.5 S β-: 100.00%
43	100Tc 15.46 S β-: 100.00% ε: 2.6E-3%	101Tc 14.02 M β-: 100.00%	102Tc 5.28 S β-: 100.00%	103Tc 54.2 S β-: 100.00%	104Tc 18.3 M β-: 100.00%	105Tc 7.6 M β-: 100.00%	106Tc 35.6 S β-: 100.00%	107Tc 21.2 S β-: 100.00%	108Tc 5.17 S β-: 100.00%
42	99Mo 65.976 H β-: 100.00%	100Mo 7.3E+18 Y 9.82% 2β-: 100.00%	101Mo 14.61 M β-: 100.00%	102Mo 11.3 M β-: 100.00%	103Mo 67.5 S β-: 100.00%	104Mo 60 S β-: 100.00%	105Mo 35.6 S β-: 100.00%	106Mo 8.73 S β-: 100.00%	107Mo 3.5 S β-: 100.00%

ENSDF

- $T_{1/2}$: 4.44(2) h
- **GS** J^{π}: $3/2^{+}$
- **Decay modes:** 100% β^{-}
- ^{105}Tc β^{-}–decay
- ^{104}Ru(n,γ) E=th
- ^{104}Ru(d,p)
- ^{173}Yb(^{24}Mg,Xγ)

- **First mentioned** in literature in **1953Hu86**:
  Fast neutron cross sections and Nuclear Level density,
  D.J.Hughes, R.C.Grath, J.S.Levin
  Phys.Rev.**91** (1953) 142
  Note: Detectors: anticoinc. counter; Deduced: σ, $T_{1/2} = 4$ h;
- **First decay information:**
  Decay of the Ru-105
  B.Saraf, P.Harihar,, R.Jambunatan
  Phys.Rev.**118** (1960) 1289
  Note: Detectors: two NaI(Tl) scintillators in coinc.; Measured: E_{γ}, I_{γ}, $\gamma-\gamma$ coinc.; Deduced: 6 levels in ^{105}Rh
- **First** (d,p) **measurement**
  Energy Levels of ^{103}*Ru and* ^{105}*Ru from the (d,p) Reaction*
  J.A.Nolen, Jr., H.T.Fortune, P. Kienle, G.C.Morrison
  Bull.Am.Phys.Soc.**13** (1968) 584
- **First Fission fragment studies:**
  Nuclear spectroscopy of short-lived fission products Nb, Mo, Tc
  EANDC(E)-115U (1969) 42
  Note: ^{105}Tc: $\beta-$ to ^{105}Ru
- **First high-sin study:**
  High-spin excitations in Ru nuclei near N=60
  Fotiades *et al.*
  Phys.Rev.**C58** (1998) 1997

(d, p) data sets

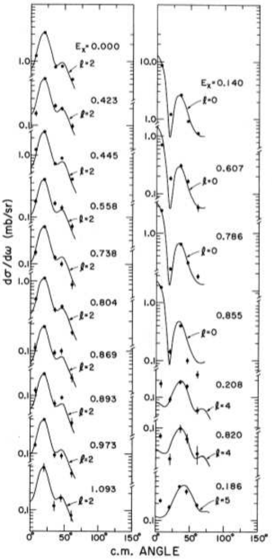


H.T.Fortune, G.C.Morrison, J.A.Nolen, Jr., P.Kienle, *Ru*^{103,105} *states observed in the reactions Ru*$^{102,104}(d, p)$ Phys.Rev.**C3** (1971) 337

1971Fo01

- **Facility:** Argonne FN tandem;
- **Beam:** E(D)=14 MeV;
- Target: 25-50 —mg/cm+2 enriched in ^{104}Ru and thin carbon backing ($\leq$ 20 mg/cm^2);
- **Detectors:** magnetic spectrograph (FWHM≈12 keV), photo emulsions, Faraday cup;
- **Measured:** $d\sigma/d\Omega(\theta)$;
- **Deduced:** ^{105}Ru level scheme, J^π from DWBA analysis with JULIE code;
- **Also** 1968No02 from the same collaboration

(d, p) data sets



H.T.Fortune, G.C.Morrison, J.A.Nolen, Jr., P.Kienle, $Ru^{103,105}$ *states observed in the reactions* $Ru^{102,104}(d,p)$ Phys.Rev.**C3** (1971) 337

1971Fo01

- **Facility:** Argonne FN tandem;
- **Beam:** E(D)=14 MeV;
- Target: 25-50 —mg/cm+2 enriched in 104RU and thin carbon backing ($\lesssim$ 20 mg/cm^2);
- **Detectors:** magnetic spectrograph (FWHM≈12 keV), photo emulsions, Faraday cup;
- **Measured:** $d\sigma/d\Omega(\theta)$;
- **Deduced:** ^{105}Ru level scheme, J^π from DWBA analysis with JULIE code;
- **Also** 1968No02 from the same collaboration

Spectroscopic factor S

$$\sigma_{exp}(\theta) = 1.65(2J_f + 1)S_{lj}\sigma_{lj}(\theta) \quad (1)$$

Noteworthy publications: (d, p) data sets

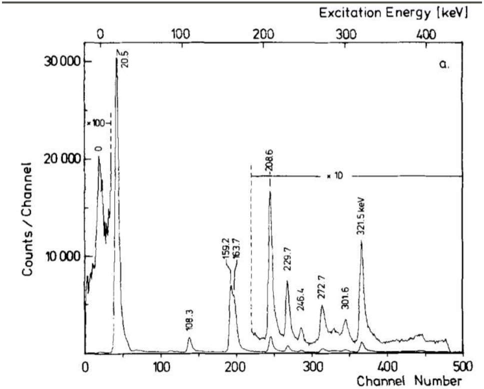
E_x [a] (MeV)	l	$(2J_f+1)S$	E_x [a] (MeV)	l	$(2J_f+1)S$
0.0	2	1.34	0.804	2	0.46
0.09	(2)	(0.05)	0.820	4	0.61
0.140	0	0.79	0.855	0	0.14
0.186	5	3.36	0.869	2	0.11
0.208	4	1.25	0.893	2	0.11
0.302	(1) (3)	(0.07)(0.37)	0.973	2	0.15
0.423	2	0.28	1.093	2	0.24
0.445	2	1.09	1.113	(1)(3)	(0.08)(0.37)
0.558	2	0.19	1.124	2	0.10
0.607	0	0.09	1.164 [b]	2	0.15
0.738	2	0.19	1.56	(2)	(0.15)
0.786	0	0.20	1.91	(2)	(0.20)

H.T.Fortune, G.C.Morrison, J.A.Nolen, Jr., P.Kienle, *$Ru^{103,105}$ states observed in the reactions $Ru^{102,104}(d,p)$*
Phys.Rev.**C3** (1971) 337

1971Fo01

- **Facility:** Argonne FN tandem;
- **Beam:** E(D)=14 MeV;
- Target: 25-50 —mg/cm+2 enriched in 104RU and thin carbon backing ($\leq$ 20 mg/cm^2);
- **Detectors:** magnetic spectrograph (FWHM≈12 keV), photo emulsions, Faraday cup;
- **Measured:** $d\sigma/d\Omega(\theta)$;
- **Deduced:** ^{105}Ru level scheme, J^π from DWBA analysis with JULIE code;
- **Also** 1968No02 from the same collaboration

(d, p) data sets

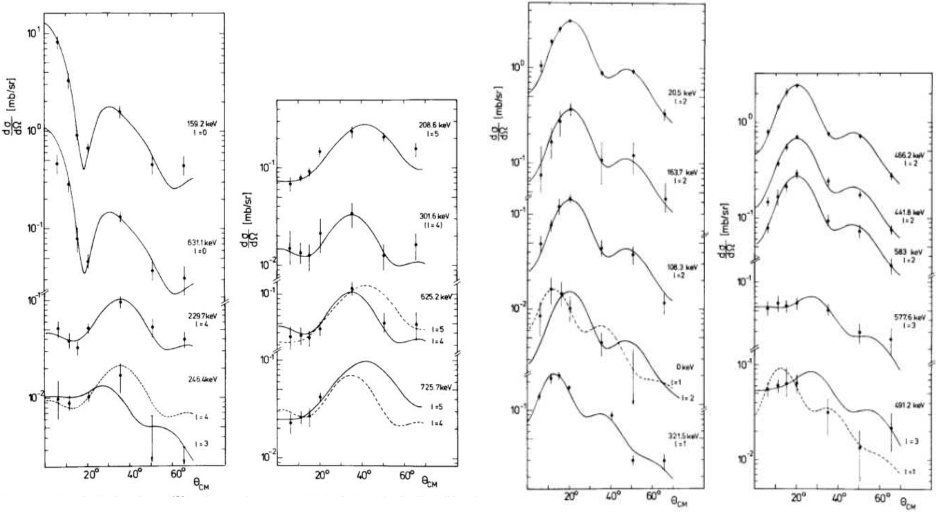


P.Maier-Komor, P.Glässel,E.Huenges, H.Rösler, H.J.Scheerer, H.K.Vonach, H.Baier,
Study of the $^{104}Ru(d, p)$-reaction at 14 MeV
Z.Phys.**A278** (1976) 327

1976Ma49

- **Facility:** MP Tandem at Munich;
- **Beam:** E(D)=14 MeV;
- **Target:** 50 mg/cm^2 enriched to 99.6% in ^{104}Ru, 10 mg/cm^2 carbon backing;
- **Detectors:** Q3D spectrograph (FWHM=5 keV), multi whire chamber ($\delta E/E \approx$2.4%), time-of-flight system, one CsI, Faraday cup, paraffin and aluminum shields;
- **Measured:** E(P), $d\sigma d\Omega(\theta)$;
- **Deduced:** ^{105}Ru level scheme, L from DWBA with DWUCK2 code, J^π

(d, p) data sets: 1976Ma49



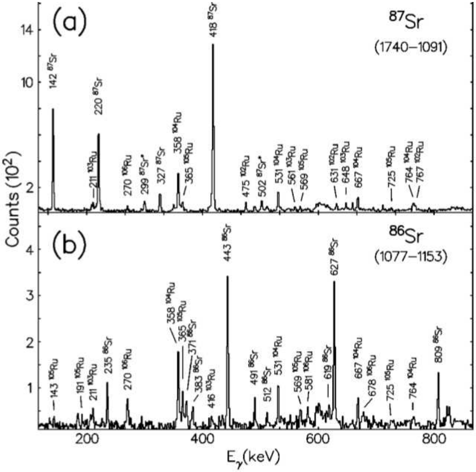
(d, p) data sets: 1976Ma49

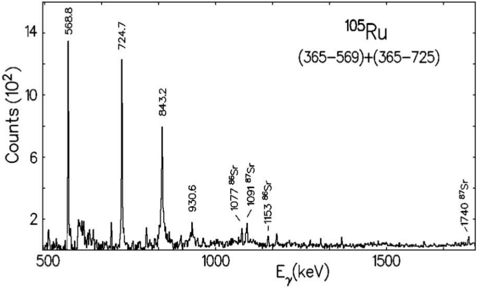
E_x (keV)	l	Single particle configuration	G_{lj}
0 ±0.2	2	$2d_{3/2}$	0.009 ±0.004
20.5±0.1	2	$2d_{5/2}$	1.54 ±0.06
108.3±0.2	2	$2d_{5/2}$	0.07 ±0.01
159.2±0.3	0	$3s_{1/2}$	0.74 ±0.06
163.7±0.3	2	$2d_{5/2}$	0.18 ±0.04
208.6±0.7	5	$1h_{11/2}$	2.7 ±0.40
229.7±0.4	4	$1g_{7/2}$	0.75 ±0.08
246.4±0.3	4	$1g_{7/2}$	0.15 ±0.03
	3	$1f_{5/2}$	0.04 ±0.01
	3	$1f_{7/2}$	0.03 ±0.01
301.6±0.9	4	$1g_{7/2}$	0.24 ±0.08
321.5±0.2	1	$2p_{3/2}$	0.08 ±0.008
441.8±0.2	2	$2d_{3/2}$	0.36 ±0.03
	2	$2d_{5/2}$	0.31 ±0.02
466.2±0.3	2	$2d_{3/2}$	1.32 ±0.07
491.2±1.5	3	$1f_{5/2}$	0.25 ±0.07
	3	$1f_{7/2}$	0.18 ±0.05
	1	$2p_{1/2}$	0.03 ±0.015
	1	$2p_{3/2}$	0.03 ±0.015
577.6±0.7	3	$1f_{5/2}$	0.21 ±0.04
	3	$1f_{7/2}$	0.15 ±0.03
583.0±0.8	2	$2d_{3/2}$	0.14 ±0.03
	2	$2d_{5/2}$	0.12 ±0.03
625.2±0.4	4	$1g_{7/2}$	0.70 ±0.2
	5	$1h_{11/2}$	1.1 ±0.4
631.1±0.2	0	$3s_{1/2}$	0.06 ±0.01
725.7±2	4	$1g_{7/2}$	0.46 ±0.23
	5	$1h_{11/2}$	0.86 ±0.43

P.Maier-Komor, P.Glässel, E.Huenges, H.Rösler, H.J.Scheerer, H.K.Vonach, H.Baier,
Study of the ^{104}*Ru*(d, p)*-reaction at 14 MeV*
Z.Phys.**A278** (1976) 327

163.7 keV ($l=2$): Angular correlation coefficients [10] agree with a spin of 5/2. Thus it has to be $5/2^+$.
208.6 keV ($l=5$): Due to its high spin value this level is not observed in the (n,γ) work. According to the observed systematics of high spin states it has most probably spin and parity $11/2^-$.

Reaction data: ^{173}Yb(^{24}Mg,Xγ)

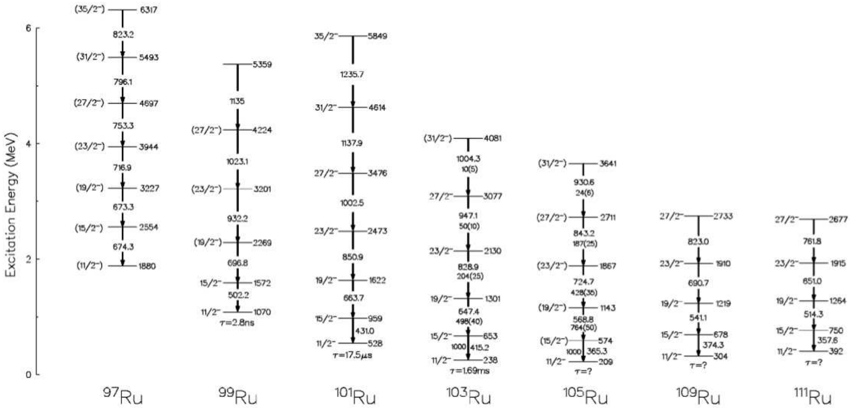




1998Fo08

- **Facility:** 88-inch Cyclotron at the LBNL;
- **Beam:** ^{24}Mg accelerated to 134.5 MeV;
- **Target:** 1 mg/cm^2 enriched in 173YB on a 7 mg/cm^2 Au backing;
- **Detectors:** GAMMASPHERE array, comprising 92 HPGe detectors;
- **Measured:** $\gamma - \gamma - \gamma$ coinc., E_γ, I_γ

Reaction data: $^{173}Yb(^{24}Mg,X\gamma)$

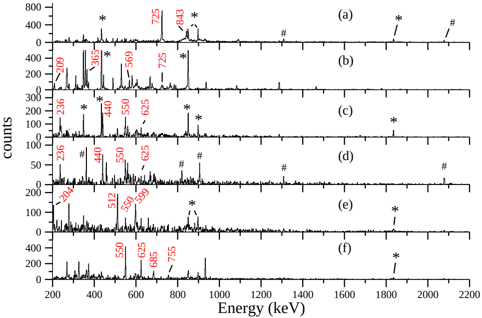


ENSDF

A ^{105}Tc β^{-} Decay C ^{104}Ru(d,p)
B ^{104}Ru(n,γ) E=Thermal D ^{173}Yb(^{24}Mg,Xγ)

E_{level}[#]	Jπ	$T_{1/2}$	XREF	Comments
0.0	3/2+	4.44 h *2*	ABCD	%β^{-}=100 **$T_{1/2}$:** weighted average of: 4.45 h 2 (1955Wi59), 4.44 h 2 (1960Ri03), 4.43 h 2 (1962Br15), 4.39 h 10 (1965Pi01); others: 1946Bo28, 1974Ca26, 1950Sl06, 1950Su07. **Jπ:** fed by (n,γ) primary γ from 1/2+; L(d,p)=1,2 possible but M1+E2 gamma of 20.6 kev level excludes pi=- and Jπ=1/2+. μ=(-)0.32 *+8-20* (1989Ra17) **μ:** From oriented ^{105}Ru decay.
20.610 *13*	(5/2)+	340 ns *15*	ABC	**Jπ:** π=+ from L(d,p)=2; J=5/2 favored by spectroscopic strength and no primary feeding in (n,γ). **$T_{1/2}$:** by γγ(t) in ^{105}Tc β^{-} decay.
107.937 *8*	5/2+		ABC	**Jπ:** L(d,p)=2; (463γ)(214γ)(θ) not consistent with 3/2.
159.518 *6*	1/2+	0.055 μs *7*	ABC	**$T_{1/2}$:** by (pulsed d, α, ^{3}He beam, 143.2γ)(t) (1978Ho06). **Jπ:** L(d,p)=0.
163.815 *15*	3/2+,5/2+	55 ns *7*	ABC	**$T_{1/2}$:** by pulsed beam, 143.2γ(t) (1978Ho06). **Jπ:** L(d,p)=2.
208.6[&] *7*	11/2-[a]		CD	**E_{level}:** from (d,p). **Jπ:** L(d,p)=5; level systematics in neighboring Ru isotopes favor 11/2-.
229.48 *4*	7/2+		ABC	**Jπ:** L(d,p)=4; γ to 3/2+ ground state excludes 9/2+.
244.41 *5*			BC	XREF(C)=*246.4
246.373 *10*	(5/2-,3/2)		ABC	XREF(C)=*246.4

Induced fission data

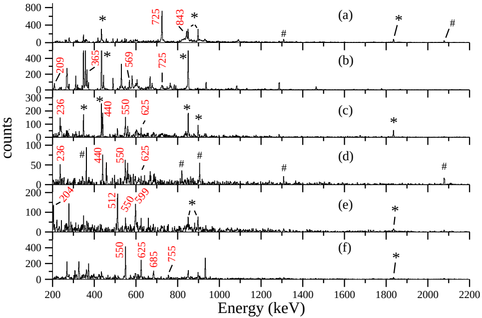


γ-ray spectra, gated on: (a) 365 and 569-keV transitions; (b) 1836 and 898-keV transitions; (c) 209 and 1836 or 209 and 898-keV transitions; (d) 209 and 2079-keV or 209 and 1309-keV transitions; (e) 209 and 235-keV transitions; (f) 209 and 440-keV transitions. The γ-lines belonging to the ^{88}Sr level scheme are denoted with a star symbol *. The γ-lines belonging to the ^{89}Sr level scheme are denoted with the hash symbol #.

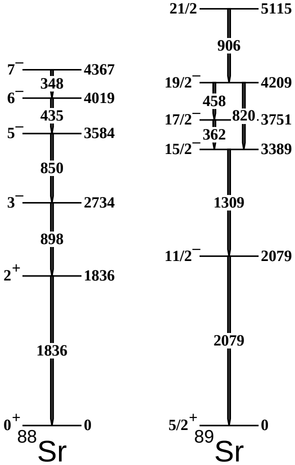
2014La15

- **Beam:** E(^{30}Si)=145 MeV;
- **Target:** 1.15 mg/cm^2 enriched in ^{168}Er; 9 mg/cm^2 Au backing
- **Detectors:** EUROBALL III
- **Measured:** E_γ, I_γ, $\gamma-\gamma-\gamma$ coinc.
- **Deduced:** ^{105}Ru level scheme

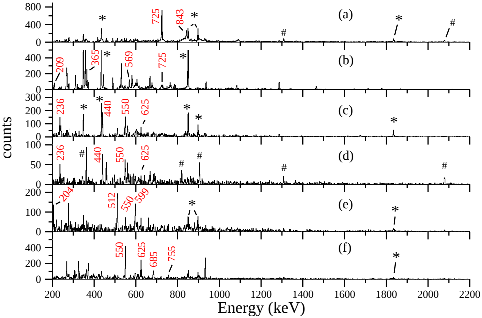
Induced fission data



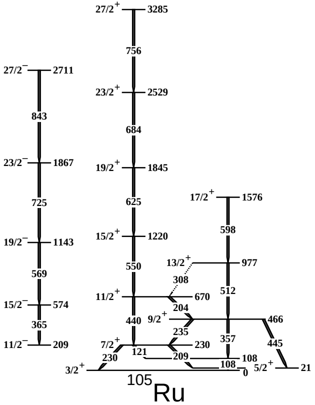
γ-ray spectra, gated on: (a) 365 and 569-keV transitions; (b) 1836 and 898-keV transitions; (c) 209 and 1836 or 209 and 898-keV transitions; (d) 209 and 2079-keV or 209 and 1309-keV transitions; (e) 209 and 235-keV transitions; (f) 209 and 440-keV transitions. The γ-lines belonging to the ^{88}Sr level scheme are denoted with a star symbol *. The γ-lines belonging to the ^{89}Sr level scheme are denoted with the hash symbol #.



Induced fission data

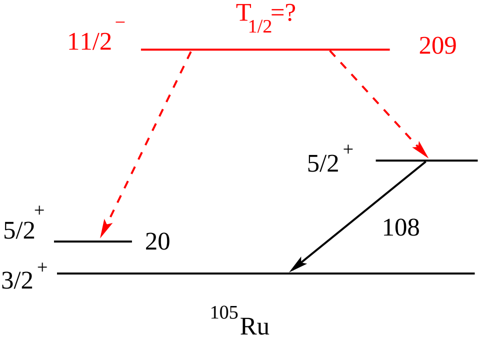


γ-ray spectra, gated on: (a) 365 and 569-keV transitions; (b) 1836 and 898-keV transitions; (c) 209 and 1836 or 209 and 898-keV transitions; (d) 209 and 2079-keV or 209 and 1309-keV transitions; (e) 209 and 235-keV transitions; (f) 209 and 440-keV transitions. The γ-lines belonging to the ^{88}Sr level scheme are denoted with a star symbol *. The γ-lines belonging to the ^{89}Sr level scheme are denoted with the hash symbol #.



S.Lalkovski *et al.*, Phys.Rev.**C89** (2014) 064312

^{105}Ru IT Decay



Mult.	100 keV	200 keV
E3	18 s	0.14 s

^{105}Ru IT Decay

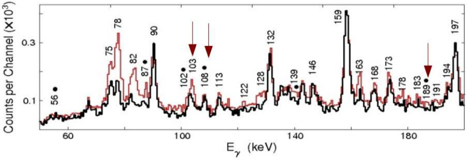
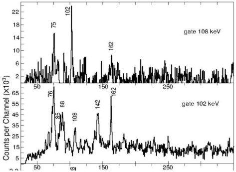
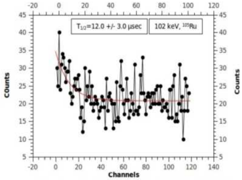
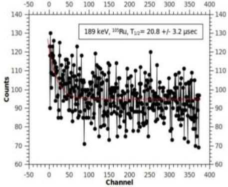


Fig.1 Low energy part of two γ-ray spectra collected for a time of 300 μs at the beginning (red line) and at the end (black line), 3.5 ms later, of the beam-off period, respectively. The lines marked with black dots (and red arrows) indicate the γ - lines appearing below 209 keV, 11/2- state of ^{105}Ru.



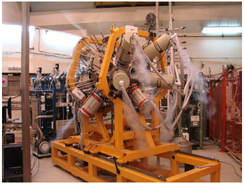


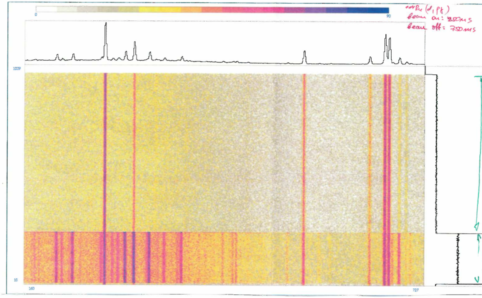


HIL experiment (J.Kownacki)

- **Reaction:** ^{16}O (85 MeV)+^{208}Pb
- **accelerator:** HIL cyclotron
- **in-beam:** 2-4 ms
- **off-beam:** 4-8 ms
- **Deduced:** $102\gamma(t)$ $T1/2 = 16\mu$s consistent with $M2$ $T_{1/2}^{W.e}$=100 μs

$(d, p\gamma)$ experiment

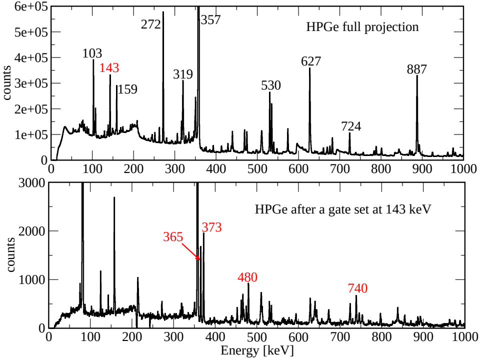


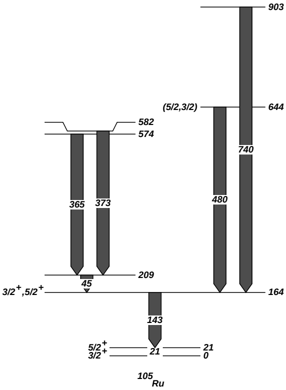


Experimental details

- **26-29 March 2015**
- **Beam:** E(^2H)=7 MeV; chopped beam
- **Target:** 50 mg/cm^2 enriched to 99% in ^{104}Ru
- **Cross-section:** 200 mB
- **Detectors:** RoSphere

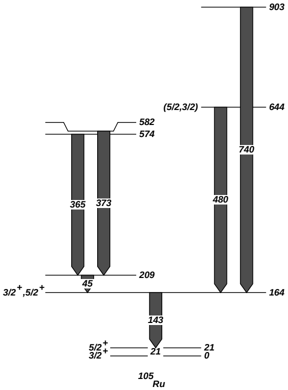
^{13}C experiment



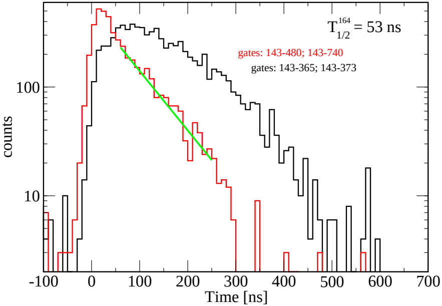


Beam: ^{13}C; E = 40 MeV

^{13}C experiment



Beam: ^{13}C; $E = 40$ MeV



Conclusion: $T_1/2(209keV)$ shorter than 53 ns

$T_{1/2}^{W.e.} E3 = 8 \times 10^5$ s.

$T_{1/2}^{W.e.}(M2)$=20 ms

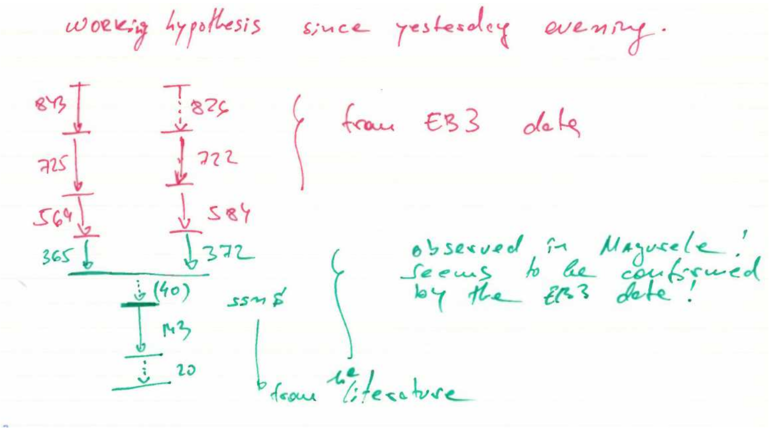
$T_{1/2}^{W.e.}(E1)$=4 ps

$\rightarrow$ consistent with $E1$ nature ...

i.e. Consistent with $E1$ nature, given that $F_W = 10^4 - 10^5$,

i.e. $7/2^- \rightarrow 5/2+$ or $9/2^- \rightarrow 7/2^+$

Conclusion


working hypothesis since yesterday evening.
843
826
725
722
564
584
365
372
(40)
143
20
from EB3 data
observed in Magurele!
seems to be confirmed
by the EB3 data!
ssms
from the literature