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Nuclear Data Sheets for A = 266–294*

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Abstract: The 2000 Nuclear Data Sheets for A=267–293 (2000Fi12) and part (A=266) of the 2001 Nuclear Data Sheets for 250,254,258,262,266 (2001Ak11) have been revised using experimental decay and reaction data received by August 12, 2005.

Cutoff Date: August 12, 2005; all references entered into the Nuclear Science References File and papers and private communications received by this date were considered.

General Policies and Organization of Material: See the introductory pages.

General Comments:

Acronyms and notations used in this evaluation:

β2 Quadrupole deformation of the nuclear ground state
BGS Berkeley Gas Filled Separator
DGFRS Dubna Gas Filled Recoil Separator at the Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia
EVR Evaporation Residue
GARIS Gas–filled Recoil Ion Separator
RILAC RIKEN Linear Accelerator facility
SHIP Separator for Heavy Ion reaction Products
t, t_n, and t_{SF} Time delay between detection of α or SF fragment and detection of previous EVR or α
TKE Total Kinetic Energy
VASSILISSA Electrostatic separator at the Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia

IUPAC/IUPAP Transfermium Working Group and Joint Working Party (Z=110–112,114,116,118): Where no substantially new data exist or the IUPAC/IUPAP Joint Working Party (JWP) Technical Reports (2001Ka70,2003Ka71) have already assigned a priority of discovery for an element (Z=110 or Ds and Z=111 or Rg), the evaluators have relied on the judgement of the JWP in determining the strength of the arguments made in the various papers. In the cases where there are new data or where the JWP has not yet assigned a priority of discovery for an element, the evaluators have attempted to follow the guidelines of the IUPAC/IUPAP Transfermium Working Group (TWG) as detailed in 1992Ba77 in their assessments of the data.

In the above context, with respect to Z=112 and the collective works of A. Marinov *et. al.*, the reader is referred to 1992Ba77, 2001Ka70, and 2003Ka71, the response by the experimenters (2004MaZS), and references therein.

Note that the TWG and JWP are primarily concerned with the priority of discovery of an element and not a specific nuclide. The purpose of this evaluation is to present the "best" set of nuclear properties for those nuclides reported between A=266 and A=294 based on data currently available and **not** to establish a priority of discovery for any element.

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It is well known that alpha decay chains seen in cold fusion reactions tend to terminate in known mass regions. The method of α–α or α–SF correlations for identifying the parent has therefore been used with confidence. Experiments carried out with hot fusion reactions, result in alpha decay chains beginning and ending with hitherto unknown nuclei, thereby necessitating the use of EVR–α or EVR–SF correlations in an attempt to identify the parent and daughters. The latter method is not as accurate as the first since a greater probability of randomness is inherant to the technique. As such, independent verification and confirmation of the data gains added importance. These facts should be taken into account when considering the suggested properties of nuclei created following a hot fusion reaction as for the synthesis of Z=114 and above.

Finally, with regard to the some of the hot fusion studies conducted by the Dubna–Livermore collaboration, 2004Mo15 have pointed out that mass assignments which are based on the excitation energy of the compound nucleus may be off by a single unit. This may also be due in part to uncertainties in the beam energy and calculated mass excesses of the expected super heavy nuclei. Once again, collateral information is required to establish the charge and approximate A of the nucleus.

$\Delta T_{1/2}$ Estimates: Where the half–lives as given by the authors have not been adopted, the evaluators have used the approximations in equation 18 of 1984Sc13 for three or more events, assuming an exponential distribution to estimate the standard uncertainty (68% confidence level) in $T_{1/2}$:

$$\tau_u/t_m \approx 1/(1-z/\sqrt{n}), \quad \tau_l/t_m \approx 1/(1+z/\sqrt{n})$$

where τ_u=upper uncertainty, τ_l=lower uncertainty, t_m=average mean time, z=1 for a 68% confidence level, and n=number of events. For one and two events, the exact values given in Table 1 have been used: τ_l/t_m=0.543 and τ_u/t_m=5.79 for n=1 and τ_l/t_m=0.606 and τ_u/t_m=2.82 for n=2. Note that except for the one event τ_u/t_m, the approximations are accurate within 10%.

Viola–Seaborg Systematics (1966Vi04 and references therein): Calculations of $T_{1/2}$ performed in the present evaluation used the relationship:

$$\log T_{1/2}(\alpha) = (aZ+b)Q^{-1/2} + (cZ+d)$$

where Z refers to the atomic number of the parent nucleus, Q is the Q–value of the α–decay in MeV and:

a=1.78722, b=–21.398, c=–0.25488, and d=–28.423.

The parameters were obtained by a fit to 65 even–even nuclei with Z>82 and N>126 (2004OgZZ). Values are revised here in accordance with the parameter set used in these evaluations. We note that these systematics are only an indication of α–decay half–lives from the ground state of a given even–Z(parent), rather than specific to any isotope of the the element under consideration. The use of this formalism in the case of odd and odd–odd nuclei is to be taken as qualitative. Some experimenters (*e.g.*, 2004OG03) use $T_{1/2}$(calc) so derived to estimate a Hindrance Factor (HF) for a given transition, attributable to the odd neutron or proton. This quantity is then given by the ratio of Tα(expt) to Tα(calc). The HF so computed is an approximate indication.

Others (Phenomenological parametrizations): See Nuclear Science References.

Fusion–Fission Dynamics: An emerging topic of interest in the trans–fermium elements is the manifestation of shell effects in the mass energy distributions (MED) of heavy nuclei as reflected in their fission and quasi–fission (QF) signatures. Studies of this type are important as QF is expected to play a greater role on the hindrance of fusion as one attempts to synthesis heavier nuclei in the approach to the "island" of stability. An understanding of this mechanism is necessary to establishing the most favorable reactions for producing heavy elements. Another unexpected hindrance to fusion was discovered by the Canberra group (1998Da24) in much lighter, asymmetric systems leading to the formation of CN ^{216}Ra*. This was found to be related to both the mass asymmetry in the entrance channel as well as the on–set of QF. It is thought that (closed) shell structure, as well as deformations of target/projectile nuclei and their relative orientation to each other in the process of CN formation, may also play an important role in reducing the probability of forming a compound system. In the face of extremely low yields and a steep decrease of production cross–sections already in evidence with available stable beam–target combinations, the influence of all possible mitigating factors must be accurately determined in order to optimize the probability of successful fusion. The formation of a super–heavy element (SHE) will be possible only if the di–nucleus survives QF going on to form a compact compound system which must then face competition from fission.

Recently (2004PrZW), a series of experiments designed to investigate fusion–fission dynamics have been carried out at FLNR–JINR in Dubna in collaboration with investigators from Belgium, France, and Italy. Nascent compound nuclei were formed in the range Z=102–122 in the reactions ^{26}Mg+^{248}Cm; ^{48}Ca with ^{208}Pb, ^{232}Th, ^{238}U, ^{244}Pu, and ^{248}Cm; and ^{58}Fe with ^{208}Pb, ^{232}Th, ^{244}Pu, and ^{248}Cm using the U400 cyclotron and the double–arm tof spectrometer "Corset". These experiments were inspired by the use of similar targets in the synthesis of Z=112, Z=114, and Z=116 at Dubna. QF was observed in nuclei ^{286}112 to ^{296}116 and multi–modal fission in the case of both ^{274}Hs and ^{256}No. Many such experiments are planned or underway to investigate the various effects.

Others (Fusion–Fission Dynamics): 2002Hi20, 2004Da11, and 2004It05 and references cited in these papers.

Experimental Estimates of Fission Barriers:

1987Mu15 deduce fission barriers (B_f) for (N–Z)=48 isotopes. For Z=92, 94, 96, 98, 100, 102, 104, 106, and 108 the experimentally derived barrier heights are respectively: B_f=6.23, 6.47, 6.35, 6.17, 6.03, 6.24, 6.64, 6.89, and 6.68 MeV (± 0.01 MeV). See 1987Mu15 for details.

2002It04, in an analysis of available experimental data, derive the $^{283-286}$112, $^{288-292}$114, and $^{292-296}$116 fission barrier heights of ≥5.5, ≥6.7, and ≥6.4 MeV, respectively.

Dubna data on ^{289}114, ^{287}114, and ^{283}112: Two possibilities have been proposed in an attempt to understand the the ^{289}114, ^{287}114 observations:

(i) that the single ^{289}114 chain seen by the DGFRS group belongs to a rare decay mode originating from an isomeric state, or that

(ii) the sequence may actually originate from ^{290}114→^{286}112→^{282}Ds→^{278}Hs (SF) (See ^{290}114 Adopted Levels).

The evaluators believe that further investigations are required to support either hypothesis.

Thus, ^{290}114, ^{286}112, ^{282}Ds and ^{278}Hs remain unobserved. Also, $T_{1/2}$ for ^{287}114 as seen by 1999Og07 (data from the VASSILISSA separator) is much larger than that observed by 2004Og12 and 2004OgZZ (15 data points, using DGFRS), although the Eα is in agreement. Such inconsistencies need to be better understood.

Note that the two papers, 2004Og12 and 2004OgZZ are identical in many respects. 2004OgZZ report more statistics in some cases.

Other comments on ^{289}114 and ^{283}112

2000Ar03, who analyzed the data for the 34–min decay chain of ^{289}114 (DGFRS data from 1999Og10), ^{287}114, and the SF events reported for ^{283}112 (VASSILISSA data from 1999Og05 and 1999Og07), classified the evidence as being "very weak", with no convincing supporting arguments for the possible production of SHE. We make the following general observations:

A total of 46 events (Table IV, 2004Og12), with 5 more events bringing the total to 51 decays (Table V: 2004OgZZ), have since been reported by the Dubna–JINR collaborations for all isotopes of Z=114. From the largest number of events as reported in 2004OgZZ, the isotopes observed are ^{289}114 (9 events), ^{288}114 (16 events), ^{287}114 (15 events) and ^{286}114 (11 α + 5 SF events). Taking all the data into consideration, the ≈34 min decay sequence postulated as originating from a rare decay mode of ^{289}114, does not seem very likely. On the other hand, a statistical analysis by 2000Zl02 suggests that the ^{289}114 decays observed are genetically linked and not the result of a background decay sequence. These discrepancies have to be resolved, along with some others.

^{283}112: The six SF events reported *via* 1999Og05 and 1999Og07 have (see also 2004Og02) with VASSILISSA, have not been reproduced in experiments done with DGFRS. There appears to be a lack of internal consistency through the collective measurements and the data are inconclusive as pointed out by experimenters (reasons given in each paper). Decay properties of parent ^{287}114 may be similar to those noted in 2004Og12 but those of the daughter ^{283}112 differ. Also, 2005Gr19 and 2002Lo15 reported no SF decays or EVR–α–α correlations with Δt(EVR–α) <20 s or Δt(α–α)<20 s in any of the ^{48}Ca + ^{238}U irradiations performed by them. See ^{283}112 Adopted Levels for details.

These observations by the experimenters are consistent with the findings of 2000Ar03 which offer a more detailed analysis. However, of the various arguments put forward therein, the following comments may be made here:

1. Total TKE's from the two presumed Z=112 fragments are in each case:
190 MeV and 212 MeV (1999Og05)
65 MeV and 170 MeV (2004Og02)
195 MeV and 165 MeV (1999Og07: Daughters of ^{287}114)
TKE for Z=112 (2004Og12; ^{282}112 observed as daughter in four events of nine attributed to ^{286}114 (Page 8, Table II(c)) is measured at 213 MeV and 211 MeV (two events, # 1 & 9, registered in both focal plane and side detectors). With one exception, all the energies measured in the three papers (1999Og05, 1999Og07, and 2004Og02) are, in fact, lower than would be expected for this mass range (Z=112 or Hs) as pointed out in 2000Ar03. However, a direct mass analysis undertaken by the experimenters (2004OG02) of the two SF nuclei (from the second experiment) after EVR implantation resulted in A=285.1 *41*. The result is in agreement with EVR's produced in ^{48}Ca+^{238}U→^{286}112*.

2. 2000Ar03 statement that correlations between the fission events and preceding signals (recoils/α's) are random. Note that a 'backward' analysis of the data was reported in 1999Og07 and in the other papers. These statements by 2000Ar03 are evidently in contradiction with those made by the experimenters. A more complete analysis would be beneficial.

3. The experimenters rely on two Z=114 chains (one measured in the 1999Og07); the ≈34 min sequence tentatively attributed to ^{289}114 quoted from an earlier experiment (and not seen since) is invoked in support of daughter Z= 112 assignments. The proposed assignment of Z=114 to both parents may be incorrect taking into account new data which do not support these observations and for reasons already mentioned. Hence, the Z=112 daughter is also possibly incorrect.

CONCLUSIONS:

Properties of Z=112 as proposed in 1999Og05, 1999Og07 and 2004Og02 are not conclusive. Overall, the results from the VASSILISSA experiments are at variance with data from experiments using DGFRS. The latter investigations are done using more stringent methods, and have greater statistics, offering better internal consistency. Some obvious discrepancies and other inconsistencies between the two sets of data remain and need to be resolved or adequately explained as does the lack of events observed in the ^{48}Ca + ^{238}U irradiations performed by 2005Gr19 and 2002Lo11.

Properties of ^{287}114 as observed in 1999Og07 and ^{289}114 quoted from earlier work are not reproduced to date.

Theoretical Calculations:

1995Mo29: β2 based on the finite–range droplet macroscopic model and folded–Yukawa single–particle microscopic model with "global" parameters.

1997Mo25: β–decay properties based on the finite–range droplet model and folded–Yukawa single particle potential. Odd–proton and odd–neutron Jπ simultaneously obtained with the calculated masses and deformations in 1995Mo29. Global parameterization from ^{16}O through A=239.

2003Mu15, 2003Mu26: β2 based on Yukawa–plus–exponential model for the macroscopic part and the Strutinski shell correction, with the Wood–Saxon single–particle potential, for the microscopic part.

2005GaZX: β2 based on self consistent calculations within the framework of the Relativistic Mean Field (RMF) theory with very few "globally" fit parameters and employing the frequently used NL3 Lagrangian parameter set. Since other parameter sets in use exhibit similar systematics, these results are expected to be representative. β2 to three decimal places are taken from 2005GaZY.

Other Measurements:

2004DrZZ has found evidence for Z=120 compound nucleus formation from lifetime measurements for ^{238}U on natural Ni at E=6.62 MeV/A (Blocking technique in single crystals).

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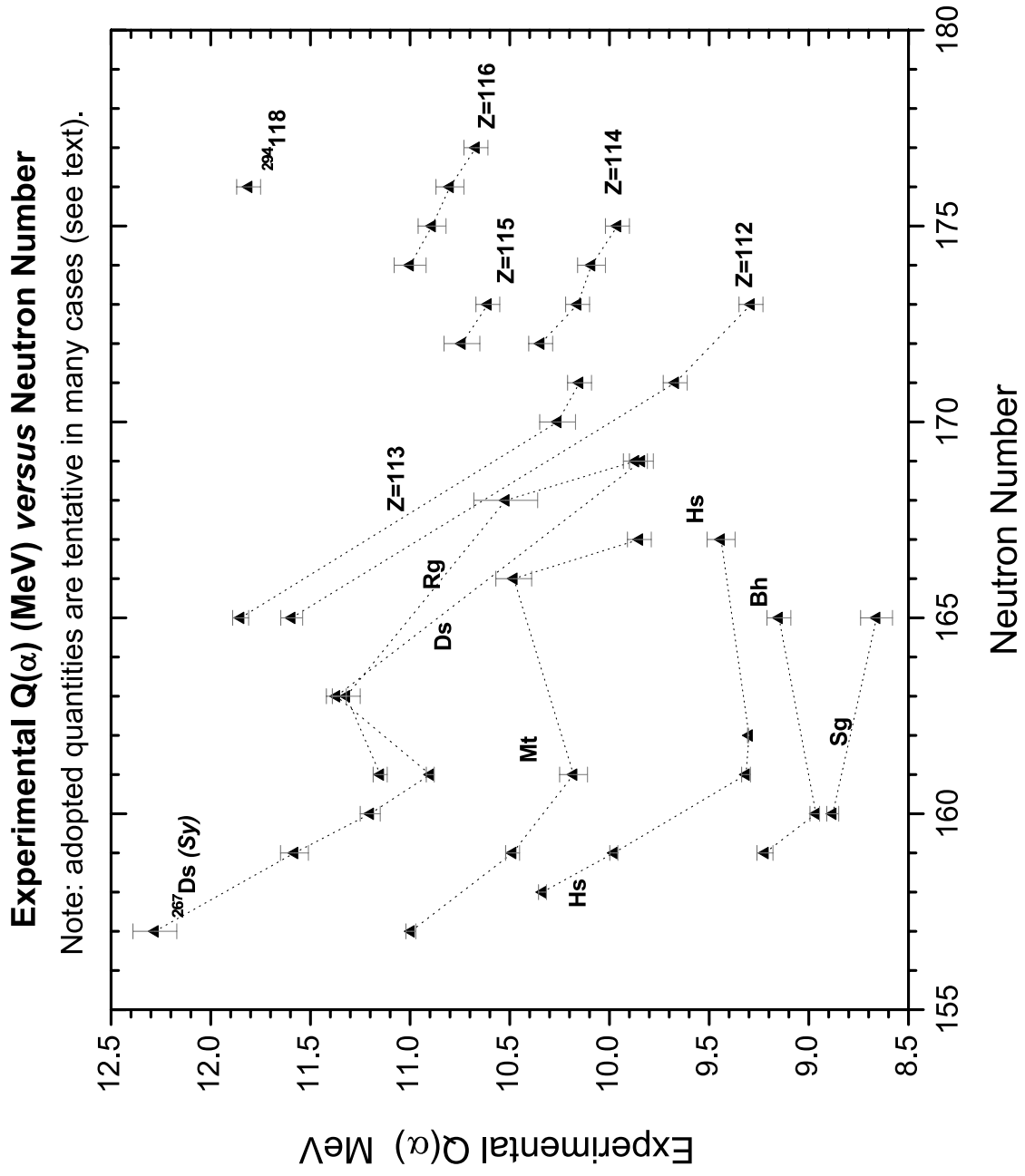
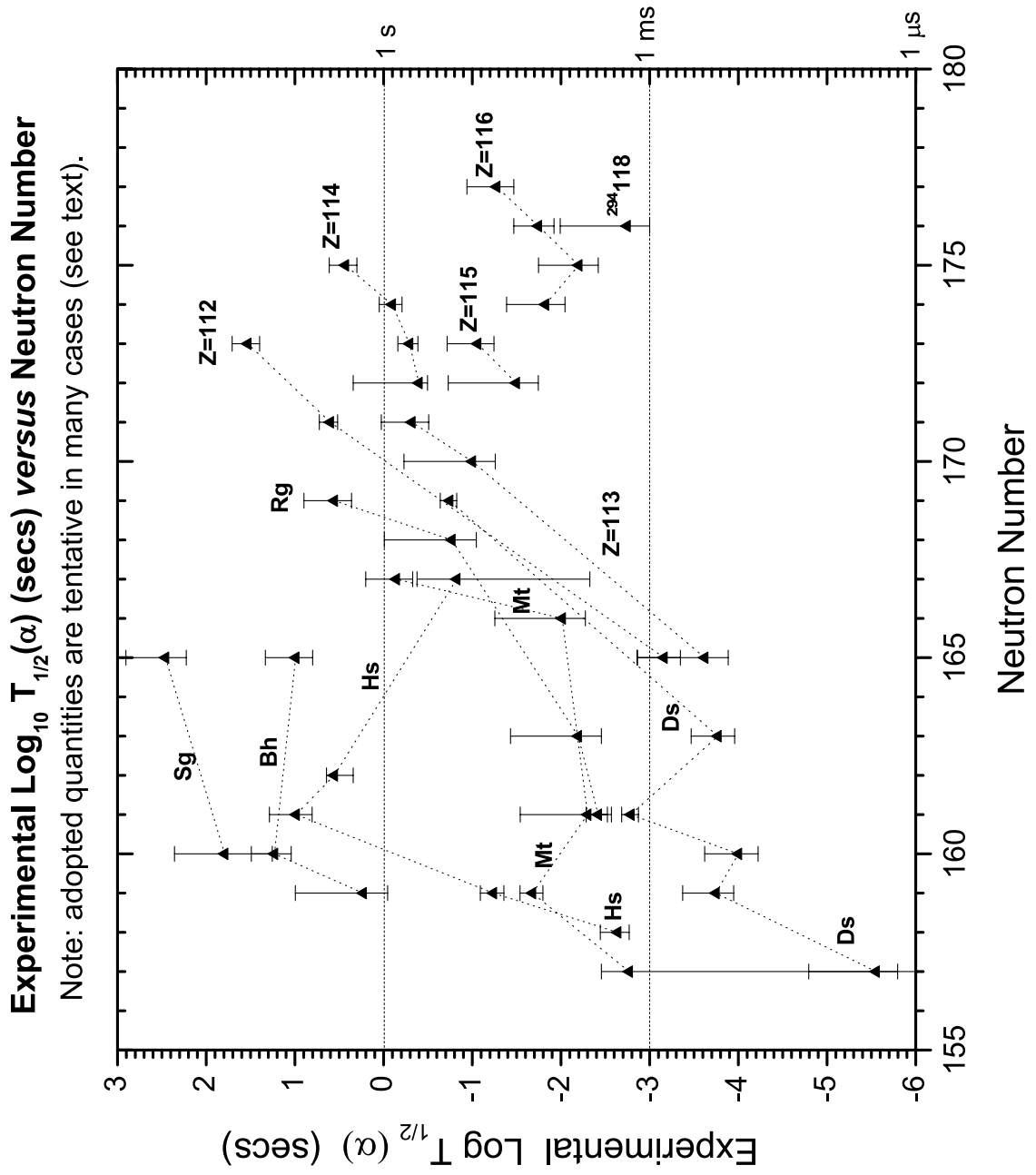
Summary of Properties for Possible Ground-States in A=266-294

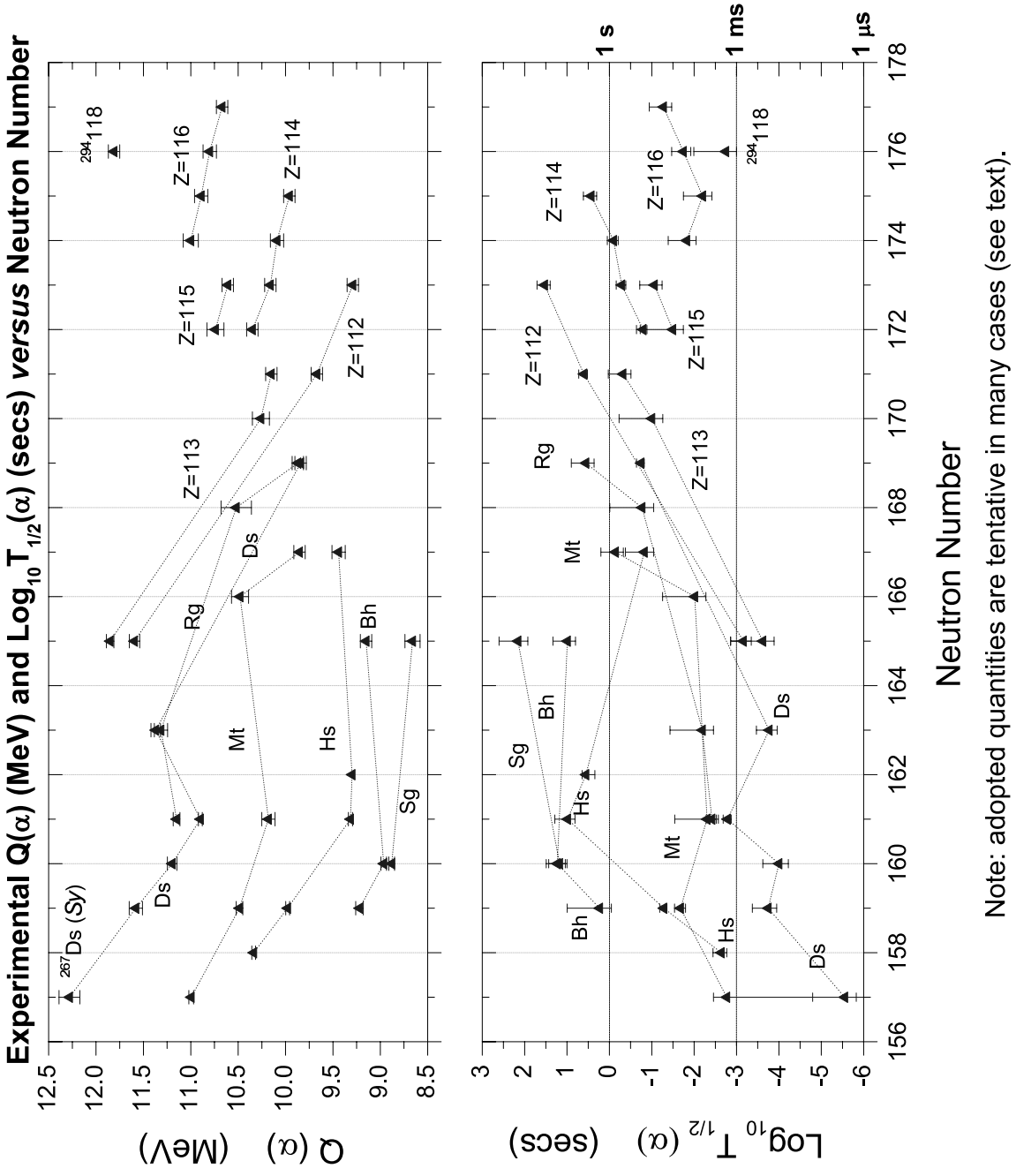
Z	A	N	N/Z	Q_α(exp) (MeV)	Branching Ratio	$T_{1/2}$(expt)	Partial $T_{1/2}$(expt) (secs)
118	294	176	1.49	11.81 *6*	%α≈100	1.8 ms *+84-8*	$T_{1/2}(\alpha)$≈0.0018 *+84-8*
116	293	177	1.53	10.67 *6*	%α≈100	53 ms *+62-19*	$T_{1/2}(\alpha)$≈0.0053 *+62-19*
116	292	176	1.52	10.80 *7*	%α≈100	18 ms *+16-6*	$T_{1/2}(\alpha)$≈0.018 *+16-6*
116	291	175	1.51	10.89 *7*	%α≈100	6.3 ms *+116-25*	$T_{1/2}(\alpha)$≈0.0063 *+116-25*
116	290	174	1.50	11.00 *8*	%α≈100	15 ms *+26-6*	$T_{1/2}(\alpha)$≈0.015 *+26-6*
115	288	173	1.50	10.61 *6*	%α≈100	87 ms *+105-30*	$T_{1/2}(\alpha)$≈0.087 *+105-30*
115	287	172	1.50	10.74 *9*	%α≈100	32 ms *+155-14*	$T_{1/2}(\alpha)$≈0.032 *+155-14*
114	289	175	1.54	9.96 *6*	%α≈100	2.7 s *+14-7*	$T_{1/2}(\alpha)$≈2.7 *+14-7*
114	288	174	1.53	10.09 *7*	%α≈100	0.80 s *+32-18*	$T_{1/2}(\alpha)$≈0.80 *+32-18*
114	287	173	1.52	10.16 *6*	%α≈100	0.51 s *+18-10*	$T_{1/2}(\alpha)$≈0.51 *+18-10*
114	286	172	1.51	10.345 *60*	%α≈40; %SF≈60	0.16 s *+7-3*	$T_{1/2}(\alpha)$≈0.40 *+18-8* $T_{1/2}$(SF)≈0.27 *+12-5*
113	284	171	1.51	10.15 *6*	%α≈100	0.48 s *+58-17*	$T_{1/2}(\alpha)$≈0.48 *+58-17*
113	283	170	1.50	10.26 *9*	%α≈100	100 ms *+490-45*	$T_{1/2}(\alpha)$≈0.100 *+490-45*
113	278	165	1.46	11.85 *4*	%α≈100	0.24 ms *+114-11*	$T_{1/2}(\alpha)$≈0.00024 *+114-11*
112	285	173	1.54	9.29 *6*	%α≈100	34 s *+17-9*	$T_{1/2}(\alpha)$≈34 *+17-9*
112	284	172	1.54	≤9.85	%SF≈100	101 ms *+41-22*	$T_{1/2}$(SF)≈0.101 *+41-22*
112	283	171	1.53	9.67 *6*	%α≥99; %SF≤1	4.0 s *+13-7*	$T_{1/2}(\alpha)$=4.0 *+14-8* $T_{1/2}$(SF)≥4×10^2 *+13-7*
112	282	170	1.52	≤10.82	%SF≈100	0.50 ms *+33-14*	$T_{1/2}$(SF)≈0.050 *+33-14*
112	277	165	1.47	11.594 *55*	%α≈100	0.69 ms *+69-24*	$T_{1/2}(\alpha)$≈0.069 *+69-24*
111	280	169	1.52	9.87 *6*	%α≈100	3.6 s *+43-13*	$T_{1/2}(\alpha)$≈3.6 *+43-13*
111	279	168	1.51	10.52 *16*	%α≈100	0.17 s *+81-8*	$T_{1/2}(\alpha)$≈0.17 *+81-8*
111	274	163	1.47	11.32 *7*	%α≈100	6.4 ms *+307-29*	$T_{1/2}(\alpha)$≈0.0064 *+307-29*
111	272	161	1.45	11.150 *35*	%α≈100	3.8 ms *+14-8*	$T_{1/2}(\alpha)$≈0.0038 *+14-8*
110	281	171	1.55	≤9.85	%SF≈100	9.6 s *+50-25*	$T_{1/2}$(SF)≈9.6 *+50-25*
110	279	169	1.54	9.84 *6*	%α≈10; %SF≈90	0.18 s *+5-3*	$T_{1/2}(\alpha)$≈1.8 *+5-3* $T_{1/2}$(SF)≈0.20 *+6-4*
110	273	163	1.48	11.37 *5*	%α≈100	0.17 ms *+17-6*	$T_{1/2}(\alpha)$≈0.00017 *+17-6*
110	271	161	1.46	10.899 *20*	%α≈100	1.63 ms *+44-29*	$T_{1/2}(\alpha)$≈0.00163 *+44-29*
110	270	160	1.45	11.20 *5*	%a≈100; %SF<0.2	0.10 ms *+14-4*	$T_{1/2}(\alpha)$≈0.00010 *+14-4* $T_{1/2}$(SF)>0.05 *+7-2*
110	269	159	1.45	11.58 *7*	%α≈100	179 μs *+245-66*	$T_{1/2}(\alpha)$≈0.000179 *+245-66*
110	267	157	1.43	12.28 *11[Sy]*	%α≈100	2.8 μs *+133-12*	$T_{1/2}(\alpha)$≈0.0000028 *+133-12*

Summary of Properties for Possible Ground-States in A=266-294 (Continued)

Z	A	N	N/Z	Q_α(exp) (MeV)	Branching Ratio	$T_{1/2}$(expt)	Partial $T_{1/2}$(expt) (secs)
109	276	167	1.53	9.85 *6*	%α≈100	0.72 s *+87-25*	$T_{1/2}(\alpha)$≈0.72 *+87-25*
109	275	166	1.52	10.480 *90*	%α≈100	9.7 ms *+460-44*	$T_{1/2}(\alpha)$≈0.0097 *+460-44*
109	270	161	1.48	10.18 *7*	%α≈100	5.0 ms *+24-3*	$T_{1/2}(\alpha)$≈0.0.0050 *+24-3*
109	268	159	1.46	10.486 *35*	%α≈100	21 ms *+8-5*	$T_{1/2}(\alpha)$≈0.021 *+8-5*
109	266	157	1.44	10.996 *25*	%α≤100	1.7 ms *+18-16*	$T_{1/2}(\alpha)$≈0.0017 *+18-16*
108	275	167	1.55	9.44 *7*	%α≈100	0.15 s *+27-6*	$T_{1/2}(\alpha)$≈0.15 *+27-6*
108	270	162	1.50	9.30 *+7-3*	%α≈100	3.6 s *+8-14*	$T_{1/2}(\alpha)$≈3.6 *+8-14*
108	269	161	1.49	9.315 *22*	%α≈100	9.7 s *+97-33*	$T_{1/2}(\alpha)$≈9.7 *+97-33*
108	267	159	1.47	9.978 *20*	%α≥80; %SF<20	52 ms *+13-8*	$T_{1/2}(\alpha)$=0.058 *+23-14* $T_{1/2}$(SF)>0.26 *+7-4*
108	266	158	1.46	10.336 *20*	%α≈100; %SF<1.4	2.3 ms *+13-6*	$T_{1/2}(\alpha)$≈0.0023 *+13-6* $T_{1/2}$(SF)>0.16 *+10-5*
107	272	165	1.54	9.15 *6*	%α≈100	10 s *+12-4*	$T_{1/2}(\alpha)$≈10 *+12-4*
107	267	160	1.50	8.96 *30*	%α≈100	17 s *+14-6*	$T_{1/2}(\alpha)$≈17 *+14-6*
107	266	159	1.49	9.22 *4*	%α≈100	1.7 s *+82-8*	$T_{1/2}(\alpha)$≈1.7 *+82-8*
106	271	165	1.56	8.66 *8*	%α≈50; %SF≈50	2.4 min *+43-10*	$T_{1/2}(\alpha)$≈2.9×10^2 *+52-12* $T_{1/2}$(SF)≈2.9×10^2 *+52-12*
106	266	160	1.51	8.88 *3*	18<%α≤50; 50<%SF≤82	21 s *+20-12*	$T_{1/2}(\alpha)$=62 *+166-44* $T_{1/2}$(SF)=32 *+20-21*
105	268	163	1.55		%SF≈100	32 h *+11-7*	$T_{1/2}$(SF)≈1.15×10^5 *+40-26*
105	267	162	1.54		%SF≈100	73 min *+350-33*	$T_{1/2}$(SF)≈4.4×10^3 *+210-20*
104	267	163	1.57		%SF≈100	2.3 h *+110-11*	$T_{1/2}$(SF)≈8×10^3 *+40-4*


Experimental Q(α) (MeV) versus Neutron Number
Note: adopted quantities are tentative in many cases (see text).
Experimental Q(α) MeV
Neutron Number
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
155
160
165
170
175
180
267Ds (Sy)
294118
Z=116
Z=115
Z=114
Z=113
Z=112
Rg
Ds
Mt
Hs
Hs
Bh
Sg

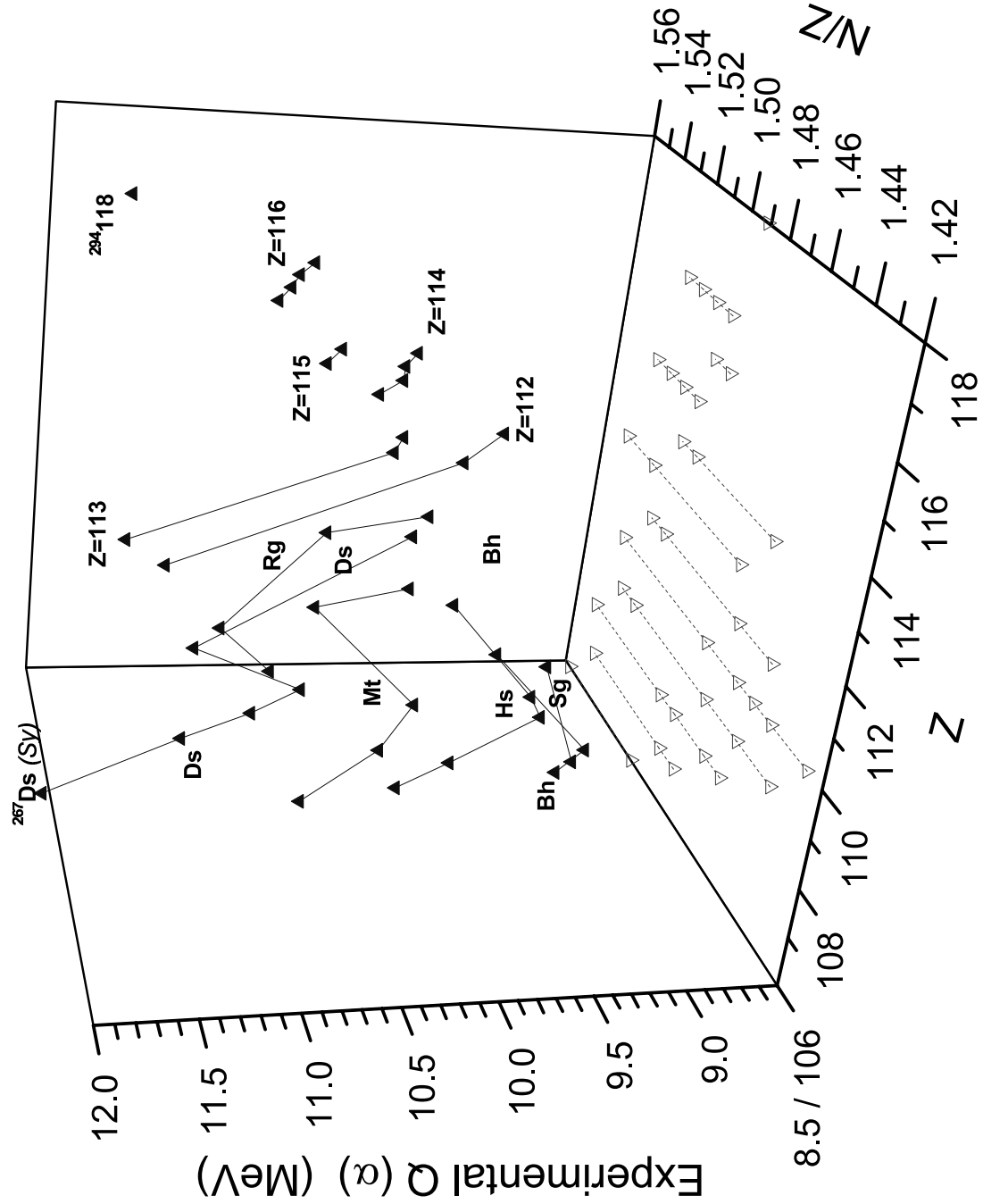

Experimental Log10 T1/2(α) (secs) versus Neutron Number
Note: adopted quantities are tentative in many cases (see text).
Experimental Log T1/2 (α) (secs)
Neutron Number
1 s
1 ms
1 μs
Z=112
Z=114
Z=116
Z=115
Z=113
294118
Sg
Bh
Hs
Mt
Ds
Rg



Note: adopted quantities are tentative in many cases (see text).

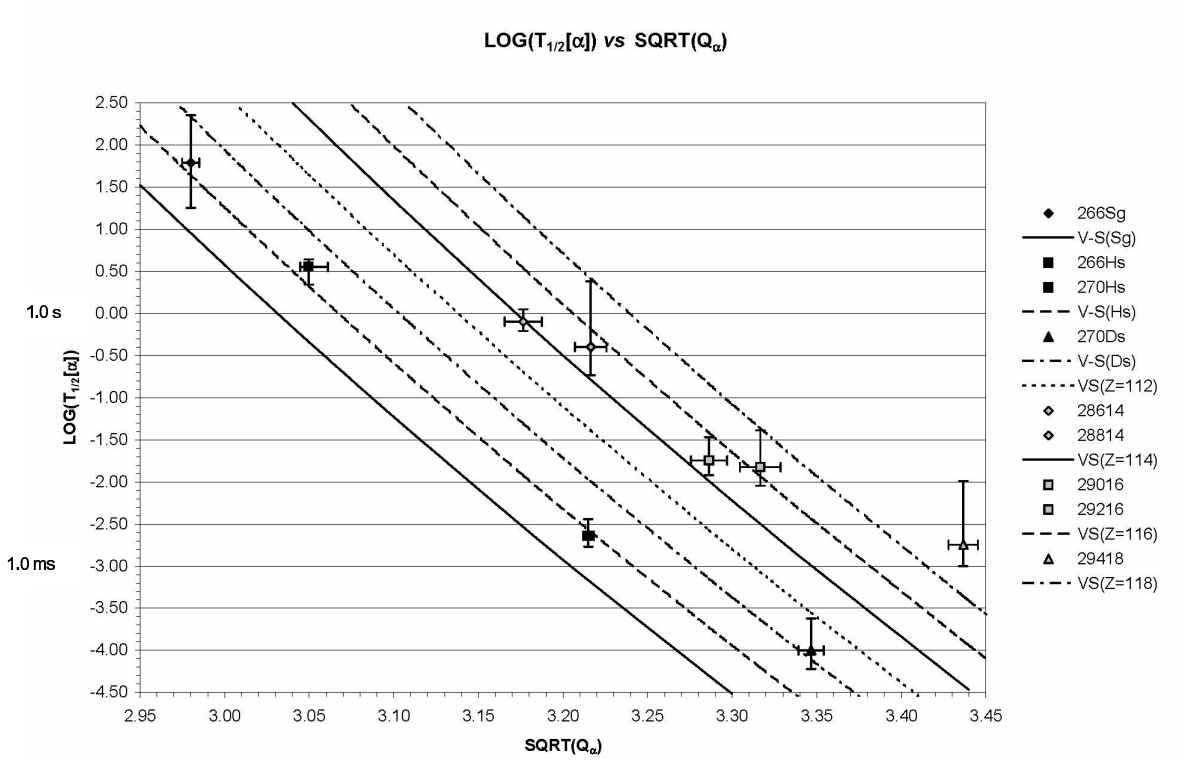
Projected experimental Q(α) (MeV) values against Z in N/Z plane

Note: adopted quantities are tentative in many cases (see text).



Properties of Possible Even-Even A=266-294 Ground States

Z	Nuclide	Q_α(keV)	$T_{½}$	Branchings	$T_{½}^{\alpha}$(V-S)[1]
106	^{266}Sg	8880 *30*	21 s *+20–12*	18<%α≤50; 50<%SF≤82	9.0 s *+22-18*
108	^{266}Hs?	10336 *20*	2.3 ms *+13–6*	%α≈100; %SF<1.4	2.7 ms *3*
108	^{270}Hs?	9300 *+70–30*	3.6 s *+8–14*	%α≈100	2.1 s *+5-8*
110	^{270}Ds?	11200 *50*	0.10 ms *+14–4*	%α≈100; %SF<0.2	0.08 ms *3*
112	^{282}112?	≤10820	0.50 ms *+33–14*	%SF≈100	≥2.3 ms
112	^{284}112?	≤9850	101 ms *+41–22*	%SF≈100	≥0.98 s
114	^{286}114?	10345 *60*	0.16 *s +7–3*	%α≈40;[2] %SF≈60	0.17 s *+7-6*
114	^{288}114?	10090 *70*	0.80 s *+32–18*	%α≈100	0.84 s *+50-31*
116	^{290}116?	11000 *80*	15 ms *+26–6*	%α≈100	12 ms *+7-5*
116	^{292}116?	10800 *70*	18 ms *+16–6*	%α≈100	38 ms *+21-13*
118	^{294}118?	11810 *60*	1.8 ms *+84–8*	%α≈100	0.44 ms *+17-12*



[1] Viola-Seaborg systematics: $\log T_{1/2}(\alpha)=(aZ+b)Q^{-1/2}+(cZ+d)$ where a=1.78722, b=–21.398, c=–0.25488, and d=–28.423.

[2] $\Delta(\%\alpha)=30$ assumed in obtaining $\Delta T_{1/2}(\alpha)$.

Index for A = 266–294

Adopted Levels

Q(β⁻)=–4540; S(n)=7190 *SY*; S(p)=4060 *SY*; Q(α)=8880 *30* 2003Au03.
Q(β⁻): estimated uncertainty=350 keV.
S(n): estimated uncertainty=290 keV.
S(p): estimated uncertainty=400 keV.
Q(α): based on data from 1994La22, 1998Tu01, and 2002Tu05. Other: 8.78 MeV *+5–3* from Eα=8.65 MeV *+5–3* (weighted av (int) of two events reported by 2003Tu05.).

1994La22: ^{248}Cm(^{22}Ne,4n) E=116, 121 MeV at the JINR U400 cyclotron. 97% ^{248}Cm and 3% ^{246}Cm targets. The total beam dose was ≈1.6×10^{19} particles with typical intensities of 1.3×10^{13} particles/s of ^{22}Ne. EVR's were separated with the DGFRS. Assignment of six α–SF correlations to ^{266}Sg based on: α–SF correlations with Eα=8.63 MeV and 0.2 to 6.5s time intervals are unique; for the synthesis reaction used, no other candidate α–SF decay sequences with other Z,a values would have similar decay properties.

Event #1: E=116 MeV
E_α=8.60 MeV
E_{SF}=105 MeV t=191 ms
Event #2: E=116 MeV
E_α=8.54 MeV
E_{SF}=89 MeV t=215 ms
Event #3: E=116 MeV
E_α=8.59 MeV
E_{SF}=96 MeV t=748 ms
Event #4: E=116 MeV
E_α=8.74 MeV
E_{SF}=118 MeV t=6453 ms
Event #5: E=121 MeV
E_α=8.69 MeV
E_{SF}=103 MeV t=360 ms
Event #6: E=121 MeV
E_α=8.60 MeV
E_{SF}=118 MeV t=2011 ms

From these six events, 1994La22 obtain E_α=8.63 MeV *5* for ^{266}Sg and $T_{1/2}(^{262}Rf)$=1.2 s *+10–5* and an estimated $T_{1/2}(^{266}Sg)$=10–30 s from E_α.

1998Tu01: ^{248}Cm(^{22}Ne,4n) E=121, 123 MeV at the GSI UNILAC. Recoiling reaction products were stopped in He gas loaded with carbon aerosols. Attached to the surface of the aerosols, the reaction products were transported within ≈2 s along a 10 min long capillary (i.d. 2 mm) to the On–Line Gas chemistry Apparatus (OLGA) which allows chemical separation of volatile species within ≈3 s.

Decay Chain #17 (Isothermal temperature=400° C. Expected number of random events=0.03)
E_α=8.52 MeV Δt=48.9 s
E_{SF}≥20 MeV Δt=2.8 s
Decay Chain #18 (Isothermal temperature=350° C. Expected number of random events=0.09)
E_α=8.79 MeV Δt=15.1 s
E_{SF}≥20 MeV Δt=1.1 s
Decay Chain #19 (Direct catch experiment. Expected number of random events=0.45)
E_α=8.74 MeV Δt=3.5 s
E_{SF}≥20 MeV Δt=2.4 s

From these three chains, 1998Tu01 obtain $T_{1/2}(^{266}Sg)$=21 s *+20–12* (1 σ) and E_α=8.52 MeV *3* (33%) and 8.77 MeV *4* (66%) and $T_{1/2}(^{262}Rf)$=2.5 s *+25–16*.

2002Du21, 2003Tu05: daughter of ^{270}Hs produced by ^{248}Cm(^{26}Mg,4n) E=143.7–146.8 MeV, chemistry. See ^{270}Hs Adopted Levels, Gammas for details.

Event #1: 12–May–2001 at 02:33:08 hrs
$E_{\alpha 1}$= 9.16 MeV *+7–3* – assigned to ^{270}Hs
$E_{\alpha 2}$= 8.66 MeV *+7–3* t_2=25.7 s – assigned to ^{266}Sg
E_{SF}=187 MeV *6* t(SF)=0.199 s – assigned to ^{262}Rf
Event #2: 12–May–2001 at 17:09:09 hrs
$E_{\alpha 1}$= 8.97 MeV *+7–3* – assigned to ^{270}Hs
$E_{\alpha 2}$= 8.64 MeV *+7–3* t_2=11.9 s – assigned to ^{266}Sg
E_{SF}= 186 MeV *6* t(SF)=1.2 s – assigned to ^{262}Rf

The above properties are from 2003Tu05. Note that the life–times of the parent could not be estimated with the applied thermochromatography technique since deposition times are not measured. 2002Du21 explains the chemical implications of these experiments.

2004Vo24 observed six α–chains from ^{248}Cm(^{26}Mg,4n) E=142–150 MeV, chem. ^{266}Sg was expected to be produced as the daughter of ^{270}Hs. Only one chain was assigned to ^{269}Hs and four could be assigned to either ^{269}Hs *or* ^{270}Hs. The sixth chain is the most likely candidate for a random correlation. See ^{269}Hs Adopted Levels for more details. The results of this experiment are not suitable for providing further proof for ^{270}Hs or the daughter products.

Other: 1997Sc48 and 2002Tu05. See also 2003Kr24 for a critical evaluation of the chemistry and a description of the techniques used.

Theory: see Nuclear Science References.

Assignment: ^{248}Cm(^{22}Ne,4n) E=116, 121 MeV (1994La22) and E=121, 123 MeV, chem (1998Tu01). $T_{1/2}(^{262}Rf)$=1.2 s *+10–5* (1994La22) and 2.5 s *+24–16* (1998Tu01) consistent with $T_{1/2}(^{262}Rf)$=2.1 s *2* from ^{244}Pu(^{22}Ne,4n) E=114–124 MeV, excit (1996La11).

Adopted Levels (continued)

^{266}Sg Levels

Cross Reference (XREF) Flags

A ^{270}Hs α Decay: Tentative

E(level)	Jπ	XREF	$T_{1/2}$	Comments
0.0	0+	A	21 s *+20–12*	$T_{1/2}$: from 1998Tu01 (68% c.i.). 2001Ak11 note that a calculated HF(8520α) of 0.3 for Iα≈33% may indicate the existence of a contaminant under this peak. If this is correct and the associated Δt=48.9 s were excluded from consideration, $T_{1/2}$=6.4 s *+118–26*. Others: 17.8 s estimated by 2003Tu05 from Eα, 10–30 s estimated by 1994La22 from Eα, and 14.6 s *+118–45* from τ=21.0 s (arithmetic mean of 48.9 s, 3.5 s, and 15.1 s (1998Tu01), 25.7 s and 11.9 s (2003Tu05)). $T_{1/2}$(calc)=9.0 s from Viola–Seaborg systematics for Q(α)=8.88 MeV. $T_{1/2}$(SF)≥11 s (2000Ho27). 18<%α≤50; 50<%SF≤82. %α,%SF: the α and SF branchings were determined as 15≤%α≤50 by 1994La22 and %α>18 by 1998Tu01. 1994La22 set the lower limit by assuming that all of the detected fission activities were from SF decay of ^{266}Sg or from its α daughter, ^{262}Rf, and the upper limit was based on the comparison of experimental and expected cross sections. $β_2$(theory): 0.230 from 1995Mo29; 0.240 from 2003Mu26; 0.262 from 2005GaZX.

^{270}Hs α Decay: Tentative 2003Tu05

Parent ^{270}Hs: E=0.0; Jπ=0+; $T_{1/2}$=3.6 s *+8–14*; Q(g.s.)=9300 *70*; %α decay≈100.
^{270}Hs–Q(α): 9.30 MeV *+7–3*.
See ^{270}Hs Adopted Levels for details.

^{266}Sg Levels

E(level)	Jπ	$T_{1/2}$	Comments
0.0	0+	20 s *+20–12*	E(level),Jπ,$T_{1/2}$: from the Adopted Levels.

α radiations

Branching: from 2/2 events.

Eα	E(level)	Comments
9160‡	0.0	ΔE=+7–3.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=–2940 *SY*; S(n)=6400 *SY*; S(p)=1860 *SY*; Q(α)=9220 *40* 2003Au03,2004Mo42.
Q(β⁻): estimated uncertainty=350 keV.
S(n): estimated uncertainty=430 keV.
S(p): estimated uncertainty=210 keV.
Q(α): from Eα=9.08 MeV *4* (2004Mo42). Others: 9.55 MeV *9* (2003Au03. Syst) and 9.43 MeV from Eα=9.29 MeV (2000Wi15).
2000Wi15: chemical investigation by American–Swiss collaboration aimed at the study of ^{266,267}Bh. See Adopted Levels for ^{267}Bh for details. Reaction: ^{249}Bk(^{22}Ne,5n) at LBNL. The 88–inch cyclotron provided the $^{22}Ne^{(6+)}$ beam at two energies; 148 and 153 MeV corresponding to 116–118 MeV and 122–124 MeV respectively in the target. The target was made using 0.81 mg/cm^2 ^{249}Bk as oxide prepared by the molecular plating technique (1974Au05,1975Mu16). Chemical separation prior to this ensured that less than 0.5% of ^{249}Cf was present. Reaction products collected in a recoil chamber located directly behind the target. This chamber was continuously swept with He gas containing KCl aerosols to collect the products. The products were then guided through a TEFLON capillary (1.4 mm, 7 min in length) to the merry–go–round (MG) rotating wheel system (1990Ho03, 1996La11) with a transport time ≈0.6 s and a transport efficiency of 38% *4*. See the original sources for details of the MG and the method of data collection and analysis. One atom of ^{266}Bh was observed at the higher beam energy of 122–124 MeV followed by an α–decay sequence:
Event #1:

$E_{\alpha 1}$=9290 keV	t_1=0.87 s	– assigned to	^{266}Bh
$E_{\alpha 2}$=8540 keV	t_2=27.83 s	– assigned to	^{262}Db
$E_{\alpha 3}$=8740 keV	t_3=0.04 s	– assigned to	^{258}Lr

The cross–section estimated for the 5*n* channel was 25–250 pb. Based on an expected unhindered half–life of $T_{1/2}$≈0.5 s for this nuclide with Q(α)=9.29 MeV. Due to the experimental set–up, this cross–section was strongly dependent on the assumed ^{267}Bh half–life. The estimated half–life for ^{266}Bh was $T_{1/2}$≈1–10 s; suggested value is within 1 s. Fission decay properties of ^{266,267}Bh could not be determined due to fission contamination attributed to ^{256}Fm.
2004Mo42: great granddaughter of ^{278}113 produced by ^{209}Bi(^{70}Zn,n) E=349 MeV. See ^{278}113 Adopted Levels for details.
Event #1: Energy of the evaporation residue=36.75 MeV

$E_{\alpha 1}$=11.68 MeV *4*	t_1=344 μs	– assigned to	^{278}113
$E_{\alpha 2}$=11.15 MeV *7*	t_2=9.26 ms	– assigned to	^{274}Rg
$E_{\alpha 3}$=10.03 MeV *7*	t_3=7.16 ms	– assigned to	^{270}Mt
$E_{\alpha 4}$= 9.08 MeV *4*	t_4=2.47 s	– assigned to	^{266}Bh
E(SF)=204.1 MeV	t(SF)=40.9 s	– assigned to	^{262}Db

The assignments of 2004Mo42 are the *most probable* ones for the reaction. Also, the identification of the parent as ^{278}113, α–decay daughter ^{274}Rg, and granddaughter ^{270}Mt, are all rendered plausible following a consistent comparison of the 4th and 5th events with known descendents. The observation of each isotope in the sequence should be considered as tentative and pending confirmation.
Other: 1987ScZR.
Theory: see Nuclear Science References.
Assignment: 2004Mo42 note that the decay time measured corresponding to $T_{1/2}$=1.7 s *+82–8* agrees to within 1 standard deviation of the value reported by 2000Wi15. Also, the discrepencies in Eα(^{266}Bh) between 2000Wi15 and 2004Mo42 may be explained by the known wide spread in α energies for odd–odd nuclides in this region. However, the evaluators believe that with only two events the assignment should be considered as tentative.

^{266}Bh Levels

Cross Reference (XREF) Flags

A ^{270}Mt α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	1.7 s *+82–8*	Jπ: Ω(p)=5/2–; Ω(n)=1/2+ from 1997Mo25 (theory). $T_{1/2}$: from 2004Mo42 (1 σ). Other: 0.6 s *+29–3* from t=0.87 s (2000Wi15). $T_{1/2}$(calc)=1.7 s from Viola–Seaborg systematics for Q(α)=9.22 MeV from 2004Mo42. %α≈100. %α: assumed 100% from 2/2 events. β_2(theory): 0.230 from 1995Mo29; 0.245 from 2003Mu26; 0.262 from 2005GaZX.

^{270}Mt α Decay: Tentative 2004Mo42

Parent ^{270}Mt: E=x; Jπ=?; $T_{1/2}$=5.0 ms *+24–3*; Q(g.s.)=10180 *70*; %α decay≈100.
^{270}Mt–Q(α): from Eα=10.03 MeV *7* (2004Mo42). Other: 10.35 MeV 50 (2003Au03. Syst.).
See ^{270}Mt Adopted Levels for details.

^{266}Bh Levels

E(level)	$T_{1/2}$	Comments
x?	1.7 s *+82–8*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Branching: presumed 100% based on 1/1 event.

Eα	E(level)
10030 *70*	x?

Adopted Levels, Gammas: ?

Q(β⁻)=–6710 *SY*; S(n)=8060 *SY*; S(p)=2680 *SY*; Q(α)=10336 *20* 2003Au03.
Q(β⁻): estimated uncertainty=450 keV.
S(n): estimated uncertainty=320 keV.
S(p): estimated uncertainty=470 keV.
Q(α): adopted by 2003Au03 from Eα=10.18 MeV *2* (2001Ho06. Unweighted average of events 2, 3, 4, and 6).
2001Ho06: daughter of ^{270}Ds produced by ^{207}Pb(^{64}Ni,n) E=317 MeV at GSI/SHIP. See ^{270}Ds Adopted Levels for details.

Event # 1: (Event 5 in sequence of detection)
$E_{\alpha 1}$=10987 keV *90* t_1=0.07 ms – assigned to ^{270}Ds
$E_{\alpha 2}$= 4168 keV (esc) t_2=0.43 ms – assigned to ^{266}Hs
E_{SF}=189 MeV t_3=11.02 ms – assigned to ^{262}Sg

Event # 2: (Event 3 in sequence of detection)
$E_{\alpha 1}$=11075 keV *90* t_1=0.18 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10196 keV *20* t_2=0.87 ms – assigned to ^{266}Hs
E_{SF}=193 MeV t_3=10.26 ms – assigned to ^{262}Sg

Event # 3: (Event 1 in sequence of detection)
$E_{\alpha 1}$= 1925 keV (esc) t_1=0.20 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10173 keV *90* t_2=2.79 ms – assigned to ^{266}Hs
E_{SF}=164 MeV t_3= 8.84 ms – assigned to ^{262}Sg

Event # 4: (Event 7 in sequence of detection)
$E_{\alpha 1}$=11151 keV *20* t_1=2.00 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10171 keV *20* t_2=18.22 ms – assigned to ^{266}Hs
E_{SF}=199 MeV t_3=13.06 ms – assigned to ^{262}Sg

Event # 5: (Event 8 in sequence of detection)
$E_{\alpha 1}$=12147 keV *50* t_1=10.35 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10281 keV *90* t_2=9.63 ms – assigned to ^{266}Hs
E_{SF}=215 MeV t_3=7.77 ms – assigned to ^{262}Sg

Event # 6: (Event 2 in sequence of detection)
$E_{\alpha 1}$=10954 keV *20* t_1=17.71 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10180 keV *20* t_2=0.34 ms – assigned to ^{266}Hs
E_{SF}=190 MeV t_3=3.98 ms – assigned to ^{262}Sg

Event # 7: (Event 4 in sequence of detection)
$E_{\alpha 2}$=578 keV (esc) t_2=0.46 ms – assigned to ^{266}Hs
E_{SF}=227 MeV t_3=2.00 ms – assigned to ^{262}Sg

Event # 8: (Event 6 in sequence of detection)
$E_{\alpha 2}$=10306 keV *90* t_2=5.40 ms – assigned to ^{266}Hs
E_{SF}=177 MeV t_3=33.91 ms – assigned to ^{262}Sg

See 2001Ho06 for details regarding assignments and pertaining to ^{270}Ds. No fission event was observed which may have been attributable to ^{266}Hs.
Theory: see Nuclear Science References.
Assignment: daughter of ^{270}Ds produced by ^{207}Pb(^{64}Ni,n) E=317 MeV (2001Ho06). The daughter ^{262}Sg has not been independently observed and there are no observed elemental signatures. Therefore, the evaluators consider the assignments as tentative.

Adopted Levels, Gammas: ? (continued)

^{266}Hs Levels

2001Ho06 do not rule out the possibility that an isomeric state may exist analogous to the one in ^{270}Ds. In this case, the α–decay would have two components with half–lives: $T_{1/2}$=0.35 ms *+28–11* and 6.3 ms *+86–23* at energies calculated to be 0.90 MeV and 0.94 MeV above the ground state. On the basis of this data however, the experimenters rule out any conclusive isomeric assignments for ^{266}Hs noting that theory is only indicative. If there are two states, 2001Ak11 suggest that the 6.3–ms state is more likely to be the g.s., based on the $r_0(^{262}Sg)$ parameters calculated by using HF(10180a)=1.0: $T_{1/2}$=0.35 ms. This yields r_0=1.56 *3* which is much higher than expected from these r_0 systematics.

Cross Reference (XREF) Flags

A ^{270}Ds α Decay (0.10 ms): ?
B ^{270}Ds α Decay (6.0 ms): ?

E(level)	Jπ	XREF	$T_{1/2}$	Comments
0.0?	0+	AB	2.3 ms *+13–6*	$T_{1/2}$: from 2001Ho06. See comment above on possible existence of two components in the α–decay. The evaluators note that the unweighted averages for chains 1, 2, 3, and 7 (events 2, 3, 4, and 6 above), all four assigned to the ground state of ^{266}Hs, are τ=5.56 ms; $T_{1/2}$=3.85 ms (corresponding to Eα=10.180 MeV and Q(α)=10.335 MeV). $T_{1/2}$(calc)=2.7 ms from Viola–Seaborg systematics for Q(α)=10336 keV. The evaluators note that four of the measured α–energies from events 2, 3, 4 and 6 agree reasonably well to within the detector resolution of 20 keV (the difference in spread being about 17 keV to 25 keV over the individual energies). %α≈100; %SF<1.4. %α,%SF: from 8/8 events. Fission branching estimated to be within 1.4% in the absence of observed SF for this nucleus (2001Ho06). β_2(theory): 0.230 from 1995Mo29; 0.242 from 2003Mu26; 0.263 from 2005GaZX.
1000? *60*		B		
1200? *60*		B		

^{270}Ds α Decay (0.10 ms): ? 2001Ho06

Parent ^{270}Ds: E=0.0; Jπ=0+; $T_{1/2}$=0.10 ms *+14–4*; Q(g.s.)=11200 *50*; %α decay≈100.
See ^{270}Ds Adopted Levels for details.

^{266}Hs Levels

E(level)	Jπ	$T_{1/2}$	Comments
0.0?	0+	2.3 ms *+13–6*	E(level),Jπ,$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)
11030 *50*	0.0?

^{270}Ds α Decay (6.0 ms): ? 2001Ho06

Parent ^{270}Ds: E=1130; Jπ=?; $T_{1/2}$=6.0 ms *+82–22*; Q(g.s.)=11200 *50*; %α decay>70.0.
^{270}Ds–E: if 12.15 MeV α feeds the ^{266}Hs g.s.
^{270}Ds–J: J≈10 *2* estimated from retardation of α–decay probability (2001Ho06). π=– (2003Au02. Syst).
See ^{270}Ds Adopted Levels for details.

^{266}Hs Levels

E(level)	Jπ	$T_{1/2}$	Comments
0.0?	0+	2.3 ms *+13–6*	E(level),Jπ,$T_{1/2}$: from the Adopted Levels.
1000?† *60*			
1200?† *60*			

† From ΔE(α) (evaluators).

α radiations

Branching: %IT≈30 seems possible but could not be definitely established.

Eα	E(level)	Comments
10950‡ *20*	1200?	May correspond to α decay of the 6.0–ms state or the decay of the g.s. following γ–decay of the 6.0–ms state to the g.s. (2001Ho06).
11150‡ *20*	1000?	218γ in coincidence.
12150‡ *50*	0.0?	HF: HF=37 due to a configuration change seems reasonable (2001Ho06).

‡ Existence of this branch is questionable.

γ(^{266}Hs)

Branching: %IT≈30 seems possible but could not be definitely established.

Eγ	Comments
x218†	218γ in coincidence with 11.15 MeV α. 2001Ho06 note that Eγ is close to the calculated energy of 299 keV from the 8+ to 6+ rotational level in ^{266}Hs. α: ≈1.87 if E2 (2005KiZW,2002Ba85).

† Placement of transition in the level scheme is uncertain.
x γ ray not placed in level scheme.

Adopted Levels

S(n)=7000 *SY*; S(p)=570 *SY*; Q(α)=10996 *25* 2003Au03.
S(n): estimated uncertainty=580 keV.
S(p): estimated uncertainty=370 keV.
Q(α): 2003Au03 adopted 10996 keV *25* based on the data of 1997Ho14. Based the comments associated with the input values used in the adjustment, the 11739α and 11306α (events 6 and 8 in table below) and several lower energy α's reported by 1997Ho14 and the α's reported by 1984Mo07 and 1989Mu16 (events A and B in table below) were apparently considered as arising from the decay of an isomeric state.
No new experimental data has appeared since the last evaluation (2001Ak11).
1984Og03: ^{209}Bi(^{58}Fe,n) E=5.5 MeV/nucleon (3.6×10^{18} ions) at Dubna U400 cyclotron; off–line detection of long–lived daughters by radiochemical separation of Cm, Cf, Es, and Fm. Detected one track of ^{258}Db and seven α's from ^{246}Cf ($T_{1/2}$=35 h *+39–14*).
1997Ho14: measured excitation function of ^{209}Bi(^{58}Fe,n) E=287.6, 289.8, and 292.0 MeV at the GSI UNILAC. A cross section maximum of 7.5 pb 7 was attained (σ(287.6 MeV)=7.4 pb *+48–33*, σ(289.8 MeV)=6.1 pb *+49–29*, and σ(292.0)=2.5 pb *+25–14*). Total beam dose was 5.4×10^{18} ions in 17.4 days; absolute accuracy of beam energy was ±0.01 MeV/u.

Event 1:
$E_{\alpha 1}$=10814 keV t_1=1.8 ms – assigned to ^{266}Mt
$E_{\alpha 2}$=10213 keV t_2=11.5 ms – assigned to ^{262}Bh
ε t_3=1.18 s – assigned to ^{258}Db

Event 2:
$E_{\alpha 1}$=10661 keV t_1=1.1 ms – assigned to ^{266}Mt
$E_{\alpha 2}$= 9834 keV t_2=14.1 ms – assigned to ^{262}Bh
$E_{\alpha 3}$= 9387 keV t_3=9.6 s – assigned to ^{258}Db

Event 3:
$E_{\alpha 1}$=10576 keV t_1=0.4 ms – assigned to ^{266}Mt
$E_{\alpha 2}$=10379 keV t_2=16.7 ms – assigned to ^{262}Bh
$E_{\alpha 3}$= 9189 keV t_3=2.2 s – assigned to ^{258}Db

Event 4:
$E_{\alpha 1}$=10561 keV t_1=1.9 ms – assigned to ^{266}Mt
$E_{\alpha 2}$=10443 keV t_2=18.4 ms – assigned to ^{262}Bh
$E_{\alpha 3}$= 9380 keV t_3=0.60 s – assigned to ^{258}Db

Event 5:
$E_{\alpha 1}$=10809 keV t_1=1.3 ms – assigned to ^{266}Mt
$E_{\alpha 2}$= 9763 keV t_2=255 ms – assigned to ^{262}Bh
ε t_3=11.2 s – assigned to ^{258}Db

Event 6:
$E_{\alpha 1}$=11739 keV t_1=7.8 ms – assigned to ^{266}Mt
$E_{\alpha 2}$=6.4 MeV (esc) t_2=6.9 ms – assigned to ^{262}Bh
$E_{\alpha 3}$= 9179 keV t_3=1.85 s – assigned to ^{258}Db

Event 7:
$E_{\alpha 1}$=10456 keV t_1=4.5 ms – assigned to ^{266}Mt
$E_{\alpha 2}$=10372 keV t_2=17.3 ms – assigned to ^{262}Bh
$E_{\alpha 3}$=1.0 MeV (esc) t_3=11.2 s – assigned to ^{258}Db

Event 8:
$E_{\alpha 1}$=11306 keV t_1=2.0 ms – assigned to ^{266}Mt
$E_{\alpha 2}$=10001 keV t_2=45 ms – assigned to ^{262}Bh
$E_{\alpha 3}$=0.6 MeV (esc) t_3=1.38 s – assigned to ^{258}Db

Event 9:
$E_{\alpha 1}$=10484 keV t_1=0.2 ms – assigned to ^{266}Mt
$E_{\alpha 2}$= 9902 keV t_2=7.5 ms – assigned to ^{262}Bh
ε t_3=7.0 s – assigned to ^{258}Db

Event 10:
$E_{\alpha 1}$=11682 keV t_1=0.2 ms – assigned to ^{266}Mt
$E_{\alpha 2}$= 9831 keV t_2=278 ms – assigned to ^{262}Bh
$E_{\alpha 3}$=1.1 MeV (esc) t_3=0.11 s – assigned to ^{258}Db

Event 11:
$E_{\alpha 1}$=10859 keV t_1=0.7 ms – assigned to ^{266}Mt
$E_{\alpha 2}$= 9803 keV t_2=21.1 ms – assigned to ^{262}Bh

Event 12:
$E_{\alpha 1}$=10848 keV t_1=2.5 ms – assigned to ^{266}Mt
$E_{\alpha 2}$=10143 keV t_2=225 ms – assigned to ^{262}Bh
$E_{\alpha 3}$= 9064 keV t_3=4.19 s – assigned to ^{258}Db

Event A (1982Mu15,1984Mu07,1988Mu15,1989Mu16):
$E_{\alpha 1}$=11.10 MeV t_1=5.0 ms – assigned to ^{266}Mt
$E_{\alpha 2}$= 1.1 MeV (esc) t_2=22.3 ms – assigned to ^{262}Bh
ε t_3=12.9 s – assigned to ^{258}Db

Continued on next page

Adopted Levels (continued)

Event B (1982Mu15,1984Mu07,1988Mu15,1989Mu16):

$E_{\alpha 1}$= 5.8 MeV (esc)	t_1=4.8 ms	– assigned to ^{266}Mt
$E_{\alpha 2}$=10.21 MeV	t_2=13.2 ms	– assigned to ^{262}Bh
ε	t_3=12.9 s	– assigned to ^{258}Db

Only the decay data for the first three members of the chains are given.

1997Ho14 obtain $T_{1/2}$=1.7 ms *+6–4* from the arithmetic mean of 14 decay times.

Theory: see Nuclear Science References.

Assignment: ^{209}Bi(^{58}Fe,n) E=288–292 MeV, excit (1997Ho14). ^{209}Bi(^{58}Fe,n) E=5.5 MeV/nucleon, chem; parent of ^{258}Rf (observed SF decay of ^{258}Rf, following ^{258}Db ε decay to ^{258}Rf) (1984Og03). IUPAC/IUPAP TWG (1992Ba77) assessment was that 1982Mu15 gave confidence that element 109 had been observed. The work of 19840g03 agrees reasonably well and could be considered a confirmation.

^{266}Mt Levels

E(level)	$T_{1/2}$	Comments
x	1.7 ms *+18–16*	$T_{1/2}$: 1.7 ms *+6–4* was obtained by 1997Ho14 from the arithmetic mean of the decay time of fourteen α groups with lifetimes between 0.2 ms and 7.8 ms. 1997Ho14 pointed out that, in view of the observed isomeric states in neighboring odd–mass nuclei, the possibility of existence of isomeric states with very similar half–lives could not be excluded. Other possibilities, such as a short–lived isomer decaying in flight, were also not ruled out. Additionally, taking into account the the dispersion of the measured lifetimes resulting in the adopted value, the uncertainty of measured $T_{1/2}$ was increased by 2001Ak11. $T_{1/2}$(calc)=123 μs if Q(α)=10996 keV and 78 μs if Q(α)=11.08 MeV (Eα=10.92 MeV. Unweighted average of 13 Eα's) from Viola–Seaborg systematics. %α≤100. %α: only α decay has been observed. The SF events detected were interpreted by 1984Og03 as being from ^{258}Rf, the ε decay daughter of ^{258}Sg which is the granddaughter of ^{266}Mt by α decays. From the systematics of SF half–lives, 1984Og03 deduced that the nucleus decays mostly by α. 2000Ho27 recommended $T_{1/2}$(SF)>5.3 ms based on the data of 1988Mu15 and 1997Ho14. Calculations by 1997Mo25 for $T_{1/2}(\alpha)/T_{1/2}(\beta)$ predict %ε+%β^+=0.48. β_2(theory)=0.230 from 1995Mo29; β_2=0.237 from 2003Mu26; β_2=0.255 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=−790 *SY*; S(n)=4740 *SY*; S(p)=5220 *SY*; Q(α)=7800 *SY* 2003Au03.
Q(β⁻): estimated uncertainty=740 keV.
S(n): estimated uncertainty=790 keV.
S(p): estimated uncertainty=870 keV.
Q(α): estimated uncertainty=300 keV other: 2004Og12 estimate Q(α)≤8.22 MeV.
2004Og12,2004OgZZ: as α decay product of ^{287}114 (15 events) and ^{283}112 (7 events). See for ^{287}114 and ^{283}112 Adopted Levels for details. ^{287}114 was synthesized using ^{242}Pu+^{48}Ca at beam energies of 235, 238 and 244 MeV with 5 measurements made at each energy. ^{283}112 was observed using ^{238}U+^{48}Ca at 230 and 234 MeV. One special case attributed to ^{287}114 in the ^{242}Pu reaction at a beam energy of 244 MeV, lasting for 6.5 min, of the type EVR–α1–α2–α3–α4–SF warrants mention. Generally, α decay is blocked below ^{279}Ds which fissions rather than α decays (%α≈10). The evaluators suggest that this longer chain which terminates with ^{271}Sg may, if confirmed, be one incidence of this 10% branch. The α energy for ^{279}Ds from this event is 9.7 MeV *6* with a lifetime of 0.2831 s. Another exception to the fissioning of ^{279}Ds appears in the case of a similar EVR–α1–α2–α3–α4–SF event originating from ^{283}112 in the ^{238}U reaction at 234 MeV. Here, the sequence ends with the fission of ^{267}Rf. The α energy for ^{279}Ds from this event is 9.8 MeV *3* with a lifetime of 0.2775 s. Although both exceptions require further investigation, their radioactive properties agree well with each other and the evaluators suggest that if confirmed, they could represent the 10% α decay branch for ^{279}Ds. Estimated Q(α)≤8.22 MeV for α–decay branch if it exists.
2005Gr19, 2002Lo15: no EVR–α–α correlations with Δt(EVR–α)<20 s or Δt(α–α)<20 s were observed in any of the ^{48}Ca + ^{238}U irradiations. See ^{283}112 Adopted Levels for details.
Theory: see Nuclear Science References.
Assignment: the assignments for Z=112, Z=114 (and Z=116) and their daughters are based on measured excitation functions and in some cases consistency of observed properties produced by cross–bombardments. In particular, the decay properties of ^{283}112 are consistent through the various measurements using the DGFRS, independent of whether they were observed as primary nuclei or as α decay daughters of parents one (Z=114) or two (Z=116) 'levels' up. In the case of ^{287}114, the second α in the decay chain has an energy of 9.54 MeV *6* which agrees well with the four measured α's (2004Og07, 20040g12) in 11 out of 14 cases. The other three α energies are 8.94, 9.36 and 9.32 MeV which the experimenters suggest may be indicative of transitions to different excited states in the daughter nucleus ^{279}Ds. Note that 2005Gr19 did not observe any SF decays or EVR–α–α correlations in any ^{48}Ca + ^{238}U irradiations.

^{267}Rf Levels

Cross Reference (XREF) Flags

A ^{271}Sg α Decay: Tentative

E(level)	XREF	Comments
x?	A	Jπ: Ω(n)=13/2− from 1997Mo25 (theory). $T_{1/2}$=2.3 h *+110–11*. $T_{1/2}$: from one SF event (evaluators. $\Delta T_{1/2}$ at 68% confidence level). 2.3 h *+980–17* (2004Og12) if 95% confidence level used. $T_{1/2}$(calc)=2.5 h from Viola–Seaborg systematics for Q(α)=7.8 MeV if α–decay branch. %SF≈100. %SF: presumed from one SF event (2004Og12). β_2(theory): 0.221 from 1995Mo29; 0.248 from 2005GaZX.

^{271}Sg α Decay: Tentative 2004Og12

Parent ^{271}Sg: E=x; Jπ=?; $T_{1/2}$=2.4 min *+43–10*; Q(g.s.)=8660 *80*; %α decay≈50.0.
^{271}Sg–$T_{1/2}$: from 2004Og12.
^{271}Sg–Q(α): from 2004Og12.
See ^{271}Sg Adopted Levels for details.

^{267}Rf Levels

E(level)	Comments
x?	$T_{1/2}$=2.3 h *+110–11*. E(level),$T_{1/2}$: from the Adopted Levels.

Adopted Levels: Tentative

Q(β⁻)=–1910 *SY*; S(n)=6820 *SY*; S(p)=3170 *SY*; Q(α)=7900 *SY* 2003Au03.
Q(β⁻): estimated uncertainty=540 keV.
S(n): estimated uncertainty=590 keV.
S(p): estimated uncertainty=710 keV.
Q(α): estimated uncertainty=300 keV.
2003OgZY and 2004Og03: identification of new nuclides: ^{287}115, ^{283}113, ^{279}Rg, ^{275}Mt and ^{267}Db. ^{267}Db is the final nuclide observed in the ^{287}115 decay produced *via* ^{243}Am(^{48}Ca,4n) E=253 MeV. The α decay of its parent, ^{271}Bh, was not observed. See ^{287}115 Adopted Levels for for experimental details.
Reaction: ^{243}Am(^{48}Ca,4n) E=253 MeV corresponding to an excitation energy of 42.4 to 46.5 MeV at the target center. ^{287}115 was formed at a cross–section of 0.9 pb *+32–8*.
Energy of the evaporation residue=12.2 MeV
E_{SF}=206 MeV t=105.96 min – assigned to ^{267}Db
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: the evaluators note that the identification of Z=115 and all associated nuclides in the chain should be treated as tentative until confirmed in independent experiments.

^{267}Db Levels

E(level)	Comments
x?	Jπ: Ω(p)=1/2– from 1997Mo25 (theory). $T_{1/2}$=73 min *+350–33*. $T_{1/2}$: from one SF event (2004Og03). $T_{1/2}$(calc)=155 min from Viola–Seaborg systematics for Q(α)=7.9 MeV if a–branch assumed. %SF≈100. %SF: from 1/1 event (2004Og03). β_2(theory): 0.230 from 1995Mo29; 0.234 from 2003Mu26; 0.267 from 2005GaZX.

Adopted Levels

Q(β⁻)=–3860 *SY*; S(n)=7410 *SY*; S(p)=2090 *SY*; Q(α)=8964 *30* 2003Au03,2000Wi15.
Q(β⁻): estimated uncertainty=280 keV.
S(n): estimated uncertainty=330 keV.
S(p): estimated uncertainty=390 keV.
Q(α): from quoted average energy (5 events) Eα=8.830 MeV *3* (2000Wi15). Others: 8957 keV from Eα=8823 keV (2000Ei05, uncertainties not stated; as estimated by evaluators, unweighted average of 6 events); 8959 keV from Eα=8825 keV (evaluators; unweighted average of 11 events) and 9370 keV *200* from systematics (2003Au03).

1984Zv02, 1995Sc53: chemical investigations based on the premise that Bh is a member of Group VII of the periodic table. These comprised the first two attempts made to chemically study Bh using an oxide hydroxide form. Reactions: ^{249}Bk(^{22}Ne,4n) (1984Zv02) and ^{254}Es(^{16}O,3n) (1995Sc03). The attempts were unsuccessful due to insufficient sensitivity of the set–up (also 2005ScZZ). They are mentioned here for completeness.

2000Wi15: chemical investigation by American–Swiss collaboration aimed at the study of ^{266,267}Bh; see data set for ^{266}Bh for details. Reaction: ^{249}Bk(^{22}Ne,5n) at LBNL. The 88–inch cyclotron provided the ^{22}Ne$^{(6+)}$ beam at two energies; 148 and 153 MeV corresponding to 116–118 MeV and 122–124 MeV respectively in the target. The target was made using 0.81 mg/cm^2 ^{249}Bk as oxide prepared by the molecular plating technique (1974Au05,1975Mu16). Chemical separation prior to this ensured that less than 0.5% of ^{249}Cf was present. Reaction products collected in a recoil chamber located directly behind the target. This chamber was continuously swept with He gas containing KCl aerosols to collect the products. The products were then guided through a TEFLON capillary (1.4 mm, 7 min in length) to the merry–go–round (MG) rotating wheel system (1990Ho03, 1996La11) with a transport time ≈0.6 s and a transport efficiency of 38 ± 4%. See the original sources for details of the MG and the method of data collection and analysis. A total of five α–decay sequences were observed attributed to ^{267}Bh: three atoms at an incident energy of 116–118 MeV and two more events at the higher beam energy of 122–124 MeV. The corresponding cross–sections were 58 pb *+33–15*, and 96 pb *+55–25*, respectively, assuming α's as the primary decay mode. It was not possible to determine if more than one ^{267}Bh α–group was present. In all cases, properties of the daughter nuclei were consistent with ^{263}Db ($T_{1/2}$=27 s, Eα=8.35 MeV) and ^{259}Lr ($T_{1/2}$=6.34 s, Eα=8.45 MeV). Fission decay properties of ^{266,267}Bh could not be determined due to fission contamination attributed to ^{256}Fm.

Event #1 (Beam energy 116–118 MeV):
$E_{\alpha 1}$=8.83 MeV t_1=5.26 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.47 MeV t_2=59.04 s – assigned to ^{263}Db or ^{259}Lr
Event #2 (Beam energy 116–118 MeV):
$E_{\alpha 1}$=8.87 MeV t_1=24.67 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.39 MeV t_2=35.02 s – assigned to ^{263}Db
Event #3 (Beam energy 116–118 MeV):
$E_{\alpha 1}$=8.87 MeV t_1=45.15 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.39 MeV t_2=24.49 s – assigned to ^{263}Db
Event #4 (Beam energy 122–124 MeV):
$E_{\alpha 1}$=8.73 MeV t_1=2.71 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.46 MeV t_2=51.90 s – assigned to ^{263}Db or ^{259}Lr
Event #5 (Beam energy 122–124 MeV):
$E_{\alpha 1}$=8.84 MeV t_1=21.83 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.36 MeV t_2=26.49 s – assigned to ^{263}Db

The experimenters estimate that one in five α–α correlations reported for the present nucleus is random. Based on this it was further estimated that 0.0016 triple–α correlations are random.

2000Ei05: an international collaboration performed this chemical investigation at the Paul Scherrer Institute in Switzerland using online gas chromatography on the relevant oxychlorides. Reaction: ^{249}Bk(^{22}Ne,4n) at a beam energy at target center of 119 MeV *1*. The target was prepared at LBNL and the ^{22}Ne beam was provided by the Phillips Cyclotron at the Paul Scherrer Institute. The target was irradiated over 4 weeks by 1.6×10^{12} ions per second. ^{176}Re was simultaneously produced in the reaction 259Tb(^{22}Ne,5n) which served as a yield monitor for the chemical separation process. All reaction products were transported *via* C–aerosol clusters to the OLGA III (online gas chromatographic apparatus) (1991Ga28) coupled to ROMA (rotating wheel multidetector analyzer). Six genetically linked α–decay chains were observed four at an isothermal temperature of 180° C (beam dose 1.02×10^{18} ^{22}Ne ions), two at 150° C (beam dose 1.0×10^{18} ^{22}Ne ions) and none at 75° C (beam dose 1.0×10^{18} ^{22}Ne ions). The events included three of the α–SF type and one with α1–α2–SF. Due to the passage of a fraction of ^{212}Pb/^{212}Bi through the chromatography column decays from ^{212}Po (Eα=8.785 MeV) partially obscured the detection of ^{267}Bh. It was estimated that 1.3 of the 4 chains observed at the isothermal temperature of 180° C were due to random correlations. Upon evaluating the relative yields of ^{267}Bh at all three isothermal temperatures, and taking into account the random correlation factor, the experimenters adopted the yield observed at 180° C as the 100% 'relative' yield.

Continued on next page

Adopted Levels (continued)

Event #1 (Isothermal temperature 150° C):
$E_{\alpha 1}$=8.81 MeV t_1=24.5 s – assigned to ^{267}Bh
E_{SF}=82 MeV t(SF)=21.1 s – assigned to ^{263}Db
Event #2 (Isothermal temperature 150° C):
$E_{\alpha 1}$=8.85 MeV t_1=34.4 s – assigned to ^{267}Bh
E_{SF}=46 MeV t(SF)=98.9 s – assigned to ^{263}Db
Event #3 (Isothermal temperature 180° C):
$E_{\alpha 1}$=8.72 MeV t_1=2.9 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.40 MeV t_2=29.9 s – assigned to ^{263}Db
Event #4 (Isothermal temperature 180° C):
$E_{\alpha 1}$=8.84 MeV t_1=26.7 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.35 MeV t_2=73.4 s – assigned to ^{263}Db
Event #5 (Isothermal temperature 180° C):
$E_{\alpha 1}$=8.91 MeV t_1=10.5 s – assigned to ^{267}Bh
$E_{\alpha 2}$=8.37 MeV t_2=0.8 s – assigned to ^{263}Db
$E_{\alpha 3}$=8.41 MeV t_3=14.6 s – assigned to ^{259}Lr
Event #6 (Isothermal temperature 180° C):
$E_{\alpha 1}$=8.81 MeV t_1=18.4 s – assigned to ^{267}Bh
E_{SF}=101+86 MeV t(SF)=16.3 s – assigned to ^{263}Db

The purpose of this experiment was the chemical study and characterisation of Bh in the form of its oxychloride. It was possible to conclude that Bh, presumably from BhO_3Cl behaves like a typical member of Group VII of the periodic table. It shows a lower volatility than its Re or Tc homologues as expected. The standard adsorption enthalpy of BhO_3Cl was evaluated to be –75 kJ mol^{-1} *+9–6* (68% c.i.) with $T_{1/2}$=17 s for this nucleus.

Other: 2002Tu05.

Theory: see papers above, 2003GaZR, and Nuclear Science References.

Assignment: ^{249}Bk(^{22}Ne,4n), E=117 MeV *1* and 123 MeV *1*, chem (2000Wi15); ^{249}Bk(^{22}Ne,4n), E=119 MeV *1*, chem (2000Ei05). The two sets of data agree well, and when taken together are consistent.

^{267}Bh Levels

E(level)	$T_{1/2}$	Comments
x	17 s *+14–6*	Jπ: Ω(p)=5/2– from 1997Mo25 (theory). $T_{1/2}$: from 2000Wi15 using maximum–likelihood technique (1991Gr05). $T_{1/2}$=14 s *+10–4* for six events (from 2000Ei05 by evaluators; uncertainties not reported by experimenters) in agreement taking into account uncertainties. Combining all 11 events, $T_{1/2}$=14 s *+6–4* (evaluators) in agreement taking into account uncertainties. $T_{1/2}$(calc)=10.7 s from Viola–Seaborg systematics if Q(α)=8964 keV and 0.62 s if Q(α)=9.37 MeV. %α≈100. %α: from 11/11 events. Fission decay properties of ^{267}Bh could not be determined by 2000Wi15 due to fission contamination attributed to ^{256}Fm. β_2(theory): 0.230 from 1995Mo29; 0.240 from 2003Mu26; 0.270 from 2005GaZX.

Adopted Levels

Q(β⁻)=–5140 *SY*; S(n)=6500 *SY*; S(p)=2770 *SY*; Q(α)=9978 *20* 2003Au03,1998Ho13.

Q(β⁻): estimated uncertainty=550 keV.

S(n): estimated uncertainty=300 keV.

S(p): estimated uncertainty=230 keV.

Q(α): from Eα=9829 keV *20* (1998Ho13). Other: 10120 keV *70* (2003Au03. Syst.); 10000 keV from average Eα=9850 keV (2004Mo40).

2000Fi12 cite 1996He07 which does not contain any information on ^{267}Hs. The evaluators believe this was a preliminary result of the work finally reported in 1998Ho13 and cited as a private communication, reference 20 in 1995La20.

1995La20: ^{267}Hs produced by ^{238}U(^{34}S,5n) E=186 MeV at Dubna. The Z=108 compound nuclei were produced at an excitation energy of about 50 MeV to allow for the evaporation of 4 or 5 neutrons required to create ^{267}Hs. The evaporation residues (EVR's) were separated by the Dubna Gas Filled Recoil Separator (DGFRS; see 1996LaZY for details) filled with hydrogen to a pressure of 1.0 torr. These separated EVR's passed through a time–of–flight (tof) system composed of two multiwire proportional chambers in a 1.5 torr pentane filled module, and were finally implanted in a 120×40 mm^2 position sensitive detector (psd) array. The cross–section for the reaction was 2.5 pb with an estimated uncertainty of ≈3. Three time and position correlated chains of α particle events were observed and ascribed to the decay of ^{267}Hs. The energies were E1=9740 keV *60*, E2=9860 keV *60*, and 9870 keV *60*. The calculated maximum likelihood half–life was $T_{1/2}$=19 ms *+29–10*. Two other correlated out–of–beam events linking the decays of ^{263}Sg, ^{259}Rf, and ^{255}No were observed. Nine EVR–SF event pairs were also observed with no apparent connection to the preceding hs decays. The most probable origin of these decays could be the 0.9 ms SF isomer of ^{240}Am with smaller contributions possibly from the 14–ms ^{242}Am and 1.0–ms ^{244}Am produced in transfer reactions with cross–sections of the order of 10–100 nb (see 1989OgZU).

1998Ho13: daughter of ^{271}Ds produced by ^{208}Pb(^{64}Ni,n). See ^{271}Ds adopted levels for experimental details. A total number of 38 α–decays were measured and assigned to nine decay chains of Ds. Decay of ^{271}Ds by consistency of lower chain member energies and lifetimes with known ^{255}No, ^{259}Rf, and ^{263}Sg data. The measured α energies and emission times are grouped as follows: five events with an average energy of E1=10738 keV *20*, two events with an average energy of E2=10682 keV *20*, one escape and one event with energy E3=10709 keV *20* with a long life–time of 81 ms corresponding to a half–life of 56 ms *+270–26*. The emission times for the first two groups were 0.2–4.4 ms and 81 ms for the last event which 1998Ho13 take as being a sign of an isomeric state in ^{271}Ds. The second member of each chain corresponds to decay of ^{267}Hs. 1998Ho13 also suggest the existence of two ^{267}Hs daughter states.

2003Gi05: daughter of ^{271}Ds produced by ^{208}Pb(^{64}Ni,n). Confirmation of ^{271}Ds was reported by experiments done at LBNL. See ^{271}Ds Adopted Levels for experimental details. Two position and time correlated event chains were assigned to ^{271}Ds. No such event sequences were seen at the other two beam energies. The two corresponding ^{267}Hs α decay energies originating from 1.6–ms ^{271}Ds were 9.89 MeV (following α decay) and 9.88 MeV (following an escape event) Both these states decay to 0.12–s ^{263}Sg with life–times of 15 ms and 32 ms, respectively.

2004Fo08: daughter of ^{271}Ds produced by ^{208}Pb(^{64}Ni,n). See ^{271}Ds Adopted Levels for experimental details. Data are in good agreement with 1998Ho13, 2003Gi05, and 2004Mo40. Seven chains observed; average energy of α's assigned to ^{267}Hs in three chains 9877 keV consistent with the known 9882–keV transition. The full energy 9830 α event in another chain can be assigned to the known 9829–keV transition.

2004Mo40,2004Mo27: daughter of ^{271}Ds produced by ^{208}Pb(^{64}Ni,n). See ^{271}Ds adopted levels for experimental details. A total of 14 decay chains attributed to the decay of ^{271}Ds over three experiments. 13 decays detected as second generation decays were attributed to ^{267}Hs and the results are in agreement with 1998Ho13. Evidence has been offered for an isomeric state in the daughter ^{267}Hs. See also 2004Mo43.

Theory: see Nuclear Science References.

Assignment: ^{238}U(^{34}S,5n), E=186 MeV; grandparent of ^{259}Rf (Eα=8.80 MeV *2*, $T_{1/2}$=2.6 s) and ^{255}No (Eα=8.10 MeV *2*, $T_{1/2}$=110 s) from 1995La20. Confirmed by 1998Ho13 as daughter of ^{271}Ds produced ^{208}Pb(^{64}Ni,n), E=311.7 MeV, 313.0 MeV, and 315.5 MeV.

Adopted Levels (continued)

^{267}Hs Levels

$T_{1/2}$(calc)=24.1 ms from Viola–Seaborg systematics support 52–ms state as being the g.s.

2004Fo08, based on the observation of two short ^{267}Hs lifetimes (0.482 ms and 2.45 ms), suggest the possibility of a short–lived ^{267}Hs state with $T_{1/2}$=0.94 ms *+12–450*. This state was not reported in the earlier work of 1998Ho13 and 2004Mo40.

Cross Reference (XREF) Flags

A ^{271}Ds α Decay (1.63 ms)
B ^{271}Ds α Decay (69 ms)

E(level)	XREF	$T_{1/2}$	Comments
0.0	AB	52 ms *+13–8*	Jπ: 1998Ho13 propose 9/2+ as the analog Nilsson state of the ^{271}Ds 9/2+[615]. 2003Au02 suggest 3/2+ based on systematics. $T_{1/2}$: mean value obtained by 2004Mo40 from τ=77 ms *+31–7* (2004Mo40) and τ=72 ms *+28–16* (1998Ho13). Others: maximum likelihood $T_{1/2}$=19 ms *+29–10* (1995La20) and 55 ms *+32–18* (2004Fo08; calculated using MLDS code). 2000Fi12 adopted 26 ms *+20–10*, an average (unweighted?) of 19 ms *+29–10* (1995La20) and 33 ms *+19–9* (from reference 20 in 1995La20). $T_{1/2}$(calc)=24.1 ms from Viola–Seaborg systematics for Q(α)=9.98 MeV. Predicted $T_{1/2}(\beta^+)$=38.1 s (1997Mo25; finite–range droplet model, folded–Yukawa single particle potential); $T_{1/2}$(α)=17.4 s and $T_{1/2}$(SF)=17.4 s (1995Ho27; syst.). %α≥80; %SF<20 (1995La20). %SF: estimated from lack of observed SF (1995La20). %ε+%β^+=18.6, %α=40.7, and %SF=40.7 from predicted partial $T_{1/2}$'s not consistent. β_2(theory):0.230 from 1995Mo29; 0.240 from 2003Mu26; 0.262 from 2005GaZX.
57? *7*	A		Reported by 1998Ho13 but not by 2004Mo40. E(level): from 1.63–ms ^{271}Ds α decay. Jπ: 1998Ho13 propose Jπ=11/2+ for 69–ms ^{271}Ds as a member of the 9/2[615] band corresponding to the 10.681 MeV transition to the first rotational state also with 11/2+ in ^{267}Hs.
x?	B		Reported by 2004Mo40 but not by 1998Ho13. Based on the long decay time (5999 ms) of the 9.31–MeV ^{263}Sg α associated with the the decay of this state, 2004Mo40 suggests that an isomeric state of ^{263}Sg may be fed. This event had Q(α)=9.88 MeV, Eα=9.73 MeV (chain #3). $T_{1/2}$=0.80 s *+380–37*. $T_{1/2}$: from 2004Mo40 corresponding to an α–decay energy of 10.44 MeV *6* from the decay of the 69–ms ^{271}Ds level. %α>0 (2004Mo40).

^{271}Ds α Decay (1.63 ms) 1998Ho13,2004Mo40

Parent ^{271}Ds: E=0; Jπ=?; $T_{1/2}$=1.63 ms *+44–29*; Q(g.s.)=10899 *20*; %α decay≈100.

^{271}Ds–Q(α): 2003Au03 adopted 10870 keV *20* assuming the 69–ms state of ^{271}Ds was the ground state.

1998Ho13: see ^{271}Ds Adopted Levels for experimental details. The measured α energies and emission times were as follows: five events with an average energy of E1=10738 keV *20*, two events with an average energy of E2=10682 keV *20* and one event with energy E3=10709 keV *20*. The emission times for the first two groups were 0.2–4.4 ms and 81 ms for the last event which 1998Ho13 take as being a sign of an isomeric state in ^{271}Ds. The second member of each chain corresponds to decay of ^{267}Hs. 1998Ho13 also suggest the existence of two ^{267}Hs daughter states.

2004Mo40,2004Mo27: see ^{271}Ds Adopted Levels for details. A total of 14 decay chains attributed to the decay of ^{271}Ds over three experiments. The energy centers of peaks in the α spectra were deduced to be at 10.45 and 10.73 MeV; the latter is in good agreement with 10.74 MeV from 1998Ho13. Measured lifetimes of the α's from ^{271}Ds could be divided into two groups; one with decay times less than 10 ms (11 events) and another with decay times greater than 10 ms (3 events). The mean lifetimes for both groups agree with the results of 1998Ho13 as do the number ratios of the two groups: 11/3 (2004Mo40) and 11/2 (1998Ho13).

Other: 2004Fo08.

^{267}Hs Levels

Decay scheme from 1998Ho13 who propose Jπ=11/2+ for 69–ms ^{271}Ds as a member of the 9/2[615] band corresponding to the 10.681 MeV transition to the first rotational state also with 11/2+ in ^{267}Hs.

E(level)	$T_{1/2}$	Comments
0.0	52 ms *+13–8*	E(level),$T_{1/2}$: from the Adopted Levels.

Continued on next page (footnotes at end of table)

^{271}Ds α Decay (1.63 ms) 1998Ho13,2004Mo40 (continued)

^{267}Hs Levels (continued)

E(level)	Comments
57? *7*	Not reported by 2004Mo40. E(level): from ΔE(α).

α radiations

1998Ho13 derive HF(10738α)≈3 and HF(10682α)≈6 using theoretical $T_{1/2}$'s calculated by the WKB method with the potentials of 1959Ig05.

Eα†	E(level)	Iα‡§
10682# *20*	57?	≈29
10738 *20*	0.0	≈71

† From 1998Ho13 (relative uncertainties of 3 keV for 10738 and 6 keV for 10682 α). Eα to g.s. in good agreement with 10.73 MeV from 2004Mo40.
‡ Based on five events for 10.74–MeV and two events for 10.68–MeV α's.
§ For α intensity per 100 decays, multiply by ≈1.00.
# Existence of this branch is questionable.

^{271}Ds α Decay (69 ms) 1998Ho13,2004Mo40

Parent ^{271}Ds: E=x; Jπ=?; $T_{1/2}$=69 ms *+56–21*; Q(g.s.)=10899 *20*; %α decay≤100.
^{271}Ds–Q(α): 2003Au03 adopted 10870 keV *20* assuming the 69–ms state of ^{271}Ds was the ground state.
1998Ho13: see ^{271}Ds Adopted Levels for experimental details. The measured α energies and emission times were as follows: five events with an average energy of E1=10738 keV *20*, two events with an average energy of E2=10682 keV *20* and one event with energy E3=10709 keV *20*. The emission times for the first two groups were 0.2–4.4 ms and 81 ms for the last event which 1998Ho13 take as being a sign of an isomeric state in ^{271}Ds. The second member of each chain corresponds to decay of ^{267}Hs. 1998Ho13 also suggest the existence of two ^{267}Hs daughter states.
2004Mo40,2004Mo27: see ^{271}Ds Adopted Levels for details. A total of 14 decay chains attributed to the decay of ^{271}Ds over three experiments. The energy centers of peaks in the α spectra were deduced to be at 10.45 and 10.73 MeV; the latter is in good agreement with 10.73 MeV from 1998Ho13. Measured lifetimes of the α's from ^{271}Ds could be divided into two groups; one with decay times less than 10 ms (11 events) and another with decay times greater than 10 ms (3 events). The mean lifetimes for both groups agree with the results of 1998Ho13 as do the number ratios of the two groups: 11/3 (2004Mo40) and 11/2 (1998Ho13).

^{267}Hs Levels

Decay scheme from 2004Mo40. 10.71–MeV α from 69–ms ^{271}Ds observed by 1998Ho13 but not assigned as feeding 0.8–s ^{267}Hs state.

E(level)†	$T_{1/2}$†	Comments
(0.0)	52 ms *+13–8*	
x?		Not reported by 1998Ho13. $T_{1/2}$=0.80 s *+380–37*.

† From the Adopted Levels.

α radiations

Branching: to explain the decay properties of ^{271}Ds, 2004Mo40 suggest the 69–ms level decays by an isomeric transition to the g.s. of ^{271}Ds and also α decays to the possible isomeric state in ^{267}Hs.

Eα	E(level)	Comments
10440‡ *60*	x?	Eα: from 2004Mo40.

Continued on next page (footnotes at end of table)

^{271}Ds α Decay (69 ms) 1998Ho13,2004Mo40 (continued)

α radiations (continued)

Eα	Comments
10709 *20*	Eα: from 1998Ho13; in good agreement with 10.71 MeV from 2004Mo40. From the discussion in 1998Ho13 and a comparison of Eα to Eα=10738 *20* for 1.63–ms ^{271}Ds α decay, this α transition does not appear to to feed the ^{267}Hs g.s. HF: HF=105 from 1998Ho13 using theoretical $T_{1/2}$'s calculated by the WKB method with the potentials of 1959Ig05.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

S(p)=730 *SY*; Q(α)=12280 *SY* 2003Au03.
S(p): estimated uncertainty=500 keV.
Q(α): estimated uncertainty=110 keV.
1995Gh05,1995Gh04: Berkeley/SASSY2 cold fusion experiment. ^{209}Bi(^{59}Co,n) E=5.1 MeV/A. Total of 1.5×10^{18} projectile particles. Observed one position and time correlated chain of α particles. Determined α energies and time intervals between successive particles. The event corresponded to a production cross–section of ≈1 pb. Data consistent with decay of ^{267}Ds assuming that the granddaughter ^{259}Sg decays by ε to produce known ^{259}Db and ^{255}Lr. The measured α energy and emission time for the event were E1=11.60 MeV *10* (Q(α)=11.78 MeV *10*), t1=4 μs. Decay of ^{263}Hs missed due to a malfunctioning transient recorder. 1995Gh05 suggest that the next member of the chain, ^{259}Sg, undergoes undetected ε decay to ^{259}Db. This nuclear assignment relies on the observation of ^{259}Db and ^{255}Lr. ^{263}Hs, the expected daughter is unknown and was not observed; the grand–daughter ^{259}Sg is known but was not observed by 1995Gh05. The 2.2 MeV α was interpreted by 1995Gh05 as a partial escape peak attributed to ^{259}Db (assumed to be the ε daughter of ^{259}Sg). Finally, 1999Ar21 point out that the possibility of the observed 11.6 MeV α belonging to ^{212}Po cannot be ruled out.
Assignment: IUPAC/IUPAP JWP assessment (2001Ka70): there were experimental difficulties and other problems associated with this experiment. Therefore, the evaluators consider the assignment to ^{267}Ds as tentative.

^{267}Ds Levels

E(level)	Comments
x?	Jπ: 2003Au02 suggest 9/2+ from systematics. Ω(n)=11/2– from 1997Mo25 (theory). $T_{1/2}$=2.8 μs *+133–12*. $T_{1/2}$: from t1=4 μs (1995Gh05); uncertainty estimated by the evaluators. $T_{1/2}(\alpha)$=300 μs predicted by 1997Mo25 (finite–range droplet model, folded–Yukawa single particle potential). Other: 2.8 μs *+130–13* (2003Au02) and 3 μs *+6–2* (2000Fi12). $T_{1/2}$(calc)=0.34 μs from Viola–Seaborg systematics for Q(α)=12.28 MeV and 3.9 μs for Q(α)=11.78 MeV. %α≈100. %α: from one event. Predicted β (1997Mo25; finite–range droplet model, folded–Yukawa single particle potential) and SF (1995Ho27, systematics, and 1997Sm03, macroscopic–microscopic model) half–lives much longer than those predicted and observed for α emission. No spontaneous fission events observed in 1995Gh05. β_2(theory): 0.220 from 1995Mo29; 0.234 from 2003Mu15; 0.254 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=–150 *SY*; S(n)=5210 *SY*; S(p)=3640 *SY*; Q(α)=8200 *SY* 2003Au03.
Q(β⁻): estimated uncertainty=760 keV.
S(n): estimated uncertainty=710 keV.
S(p): estimated uncertainty=780 keV.
Q(α): estimated uncertainty=300 keV.

2003OgZY and 2004Og03: identification of new nuclides: ^{288}115, ^{284}113, ^{280}Rg, ^{276}Mt, ^{272}Bh, and ^{268}Db. ^{268}Db observed as α–decay daughter of parent ^{272}Bh and α–decay grand–daughter of ^{276}Mt. Reaction: ^{243}Am(^{48}Ca,3n) E=248 MeV corresponding to an excitation energy of 38.0 to 42.5 MeV at the target center. Experiments performed by the Dubna–LLNL collaboration. ^{288}115 was formed at a cross–section of 2.7 pb *+48–16*.

Experiments were done at the U400 cyclotron with the Dubna gas–filled recoil seperator (DGFRS) at FLNR–JINR. The evr's recoiling from the target were separated by DGFRS in flight from the ^{48}Ca beam ions, scattered particles and transfer–reaction products with a transmission efficiency of 35% for 115 nuclei.

Detection system: multiwire proportional counter for tof measurement; semi–conductor focal–plane detector array with 12 vertical position– sensitive strips, which measured the decay of the implanted recoils. This detection system surrounded by eight side detectors with no position sensitivity. The α spectrum was measured in the range 9.6 to 11.0 MeV. The resolution of the detector system was FWHM=60–100 keV for α particles absorbed in the focal–plane detector; 140–200 keV for α's escaping the focal–plane detector and registered by the side detectors.

Three similar decay chains with five consecutive α decays were detected in a time interval of 20 s (in the beam–off mode following the first recoil expected to belong to Z=115) terminated by an SF event with a release of total kinetic energy of ≈220 MeV. These events were assigned to the (^{48}Ca,3n) channel with the production of the parent nuclide ^{288}115; the sixth and final event in the chain was assigned to ^{268}Db which decays by SF/electron capture (ε). Properties of ^{268}Db from the three chains are listed below by event. The identification of Z=115 and 113 and all associated nuclides in the chain should be treated as tentative until confirmed by independent experiments.

Event #1: Energy of the evaporation residue=10.4 MeV
E_{SF}=150+55 MeV=205 MeV t=28.69 h – assigned to ^{268}Db
Event #2: Energy of the evaporation residue=11.0 MeV
E_{SF}=148+52 MEV=200 MeV t=23.54 h – assigned to ^{268}Db
Event #3: Energy of the evaporation residue=9.1 MeV
E_{SF}=140 MEV t=16.8 h – assigned to ^{268}Db
Total TKE for fission fragments ≈220 MeV.

2004DmZZ: chemical identification of Db as α decay product of Z=115 carried out in Dubna in collaboration with scientists from Switzerland and USA. Radiochemical separation by isolation of Group V elements for Z=105 at FLNR/JINR using the U400 cyclotron in June 2004. A 32 cm^2 rotating target was made from 99.9% enriched ^{243}Am in oxide form deposited on a 1.5 μm Ti foil to a thickness of 1.2 mg/cm^2 of ^{243}Am. The ^{48}Ca beam impinged on the target center at an energy of 247 MeV with an average intensity of 5×10^{12} ions/sec. Recoils from the reaction products were passed through a collimator and stopped in a copper catcher 50 mm in diameter with an estimated collection efficiency of close to 100%. A total of 8 identical runs were made over 20 to 45 hours. Following each irradiation and after cleaning, micro–cuts of the upper layer were radiochemically analyzed for Group V elements after dissolving these micro–layers in a solution of HNO_3. α–particles and SF fragments were detected (efficiency for fission fragments ≈90%) by placing the sample in a detector arrangement consisting of four identical chambers each with two semi– conductor detectors, all placed within a neutron detector (efficiency ≈40%). In eight runs with a total beam dose of 3.4×10^{18} ^{48}Ca ions, 15 SF events were detected over 910 hours. The total TKE for fission and $T_{1/2}$(SF) are:

TKE=235 MeV $T_{1/2}$(SF)=32 h *+11–7*

The average neutron multiplicity (ν) per fission was ≈4.2. The ninth experiment was carried out under similar conditions but with no chemical separation of products, to determine SF background. An analysis of all data lead to the unambiguous conclusion that all 15 events were due to ^{268}Db. Deduced cross–section: ≈4 pb in reasonable agreement with DGFRS value for 3*n* channel ≈3 pb. Separation efficiency for chemical study was ≈80% as compared to ≈35% using kinematic techniques (DGFRS, 2004Og03).

The evaluators suggest that this experiment offers independent support for the synthesis of Z=115 and its decay products as suggested by this collaboration in 2004Og03. The experimenters note that yield of super–heavy isotopes provided by this method is a factor of 5 higher than that realized by kinematic techniques.

Other data: ^{248}Cm average TKE=181 MeV, ν=3.14; ^{252}Cf average TKE=185 MeV, ν=3.75 (2004DmZZ).

Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.

Assignment: final descendent of ^{288}115 produced by ^{243}Am(^{48}Ca,3n) E=248 MeV (2003OgZY,2004Og03) and E=243 MeV, chem (2004DmZZ). The evaluators suggest that 2004DmZZ offers independent support to the synthesis of ^{288}115 (2004Og03) having precisely determined the atomic number for Z=105 by isolation of Group V elements. The properties are in agreement with ^{268}Db measured in the three chains seen earlier by 2004Og03, thereby providing evidence in favor of the synthesis of ^{288}115 and daughters. However, since the identification relies on the measurement of SF fragments, the possibility that the observed nucleus is actually ^{268}Rf following (undetected) ε from the parent ^{268}Db, cannot be excluded.

Adopted Levels: Tentative (continued)

^{268}Db Levels

Cross Reference (XREF) Flags

A ^{272}Bh α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	32 h *+11–7*	Jπ: Ω(p)=1/2–; Ω(n)=13/2+ from 1997Mo25 (theory). $T_{1/2}$: value adopted from 2004DmZZ based on 15/15 SF events observed. Other: 16 h *19*–6 from 2004Og03 based on 3/3 events observed; 29 h *+9–6* based on 18/18 events (evaluators). $T_{1/2}$(calc)=12.5 h from Viola–Seaborg systematic for Q(α)=8.2 MeV. %SF≈100. %SF: assumed although α–decay not excluded (2004Og03). β_2(theory): 0.221 from 1995Mo29; 0.226 from 2003Mu26; 0.249 from 2005GaZX.

^{272}Bh α Decay: Tentative 2004Og03,2003OgZY

Parent ^{272}Bh: E=x; Jπ=?; $T_{1/2}$=10 s *+12–4*; Q(g.s.)=9150 *60*; %α decay≈100.
See ^{272}Bh Adopted Levels for details.

^{268}Db Levels

E(level)	$T_{1/2}$
x?	32 h *+11–7*

α radiations

Eα	E(level)
9020 *60*	x?

Adopted Levels

Q(β⁻)=–4720 *SY*; S(n)=6750 *SY*; S(p)=830 *SY*; Q(α)=10486 *35* 2003Au03,2004Mo26.
Q(β⁻): estimated uncertainty=590 keV.
S(n): estimated uncertainty=630 keV.
S(p): estimated uncertainty=330 keV.
Q(α): from Eα=10329 keV *35* (2004Mo26. Arithmetic mean of 12 events). Other: 11.44 MeV *10* (2003Au03. Syst.).
As α decay daughter of ^{272}Rg. See ^{272}Rg Adopted Levels for experimental details.
1995Ho04: GSI/SHIP cold fusion experiment. See ^{272}Rg Adopted Levels for details. Three position and time correlated chains of α particle events. Determined α energies and time intervals between successive particles. Assigned to decay of ^{272}111 by consistency of lower chain member energies and lifetimes with known Db and Lr data. Second member of each chain corresponds to α decay of ^{268}Mt. The measured α energies and emission times for the three events were:

Event #1: 8–Dec–1994

$E_{\alpha 1}$= 533 keV (esc+155–keV X–ray)	t_1=3.600 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10259 keV	t_2=71 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9475 keV	t_3=98 ms	– assigned to	^{264}Bh
$E_{\alpha 4}$= 1969 keV (esc)	t_4=1.969 s	– assigned to	^{260}Db

Event #2: 13–Dec–1994

$E_{\alpha 1}$= 4612 keV (esc)	t_1=0.696 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10097 keV	t_2=171 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9618 keV	t_3=334 ms	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9146 keV	t_4=953 ms	– assigned to	^{260}Db

Event #3: 17–Dec–1994

$E_{\alpha 1}$=10820 keV	t_1=2.042 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10221 keV	t_2=72 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9621 keV	t_3=1.452 s	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9200 keV	t_4=573 ms	– assigned to	^{260}Db
$E_{\alpha 5}$= 8463 keV	t_5=66.3 s	– assigned to	^{256}Lr

These are consistent with one parent state and two daughter states. The second event has been suggested as a candidate for an isomeric state of ^{268}Mt (2002Ho11).
IUPAC/IUPAP JWP assessment (2001Ka70): insufficient internal redundancy to warrant conclusive observations.
2002Ho11: experiments repeated at GSI/SHIP, using the UNILAC with the same reaction ^{209}Bi(^{64}Ni,n) at a beam energy of 320 MeV. See ^{272}Rg Adopted Levels for details. Three events were observed:

Event #1: Energy of the evaporation residue=41.76 MeV

$E_{\alpha 1}$= 3503 keV (esc)	t_1=3.36 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10294 keV	t_2=4.23 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9385 keV	t_3=944 ms	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9156 keV	t_4=364 ms	– assigned to	^{260}Db
$E_{\alpha 5}$= 8465 keV	t_5=55.8 s	– assigned to	^{256}Lr

Event #2: Energy of the evaporation residue=36.55 MeV

$E_{\alpha 1}$=11008 keV	t_1=1.38 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$= 6953 keV	t_2=7.32 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9514 keV	t_3=2.99 s	– assigned to	^{264}Bh
$E_{\alpha 4}$= 1706 keV (esc)	t_4=14.98 s	– assigned to	^{260}Db
$E_{\alpha 5}$= 877 keV (esc)	t_5=47.0 s	– assigned to	^{256}Lr

Event #3: Energy of the evaporation residue=39.19 MeV

$E_{\alpha 1}$=11046 keV	t_1=2.70 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$= 765 keV (esc)	t_2=37.14 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9113 keV	t_3=3.01 s	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9129 keV	t_4=4.06 s	– assigned to	^{260}Db
$E_{\alpha 5}$= 8423 keV	t_5=20.6 s	– assigned to	^{256}Lr

Four event average (including data points from first experiment) for t_2=60 ms.
IUPAC/IUPAP JWP assessment (2003Ka71): priority of discovery of Z=111 by 1995Ho04 is now confirmed owing to additional convincing observations reported in 2002Ho11.
2004Fo08: cold fusion experiment done at LBNL using the ^{208}Pb(^{65}Cu,n) reaction. See ^{272}Rg Adopted Levels for details. One EVR–α1–α2–α3–α4–α5... Event was observed:

Energy of evaporation residue=28.58 MeV

$E_{\alpha 1}$=11042 keV *20*	t_1=0.263 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10114 keV *20*	t_2=12.6 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 993 keV (esc)	t_3=1.16 s	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9416 keV *20*	t_4=1.45 s	– assigned to	^{260}Db
$E_{\alpha 5}$= 8613 keV *20*	t_5=3.16 s	– assigned to	^{256}Lr

ΔE assumed by the evaluators.
2004Mo26 (in a collaboration with French and Chinese scientists): see ^{272}Rg Adopted Levels for experimental details. Using the reaction ^{209}Bi(^{64}Ni,n), as in 2002Ho11, three beam energies were employed: 323 MeV (9 events), 326 MeV (no event at a beam dose of 2.5×10^{18} ions), 320 MeV (3 events) and repeat runs at 323 MeV (2 more events). A total of 14 correlated decay sequences were observed with two 'escaped' α's (events 3 and 8). The cross–section at each of these energies was: 2.6 pb *+23–15* (320 MeV); 2.5 pb *+12–9* (323 MeV); and 0.0 pb *+11–0* (326 MeV) with varying target thicknesses.

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Adopted Levels (continued)

Event 1: Feb. 17, 2003; E=(323 MeV); tof=48.3 ns; E(EVR)=33.1 MeV
$E_{\alpha 1}$=11.08 MeV t_1=11.0 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.36 MeV t_2=9.20 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.81 MeV t_3=1.38 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.17 MeV t_4=1.93 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.39 MeV t_5=11.9 s – assigned to ^{256}Lr

Event 2: Feb. 17, 2003; E=(323 MeV); tof=45.8 ns; E(EVR)=33.0 MeV
$E_{\alpha 1}$=11.04 MeV t_1=4.42 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.68 MeV t_2=13.0 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.60 MeV t_3=1.45 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.05 MeV t_4=10.9 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.37 MeV t_5=21.9 s – assigned to ^{256}Lr

Event 3: Feb. 20, 2003; E=(323 MeV); tof=46.5 ns; E(EVR)=33.2 MeV
$E_{\alpha 1}$=11.56 MeV t_1=14.9 ms – assigned to ^{272}Rg
$E_{\alpha 2}$= 1.12 MeV (esc) t_2=122 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.85 MeV t_3=21.8 ms – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.34 MeV t_4=0.505 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.65 MeV t_5=33.5 s – assigned to ^{256}Lr

Event 4: Feb. 26, 2003; E=323 MeV; tof=47.3 ns; E(EVR)=30.5 MeV
$E_{\alpha 1}$=11.25 MeV t_1=1.42 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.43 MeV t_2=36.6 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.66 MeV t_3=1.87 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.40 MeV t_4=1.52 s – assigned to ^{260}Db
$E_{\alpha 5}$= 3.12 MeV (esc) t_5=46.8 s – assigned to ^{256}Lr

Event 5: Feb. 26, 2003; E=323 MeV; tof=46.3 ns; E(EVR)=31.6 MeV
$E_{\alpha 1}$=10.82 MeV t_1=7.11 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.29 MeV t_2=0.715 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.57 MeV t_3=0.543 s – assigned to ^{264}Bh
E_{SF}=231 MeV t_4=1.71 s – assigned to ^{260}Db

Event 6: Apr. 8, 2003; E=323 MeV; tof=47.5 ns; E(EVR)=32.7 MeV
$E_{\alpha 1}$=11.31 MeV t_1=2.82 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.78 MeV t_2=44.0 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.58 MeV t_3=0.442 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 8.81 MeV t_4=48.5 s – assigned to ^{260}Db

Event 7: Apr. 15, 2003; E=323 MeV; tof=47.5 ns; E(EVR)=32.7 MeV
$E_{\alpha 1}$=10.58 MeV t_1=1.17 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.35 MeV t_2=38.3 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.31 MeV t_3=3.6 ms – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.01 MeV t_4=4.87 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.50 MeV t_5=45.8 s – assigned to ^{256}Lr

Event 8: Apr. 15, 2003; E=323 MeV; tof=46.0 ns; E(EVR)=31.1 MeV
$E_{\alpha 1}$=10.96 MeV t_1=8.89 ms – assigned to ^{272}Rg
$E_{\alpha 2}$= 2.76 MeV (esc) t_2=26.2 ms – assigned to ^{268}Mt
E_{SF}=208 MeV t_3=0.967 s – assigned to ^{264}Bh

Event 9: Apr. 16, 2003; E=323 MeV; tof=47.0 ns; E(EVR)=31.1 MeV
$E_{\alpha 1}$=11.06 MeV t_1=5.11 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.43 MeV t_2=19.1 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.50 MeV t_3=1.34 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.10 MeV t_4=3.69 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.41 MeV t_5=48.5 s – assigned to ^{256}Lr

Event 10: Apr. 30, 2003; E=320 MeV; tof=47.5 ns; E(EVR)=31.0 MeV
$E_{\alpha 1}$=10.21 MeV t_1=1.00 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.03 MeV t_2=8.81 ms – assigned to ^{268}Mt
E_{SF}=206 MeV t_3=4.93 s – assigned to ^{264}Bh

Event 11: May 6, 2003; E=320 MeV; tof=47.8 ns; E(EVR)=32.2 MeV
$E_{\alpha 1}$=10.85 MeV t_1=0.773 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.34 MeV t_2=32.4 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 8.87 MeV t_3=1.91 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 8.50 MeV t_4=21.0 s – assigned to ^{260}Db

Event 12: May 8, 2003; E=320 MeV; tof=47.0 ns; E(EVR)=32.4 MeV
$E_{\alpha 1}$=11.00 MeV t_1=6.92 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.58 MeV t_2=35.5 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.34 MeV t_3=1.00 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.14 MeV t_4=1.14 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.47 MeV t_5=38.6 s – assigned to ^{256}Lr

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Adopted Levels (continued)

Event 13: May 8, 2003; E=323 MeV; tof=44.8 ns; E(EVR)=28.9 MeV
$E_{\alpha 1}$=11.01 MeV t_1=6.84 ms – assigned to ^{272}Rg
$E_{\alpha 2}$= 9.40 MeV t_2=37.2 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.56 MeV t_3=1.23 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 8.29 MeV t_4=0.334 s – assigned to ^{260}Db
Event 14: May 12, 2003; E=323 MeV; tof=47.8 ns; E(EVR)=33.0 MeV
$E_{\alpha 1}$=11.08 MeV t_1=4.46 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.28 MeV t_2=3.35 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.63 MeV t_3=0.81 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.13 MeV t_4=2.42 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.63 MeV t_5=6.85 s – assigned to ^{256}Lr
Projectile energies in parentheses are uncertain due to target deterioration.

Theory: see Nuclear Science References.

Assignment: daughter of ^{272}Rg produced by ^{209}Bi(^{64}Ni,n) E=318 and 230 MeV (1995Ho04), 320 MeV (2002Ho11), and 320, 323, and 326 MeV (2004Mo26). ^{208}Pb(^{65}Cu,n) E=321 MeV (2004Fo08). IUPAC/IUPAP JWP assessment (2003Ka71): priority of discovery of Z=111 by 1995Ho04 is now confirmed owing to additional convincing observations reported in 2002Ho11. The work of 2004Fo08 and 2004Mo26 provide further support to ^{272}Rg through its decay to the previously unknown daughters ^{268}Mt (this nucleus) and ^{264}Bh to the known nuclides ^{260}Db and ^{268}Lr (evaluators).

^{268}Mt Levels

Cross Reference (XREF) Flags

A ^{272}Rg α Decay

E(level)	XREF	$T_{1/2}$	Comments
x	A	21 ms *+8–5*	Jπ: 2003Au02 suggest 5+,6+ based on systematics. Ω(p)=11/2–; Ω(n)=1/2+ from 1997Mo25 (theory). $T_{1/2}$: from 2004Mo26 (arithmetic mean of all 14 events; t_2=30 ms). Others: 42 ms *+29–12* (2002Ho11); 27 ms *+8–5* from average t_2=38.2 ms (21 events. Evaluators). 2002Ho11 do not exclude the presence of isomeric states (*e.g.*, 171 ms). 2004Mo26 tentatively assigned all of the decays to one state since the decay time distribution exhibited no clear peculiarities. 2004Mo26 note that 1995Ho04 observed one fairly long–lived α–decay (171 ms) with an energy 0.16 MeV lower than the other two events. 2004Mo26 also observed a 122–ms event but the α escaped. These two decays may indicate an isomeric state in ^{268}Mt and, if excluded, the results of 2002Ho11 and 2004Mo26 are consistent within uncertainties. $T_{1/2}$(calc)=2.2 ms from Viola–Seaborg systematics for Q(α)=10486 keV. %α≈100. %α: 21 α–decay events observed in four experiments; no SF decay reported. β_2(theory): 0.221 from 1995Mo29; 0.236 from 2003Mu26; 0.253 from 2005GaZX.

^{272}Rg α Decay 2004Mo26,2002Ho11,1995Ho04

Parent ^{272}Rg: E=x; Jπ=?; $T_{1/2}$=3.8 ms *+14–8*; Q(g.s.)=11150 *35*; %α decay≈100.
^{272}Rg–$T_{1/2}$: from 2004Mo26.
^{272}Rg–Q(α): from Eα=10986 keV *35* (2004Mo26. Unweighted average of 14 events). Other: 11.44 MeV *10* (2003Au03. Syst.).
See ^{272}Rg Adopted Levels for details.

^{268}Mt Levels

E(level)	$T_{1/2}$	Comments
x	21 ms *+8–5*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
10986 *35*	x	Eα: unweighted average of 14 events (2004Mo26).

Adopted Levels: Not Observed

$Q(\beta^-)$=–1810 *SY*; S(n)=5140 *SY*; S(p)=4210 *SY*; $Q(\alpha)$=8800 *SY* 2003Au03.
$Q(\beta^-)$: estimated uncertainty=780 keV.
S(n): estimated uncertainty=850 keV.
S(p): estimated uncertainty=840 keV.
$Q(\alpha)$: estimated uncertainty=500 keV.
The data of 1999Ni03 cited by 2000Fi12 have been retracted (2002Ni10) and have not been confirmed in a repeated experiment at LBNL (2003Gr26). Also, 2001MoZU and 2000HoZZ found no evidence for ^{293}118 in ^{208}Pb(^{86}Kr,n) reaction at 457.6 MeV (2001MoZU) and at 453.9 and 456.7 MeV (2000HoZZ). The statistical analysis of 2000Sc26 also indicate that the data of 1999Ni03 do not originate from radioactive decays with an error probability of less than 5%.

Adopted Levels

Q(β⁻)=–4660; S(n)=6310 *SY*; S(p)=3280 *SY*; Q(α)=9315 *22* 2003Au03.
Q(β⁻): estimated uncertainty=560 keV.
S(n): estimated uncertainty=430 keV.
S(p): estimated uncertainty=400 keV.
Q(α): from Eα=9176 keV *21*; unweighted average of: 9.23 MeV *2* (1996Ho13), 9.18 MeV *2* (2002Ho11), 9.17 MeV *4* and 9.25 MeV *7* (2004MoZU), 9.18 MeV *+7–3* and 9.10 MeV *+7–3* (2003Tu05) and 9.12 MeV (2004Vo24), assuming g.s. to g.s. transition. Other: 9.63 MeV *10* (2003Au03. Syst).

1996Ho13: granddaughter of ^{277}112 produced by ^{208}Pb(^{70}Zn,n), E=343.8 MeV (E*=10.1 MeV; σ=1.0 pb *+18–4*) at GSI/SHIP. Two EVR–α1–α2–α3–α4–α5–α6 events observed. One event retracted by 2002Ho11; σ revised to 0.4 pb *+9–3*. See ^{277}112 Adopted Levels for details.

1996La12: missing daughter of ^{273}Ds produced by ^{244}Pu(^{34}S,5n) E=190 MeV at Dubna using DGFRS in collaboration with LLNL. Observed one EVR–α1–α3–α4 event. See ^{273}Ds Adopted Levels for details.

IUPAC/IUPAP 2001 JWP (2001Ka70): see ^{273}Ds and ^{277}112 Adopted Levels for conclusions on Z=110 and 112, respectively.

2002Ho11: granddaughter of ^{277}112. The experiment of 1996Ho13 was redone at GSI/SHIP. The ^{208}Pb(^{70}Zn,n) reaction was again used at projectile energies of 346.1 MeV (E*=12.0 MeV; σ=0.5 pb *+11–4*; 1 event) and 343.8 MeV (E*=10.1 MeV; σ<2.6 pb; 0 events). One EVR–α1–α2–α3–α4–SF event observed. Retracted one event observed by 1996Ho13. See ^{277}112 Adopted Levels for details.

IUPAC/IUPAP 2003 JWP (2003Ka71): see ^{273}Ds and ^{277}112 Adopted Levels for conclusions on Z=110 and 112, respectively.

2003Tu05, 2002Du21: ^{269,270}Hs produced by ^{248}Cm(^{26}Mg,xn), E=143.7–146.8 MeV (σ(^{269}Hs)≈6 pb, σ(^{270}Hs)≈4 pb) at GSI using UNILAC with *In situ* Volatilization and Online detection (IVO) as part of a large international collaboration. Three decay chains were attributed to ^{269}Hs and two decay chains were tentatively assigned to ^{270}Hs. Overall efficiency of system assumed to be 40%. Chemically separated Hs atoms were identified by observing genetically linked decay chains. From the measured Eα=9.16 MeV *+7–3*, an α–decay half–life of 3.6 s *+8–14* was estimated for ^{270}Hs (see ^{270}Hs Adopted Levels for details).

Event #1: 12–May–2001 at 09:55:03 hrs
$E_{\alpha 1}$=9180 MeV +7–3 – assigned to ^{269}Hs
$E_{\alpha 2}$=8.69 MeV +7–3 t_2=4.4 s – assigned to ^{265}Sg
$E_{\alpha 3}$=8.50 MeV +7–3 t_3=2.4 s – assigned to ^{261}Rf
$E_{\alpha 4}$=8.21 MeV +7–3 t_4=55.6 s – assigned to ^{257}No

Event #2: 12–MAY–2001 at 22:00:28 hrs
$E_{\alpha 1}$=9.10 MeV +7–3 – assigned to ^{269}Hs
$E_{\alpha 2}$=8.68 MeV +7–3 t_2=9.3 s – assigned to ^{265}Sg
E_{SF}=179 MeV 6 t_3=7.9 s – assigned to ^{261}Rf

Event #3: 13–May–2001 at 10:02:07 hrs
$E_{\alpha 1}$=8.88 MeV +7–3 (partial Eα) – assigned to ^{269}Hs
$E_{\alpha 2}$=8.90 MeV +7–3 t_2=17.1 s – assigned to ^{265}Sg
$E_{\alpha 3}$=8.50 MeV +7–3 t_3=0.846 s – assigned to ^{261}Rf

The above properties are from 2003Tu05. Note that the life–times of the parent could not be estimated with the applied thermochromatography technique since deposition times are not measured. Two more possible candidates for ^{269}Hs are shown in 2002Du21 but not included here since the parent (in the first event) and daughter (in the second event) were not seen. 2002Du21 also explains the chemical implications of these experiments and proposes strong qualitative evidence in support of Hs being an ordinary member of Group VIII of the periodic table. It is suggested that it may behave like its lighter homologue, Os. See also 2004Ga18.

2002Ho11 tentatively assigned the α–decay and SF event in the two ^{277}112 chains to the g.s. of ^{261}Rf. With the three additional chains noted above, 2003Tu05 calculated $T_{1/2}$=4.2 s *+34–13* and %SF≈40 for the decay of ^{261}Rf and suggest the previously observed 78–s state is a metastable state.

2004MoZU: granddaughter of ^{277}112. Confirmatory experiments performed by the Japanese group at RIKEN with ^{208}Pb(^{70}Zn,^{1}n), E=345.9 MeV (σ=0.44 pb *+59–29*). Two EVR–α1–α2–α3–α4–SF events observed. Confirmed results of 2002Ho11. See ^{277}112 Adopted Levels for details.

2004Vo24: ^{269,270}Hs produced by ^{248}Cm(^{26}Mg,xn), E=142–150 MeV at GSI using the UNILAC with Continuously Working Arrangement for Clusterless Transport of *In–Situ* Produced Volatile Oxides (CALLISTO). Experiment done in two parts of the beam time (305 hours; 2.82×10^{18} ^{26}Mg^{5} ions). In the first part two ^{248}Cm segments (0.6 mg/cm^2 each) and one Gd segment (30.6% enriched ^{152}Gd; 0.8 mg/cm^2) were irradiated by 1.18×10^{18} particles at E=144–149 MeV. After 25 beam shifts the ^{152}Gd–target segment was replaced with a ^{248}Cm/^{152}Gd–hybrid segment (0.5 mg/cm^2; 4% enriched Gd) to enhance the Hs production and irradiated by 1.64×10^{18} particles at E=142–160 MeV. Recoils stopped in He/O_2 mixture resulting *in–situ* formation of volatile oxides. Transport yield estimated as ≈70% and deposition on 290 NaOH–coated also estimated at ≈70%. Detector resolution 80–120 keV. For data analysis a time window of five times the respective half–lives and an energy window of ±150 keV around the known α energies were used. One correlated α–α–α chain and five α–SF chains observed; one α–SF chain a most likely candidate for a random correlation.

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Adopted Levels (continued)

Event #1: ^{269}Hs. October 30, 2002 (Probability to encounter this at random: <4×10^{3})
$E_{\alpha 1}$=9.12 MeV – assigned to ^{269}Hs
$E_{\alpha 2}$=8.65 MeV t_2=24.886 s – assigned to ^{265}Sg
$E_{\alpha 3}$=escape – assigned to ^{261}Rf
$E_{\alpha 4}$=8.20 MeV t_4=8.029 s – assigned to ^{257}No
Event #2: ^{269,270}Hs. October 29, 2002
$E_{\alpha 1}$=9.284 MeV – assigned to ^{269,270}Hs
$E_{\alpha 2}$=escape – assigned to ^{265,266}Sg
E_{SF}=31 MeV t_3=10.484 s – assigned to ^{261,262}Rf
Event #3: ^{269,270}Hs. November 8, 2002; 8:00 a.m.
$E_{\alpha 1}$=9.124 MeV – assigned to ^{269,270}Hs
$E_{\alpha 2}$=escape – assigned to ^{265,266}Sg
E_{SF}=31 MeV t_3=17.721 s – assigned to ^{261,262}Rf
Event #4: ^{269,270}Hs. November 10, 2002
$E_{\alpha 2}$=8.695 MeV – assigned to ^{265,266}Sg
E_{SF}=51 MeV t_3=13.599 s – assigned to ^{261,262}Rf
Event #4: ^{269,270}Hs. November 8, 2002; 9:20 a.m.
$E_{\alpha 2}$=8.902 MeV – assigned to ^{265,266}Sg
E_{SF}=85 MeV t_3=14.561 s – assigned to ^{261,262}Rf

Other: 2000OgZS.

Theory: see Nuclear Science References.

Assignment: ^{248}Cm(^{26}Mg,5n), E=143.7–146.8 MeV, chem (2003Tu05, 2002Du21); E=142–150 MeV, chem (2004Vo24). Granddaughter of ^{277}112 produced by produced by ^{208}Pb(^{70}Zn,n) E=343.8 MeV (1996Ho13), 346.1 MeV (2002Ho11), and 345.9 MeV (2004MoZU). Chemical extraction established that element 108 was produced. The ^{277}112 decay chain seems to be well established through ^{265}Sg; see ^{277}112 Adopted Levels for details.

^{269}Hs Levels

Cross Reference (XREF) Flags

A ^{273}Ds α Decay

E(level)	XREF	$T_{1/2}$	Comments
x	A	9.7 s *+97–33*	$T_{1/2}$: from arithmetic mean τ=14.04 s of τ=19.7 s (1996Ho13), 22.0 s (2002Ho11), and 14.2 s and 0.270 s (2004MoZU). $T_{1/2}$(calc)=1.9 s from Viola–Seaborg systematics assuming Q(α)=9315 keV. Of the available data, the g.s. may have properties close to the $T_{1/2}$=0.187 s, Q(α)=9.390 MeV state observed in 2004MoZU, when compared against Viola–Seaborg systematics. %α≈100. %α: from 8 events. β_2(theory): 0.231 from 1995Mo29; 0.237 from 2003Mu26; 0.260 from 2005GaZX.

^{273}Ds α Decay 1996Ho13,2002Ho11,2004MoZU

Parent ^{273}Ds: E=0; Jπ=?; $T_{1/2}$=0.17 ms *+17–6*; Q(g.s.)=11370 *50*; %α decay≈100.
^{273}Ds–J: 2003Au02 suggest 13/2– based on systematics.
See ^{277}112 Adopted Levels for details. Other: 1996La12.

^{269}Hs Levels

E(level)	$T_{1/2}$
x	9.7 s *+97–33*

α radiations

Eα	E(level)	Comments
11200 *20*	x	Eα: from 2002Ho11. Others: 11083 keV *20* (1996Ho13) and 11.14 MeV *7* and 11.15 MeV *7* (2004MoZU). Difference of 117 keV *28* between 2002Ho11 and 1996Ho13 suggestive of two transitions; however, data from 2004MoZU overlaps both values.

Adopted Levels

S(n)=6830 *SY*; S(p)=1330 *SY*; Q(α)=11580 *70* 2003Au03.
S(n): estimated uncertainty=520 keV.
S(p): estimated uncertainty=340 keV.
Q(α): based on 1995Ho03. Unweighted average of three events from 1995Ho03: Eα=11112 keV *20*; Q(α)=11280 keV *20*. Retraction of second event by 2002Ho11 does not affect the value.
1995Ho03: GSI/SHIP cold fusion experiment, ^{208}Pb(^{62}Ni,n) E=5 MeV/A by an international collaboration. Reaction cross–section was 3.5 pb *+27–18* (4 events). Total of 2.2×10^{18} projectile particles on 99.0% enriched Pb target. Eight targets were mounted on a wheel 310 mm in diameter rotating at 1125 rpm. EVR's separated by velocity filter SHIP. Observed four position and time correlated chains of α particle events. Determined α energies and time intervals between successive particles. Assigned to decay of ^{269}Ds by consistency of lower chain member energies and lifetimes with known Hs, Sg, Rf and No data. The measured α energies (to within ±20 keV) and emission times for the nuclei in each α–decay sequence were:

Event # 1: (9 November 1994)
$E_{\alpha 1}$=11132 keV t_1=393 μs – assigned to ^{269}Ds
$E_{\alpha 2}$=10574 keV t_2=583 μs – assigned to ^{265}Hs
$E_{\alpha 3}$= 9576 keV t_3=72 ms – assigned to ^{261}Sg
$E_{\alpha 4}$= 2113 keV (esc) t_4=779 ms – assigned to ^{257}Rf

Event # 2: (11 November 1994)
$E_{\alpha 1}$= 1939 keV (esc) t_1=201 μs – assigned to ^{269}Ds
$E_{\alpha 2}$=10534 keV t_2=2015 μs – assigned to ^{265}Hs
$E_{\alpha 3}$= 9524 keV t_3=373 ms – assigned to ^{261}Sg

Event # 3: (12 November 1994)
$E_{\alpha 1}$=11095 keV t_1=142 μs – assigned to ^{269}Ds
$E_{\alpha 2}$=10519 keV t_2=126 μs – assigned to ^{265}Hs
$E_{\alpha 3}$= 9554 keV t_3=156 ms – assigned to ^{261}Sg
$E_{\alpha 4}$= 8705 keV t_4=26.1 s – assigned to ^{257}Rf
$E_{\alpha 5}$= 8144 keV t_5=224 s – assigned to ^{253}No

Event # 4: (17 November 1994)
$E_{\alpha 1}$=11110 keV t_1=241 μs – assigned to ^{269}Ds
$E_{\alpha 2}$=10571 keV t_2=2324 μs – assigned to ^{265}Hs
$E_{\alpha 3}$= 9468 keV t_3=34 ms – assigned to ^{261}Sg
$E_{\alpha 4}$= 8615 KeV t_4=13.9 s – assigned to ^{257}Rf
$E_{\alpha 5}$= 8022 keV t_5=42.7 s – assigned to ^{253}No

Assignments are consistent with one parent and one daughter state.
Other: excitation functions for (a) ^{258}Rf with ^{50}Ti+^{208}Pb within a projectile energy range (4.52 to 5.10)×A MeV; (b) ^{266}Hs with ^{58}Fe+^{208}Pb; and decay of ^{265}Hs (see ^{265}Hs data set).
2002Ho11: retraction of second event dated 11 November 1994 following reanalysis of original data from which this sequence could not be reconstructed.
Theory: see Nuclear Science References.
Assignment: IUPAC/IUPAP JWP assessment (2003Ka71) maintains priority of discovery of Z=110 to GSI collaboration. Even with the subsequent retraction of the second event sequence, the extant chains remain persuasive.

^{269}Ds Levels

E(level)	Comments
x	Jπ: 2003Au02 suggest 3/2+ based on systematics. $T_{1/2}$=179 μs *+245–66*. $T_{1/2}$: from arithmetic mean τ=241 μs based on 393 μs, 142 μs, and 241 μs. Other: 2000Fi12 adopted 0.17 ms *+17–6* based on the data of 1995Ho03. $T_{1/2}$(calc)=11 μs and 51 μs for Q(α)=11.58 MeV and Q(α)=11.280 MeV, respectively, from Viola–Seaborg systematics. Ground state is consistent with the observations. Given that the three α–energies and decay times agree well with each other (with two α–energies to within the detector resolution of 20 keV) leading to a redundancy in measurement, a high likelyhood exists that the data describe a single parent (to daughter) state. %α≈100. %α: predicted β (1997Mo25) and SF (1995Ho27,1997Sm03) half–lives much longer than those predicted and observed for α emission. No spontaneous fission events observed by 1995Ho03. α channel is expected to be 100% with the non–observation of proton evaporation believed to be competitive and energetically possible. β_2(theory): 0.221 from 1995Mo29; 0.232 from 2003Mu15; 0.250 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=–5600; S(n)=7250 *SY*; S(p)=3600 *SY*; Q(α)=9300 *+7–3* 2003Au03,2003Tu05.

Q(β⁻): estimated uncertainty=610 keV.

S(n): estimated uncertainty=310 keV.

S(p): estimated uncertainty=500 keV.

Q(α): from Eα=9.16 MeV *+7–3* (2003Tu05). Other: 9.30 MeV *3* (2003Au03. Based on preliminary data later reported in 2003Tu05).

2002Du21, 2003Tu05: first report of ^{270}Hs from chemical investigations employing gas chromatography undertaken by a large international collaboration at GSI using the UNILAC facility. ^{269,270}Hs observed with two decay chains attributed tentatively to ^{270}Hs and three decay chains to ^{269}Hs (see ^{269}Hs Adopted Levels for details). Assuming an overall efficiency of ≈40%, a production cross–section of 4 pb for ^{270}Hs and 6 pb for ^{269}Hs was estimated, accurate to within a factor of about 3. Reaction: ^{26}Mg beam at 143.7–146.8 MeV on ^{248}Cm. Following chemical separation Hs atoms were identified by observing genetically linked decay chains. From the measured Eα=9.16 MeV *+7–3*, an α–decay half–life of 3.6 s *+8–14* was estimated for ^{270}Hs.

Event #1: 12–May–2001 at 02:33:08 hrs

$E_{\alpha 1}$= 9.16 MeV *+7–3* – assigned to ^{270}Hs

$E_{\alpha 2}$= 8.66 MeV *+7–3* t_2=25.7 s – assigned to ^{266}Sg

E_{SF}=187 MeV *6* t(SF)=0.199 s – assigned to ^{262}Rf

Event #2: 12–May–2001 at 17:09:09 hrs

$E_{\alpha 1}$= 8.97 MeV *+7–3* – assigned to ^{270}Hs

$E_{\alpha 2}$= 8.64 MeV *+7–3* t_2=11.9 s – assigned to ^{266}Sg

E_{SF}= 186 MeV *6* t(SF)=1.2 s – assigned to ^{262}Rf

The above properties are from 2003Tu05. Note that the life–times of the parent could not be estimated with the applied thermochromatography technique since deposition times are not measured. 2002Du21 also explains the chemical implications of these experiments and proposes strong qualitative evidence in support of Hs being an ordinary member of Group VIII of the periodic table. It is suggested that it may behave like its lighter homologue, Os.

2004Vo24 observed six α–chains from ^{248}Cm(^{26}Mg,4n) E=142–150 MeV, chem. One chain was assigned to ^{269}Hs; four could be assigned to ^{269}Hs or ^{270}Hs; and the sixth chain is the most likely candidate for a random correlation. See ^{269}Hs Adopted Levels for more details. Results of this experiment are not suitable for providing further proof for ^{270}Hs.

Other: 2004Ga18.

Theory: see Nuclear Science References.

Assignment: ^{248}Cm(^{26}Mg,4n) E=144–147 MeV (2002Du21,2003Tu05). 2003Tu05 consider their assignment as tentative. Measurements by 2004Vo24 are not suitable for providing further prove for ^{270}Hs.

^{270}Hs Levels

E(level)	$T_{1/2}$	Comments
0.0?	3.6 s *+8–14*	Jπ: 0+ if g.s. $T_{1/2}$: $T_{1/2}(\alpha)$ estimated by 2003Tu05 from measured Q(α)=9.30 MeV *+7–3*. $T_{1/2}$(calc)=2.1 s from Viola–Seaborg systematics with Q(α)=9.30 MeV. %α≈100. %α: from 2/2 events. β_2(theory): 0.231 from 1995Mo29; 0.233 from 2003Mu26; 0.257 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=–1860 *SY*; S(n)=6580 *SY*; S(p)=1140 *SY*; Q(α)=10180 *70* 2003Au03,2004Mo42.
Q(β⁻): estimated uncertainty=610 keV.
S(n): estimated uncertainty=770 keV.
S(p): estimated uncertainty=550 keV.
Q(α): from Eα=10.03 MeV *7* (2004Mo42). Other: 10.35 MeV *50* (2003Au03. Syst.).
2004Mo42: granddaughter of ^{278}113 produced by ^{209}Bi(^{70}Zn,n) E=349 MeV. See ^{278}113 Adopted Levels for details.
Event #1: Energy of the evaporation residue=36.75 MeV

$E_{\alpha 1}$=11.68 MeV *4* t_1=344 μs – assigned to ^{278}113
$E_{\alpha 2}$=11.15 MeV *7* t_2=9.26 ms – assigned to ^{274}Rg
$E_{\alpha 3}$=10.03 MeV *7* t_3=7.16 ms – assigned to ^{270}Mt
$E_{\alpha 4}$= 9.08 MeV *4* t_4=2.47 s – assigned to ^{266}Bh
E(SF)=204.1 MeV t(SF)=40.9 s – assigned to ^{262}Db

Theory: see Nuclear Science References.
Assignments: the assignments are the *most probable* ones for the reaction. Also, the identification of the parent as ^{278}113, α–decay daughter ^{274}Rg, and grand–daughter ^{270}Mt, are all rendered plausible following a consistent comparison of the 4th and 5th events with known descendents. The observation of each isotope in the sequence should be considered as tentative and pending confirmation.

^{270}Mt Levels

Cross Reference (XREF) Flags

A ^{274}Rg α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	5.0 ms *+24–3*	Jπ: Ω(p)=11/2+; Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$: 4.96 ms *+237–23* corresponding to Δt=7.16 ms (2004Mo42; experimental uncertainty not given); uncertainty estimated by the evaluators. $T_{1/2}$(calc)=14 ms from Viola–Seaborg systematics for Q(α)=10.18 MeV. %α≈100. %α: assumed 100% from 1/1 event. β_2(theory): 0.222 from 1995Mo29; 0.233 from 2003Mu26; 0.255 from 2005GaZX.

^{274}Rg α Decay: Tentative 2004Mo42

Parent ^{274}Rg: E=x; Jπ=?; $T_{1/2}$=6 ms *+31–3*; Q(g.s.)=11320 *70*; %α decay≈100.
^{274}Rg–$T_{1/2}$: 6.4 ms *+308–29*.
See ^{278}113 Adopted Levels for details.

^{270}Mt Levels

E(level)	$T_{1/2}$
x?	5.0 ms *+24–3*

α radiations

Eα	E(level)
11150 *70*	x?

Adopted Levels: Tentative

S(n)=8450 *SY*; S(p)=2010 *SY*; Q(α)=11200 *50* 2003Au03.
S(n): estimated uncertainty=320 keV.
S(p): estimated uncertainty=620 keV.
Q(α): based on Eα=11031 keV *50* (2001Ho06).
2001Ho06: experiments done at GSI using SHIP by an international collaboration from Germany, Slovakia, Poland, and Russia using the reaction ^{64}Ni+^{207}Pb. Eight events measured at an estimated cross–section of 13 pb *5*. The ^{64}Ni^{+} beam was provided by the UNILAC at an energy of 317 MeV corresponding to an excitation energy of 14 MeV at the center of the target. A total beam dose of 1.3×10^{18} ions was collected over a period of 7.3 days. The ^{207}Pb target was enriched to 92.4%. Of the eight events, six were of the type EVR–α1–α2–SF and two of the type EVR–α2–SF:
Event # 1: (Event 5 in sequence of detection)
$E_{\alpha 1}$=10987 keV *90* t_1=0.07 ms – assigned to ^{270}Ds
$E_{\alpha 2}$= 4168 keV (esc) t_2=0.43 ms – assigned to ^{266}Hs
E_{SF}=189 MeV t_3=11.02 ms – assigned to ^{262}Sg
Event # 2: (Event 3 in sequence of detection)
$E_{\alpha 1}$=11075 keV *90* t_1=0.18 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10196 keV *20* t_2=0.87 ms – assigned to ^{266}Hs
E_{SF}=193 MeV t_3=10.26 ms – assigned to ^{262}Sg
Event # 3: (Event 1 in sequence of detection)
$E_{\alpha 1}$= 1925 keV (esc) t_1=0.20 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10173 keV *90* t_2=2.79 ms – assigned to ^{266}Hs
E_{SF}=164 MeV t_3= 8.84 ms – assigned to ^{262}Sg
Event # 4: (Event 7 in sequence of detection)
$E_{\alpha 1}$=11151 keV *20* t_1=2.00 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10171 keV *20* t_2=18.22 ms – assigned to ^{266}Hs
E_{SF}=199 MeV t_3=13.06 ms – assigned to ^{262}Sg
Event # 5: (Event 8 in sequence of detection)
$E_{\alpha 1}$=12147 keV *50* t_1=10.35 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10281 keV *90* t_2=9.63 ms – assigned to ^{266}Hs
E_{SF}=215 MeV t_3=7.77 ms – assigned to ^{262}Sg
Event # 6: (Event 2 in sequence of detection)
$E_{\alpha 1}$=10954 keV *20* t_1=17.71 ms – assigned to ^{270}Ds
$E_{\alpha 2}$=10180 keV *20* t_2=0.34 ms – assigned to ^{266}Hs
E_{SF}=190 MeV t_3=3.98 ms – assigned to ^{262}Sg
Event # 7: (Event 4 in sequence of detection)
$E_{\alpha 2}$=578 keV (esc) t_2=0.46 ms – assigned to ^{266}Hs
E_{SF}=227 MeV t_3=2.00 ms – assigned to ^{262}Sg
Event # 8: (Event 6 in sequence of detection)
$E_{\alpha 2}$=10306 keV *90* t_2=5.40 ms – assigned to ^{266}Hs
E_{SF}=177 MeV t_3=33.91 ms – assigned to ^{262}Sg
2001Ho06 have suggested two groups for the six α–decays assigned to ^{270}Ds: events 1, 2, and 3 listed above belong to g.s. 0+→0+→0+ transitions in all three isotopes and events 4, 5, and 6 to states originating from a K–isomer (as in the case of the longest lived state, seen in event 6) or γ–decay. See 2001Ho06 for details regarding assignments. No fission branch observed for ^{270}Ds.
2002Ho11 reanalyzed all GSI data for Z=110, 111, and 112 taken since 1994. The data of 2001Ho06 were exactly reproduced.
Theory: see Nuclear Science References.
Assignment: ^{207}Pb(^{64}Ni,n) E=317 MeV (2001Ho06). The daughter (^{266}Hs) and granddaughter (^{262}Sg) have not been independently observed. In the absence of observed elemental signatures the evaluators consider the assignments as tentative.

^{270}Ds Levels

E(level)	Jπ	$T_{1/2}$	Comments
0.0?	0+	0.10 ms *+14–4*	$T_{1/2}$: 100 μs *+140–40* from 2001Ho06; arithmetic mean for the three events assigned to the ^{270}Ds g.s. (events listed as 1, 2, and 3 above). $T_{1/2}$(calc)=0.078 ms from Viola–Seaborg systematics for Q(α)=11.20 MeV. %α≈100; %SF<0.2. %α: from 8/8 events. No SF decay observed.

Continued on next page

Adopted Levels: Tentative (continued)

^{270}Ds Levels (continued)

E(level)	$T_{1/2}$	Comments
1130?	6.0 ms *+82–22*	E(level): if 12.15–MeV α feeds the ^{266}Hs g.s. (2001Ho06). Jπ: J≈10 *2* estimated from retardation of α–decay probability (2001Ho06). π=– (2003Au02. Syst). $T_{1/2}$: from 2001Ho06; unweighted average for events 4, 5 and 6 attributed to isomeric state. %α>70; %IT≤30? %α,%IT: %IT≈30 seems possible but could not be definitely established (2001Ho06). configuration: possible high–spin K–isomer. In calculations by 2001Ho06 for ^{266}Hs and ^{270}Ds, the lowest two neutron quasiparticle states are at 1.31 and 1.34 MeV for ^{270}Ds and at 0.90 and 0.94 MeV for ^{266}Hs. These states are formed a pair in orbits with asymptotic Nilsson quantum numbers $\nu[613]_{7/2+}$ and $\nu[615]_{9/2+}$, respectively, and raising the neutron with spin and angular momentum in the same direction into the orbit $\nu[725]_{11/2-}$. Resulting Jπ's are 9– and 10–, respectively. β_2(theory): 0.221 from 1995Mo29; 0.228 from 2003Mu15; 0.248 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=–3060 *SY*; S(n)=5140 *SY*; S(p)=4720 *SY*; Q(α)=8660 *80* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=780 keV.
S(n): estimated uncertainty=900 keV.
S(p): estimated uncertainty=970 keV.
Q(α): from Eα=8.53 MeV *8* (2004Og12). Other: 8.7 MeV *3* (2003Au03. Syst.).
2004Og12,2004OgZZ: as α decay product of ^{287}114 (15 events) and ^{283}112 (7 events). See for ^{287}114 and ^{283}112 Adopted Levels for details. ^{287}114 was synthesized using ^{242}Pu+^{48}Ca at beam energies of 235, 238 and 244 MeV with 5 measurements made at each energy. ^{283}112 was observed using ^{238}U+^{48}Ca at 230 and 234 MeV. One special case attributed to ^{287}114 in the ^{242}Pu reaction at a beam energy of 244 MeV, lasting for 6.5 min, of the type EVR–α1–α2–α3–α4–SF warrants mention. Generally, α decay is blocked below ^{279}Ds which fissions rather than α decays (%α≈10). The evaluators suggest that this longer chain which terminates with ^{271}Sg may, if confirmed, be one incidence of this 10% branch. The α energy for ^{279}Ds from this event is 9.7 MeV *6* with a lifetime of 0.2831 s. Another exception to the fissioning of ^{279}Ds appears in the case of a similar EVR–α1–α2–α3–α4–SF event originating from ^{283}112 in the ^{238}U reaction at 234 MeV. Here, the sequence ends with the fission of ^{267}Rf. The α energy for ^{279}Ds from this event is 9.8 MeV *3* with a lifetime of 0.2775 s. Although both exceptions require further investigation, their radioactive properties agree well with each other and the evaluators suggest that if confirmed, they could represent the 10% α decay branch for ^{279}Ds.
2005Gr19, 2002Lo15: no EVR–α–α correlations with Δt(EVR–α)<20 s or Δt(α–α)<20 s were observed in any of the ^{48}Ca + ^{238}U irradiations. See ^{283}112 Adopted Levels for details.
Theory: see Nuclear Science References.
Assignment: the assignments for Z=112, Z=114 (and Z=116) and their daughters are based on measured excitation functions and in some cases consistency of observed properties produced by cross–bombardments. In particular, the decay properties of ^{283}112 are consistent through the various measurements using the DGFRS, independent of whether they were observed as primary nuclei or as α decay daughters of parents one (Z=114) or two (Z=116) 'levels' up. In the case of ^{287}114, the second α in the decay chain has an energy of 9.54 MeV *6* which agrees well with the four measured α's (2004Og07, 2004Og12) in 11 out of 14 cases. The other three α energies are 8.94, 9.36 and 9.32 MeV which the experimenters suggest may be indicative of transitions to different excited states in the daughter nucleus ^{279}Ds. Assignments to this nucleus should be taken as tentative. Note that 2005Gr19 did not observe any SF decays or EVR–α–α correlations in any ^{48}Ca + ^{238}U irradiations.

^{271}Sg Levels

Cross Reference (XREF) Flags

A ^{275}Hs α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	2.4 min *+43–10*	Jπ: Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$: from 2 half–lives/1 α events (2004Og12,2004OgZZ). $T_{1/2}$(calc)=46.2 s (0.77 min) from Viola–Seaborg systematics for Q(α)=8.66 MeV. %α≈50; %SF≈50. %α,%SF: from 2 half–lives/1 α events (2004Og12). β_2(theory): 0.212 from 1995Mo29; 0.218 from 2003Mu26; 0.219 from 2005GaZX.

^{275}Hs α Decay: Tentative 2004Og12

Parent ^{275}Hs: E=x; Jπ=?; $T_{1/2}$=0.15 s *+27–6*; Q(g.s.)=9440 *70*; %α decay≈100.
^{275}Hs–$T_{1/2}$: from 2004Og12.
^{275}Hs–Q(α): from 2004Og12.
See ^{275}Hs Adopted Levels for details.

^{271}Sg Levels

E(level)	$T_{1/2}$	Comments
x?	2.4 min *+43–10*	E(level),$T_{1/2}$: from the Adopted Levels.

Adopted Levels: Tentative

Q(β^-)=–2310 *SY*; S(n)=6620 *SY*; S(p)=2770 *SY*; Q(α)=9500 *SY* 2003Au03.
Q(β^-): estimated uncertainty=650 keV.
S(n): estimated uncertainty=730 keV.
S(p): estimated uncertainty=830 keV.
Q(α): estimated uncertainty=300 keV.
2003OgZY and 2004Og03: identification of new nuclides: ^{287}115, ^{283}113, ^{279}Rg, ^{275}Mt and ^{267}Db. The α decay of ^{271}Bh, the penultimate descendent of ^{287}115 produced *via* ^{243}Am(^{48}Ca,4n) E=253 MeV was not observed; see ^{287}115 Adopted Levels for experimental details. However, the SF decay of ^{267}Db ($T_{1/2}$=73 min *+350–33*. TKE=206 MeV) and the α decay of ^{275}Mt ($T_{1/2}$=9.7 ms *+46–44*. Eα=10.33 MeV *9*) were observed.
Theory: see Nuclear Science References.
Assignment: the evaluators note that the identification of Z=115 and all associated nuclides in the chain should be treated as tentative until confirmed in independent experiments.

^{271}Bh Levels

Cross Reference (XREF) Flags

A ^{275}Mt α Decay: Tentative

E(level)	XREF	Comments
x?	A	Jπ: Ω(p)=1/2– from 1997Mo25 (theory). $T_{1/2}$: 40 s (2003Au03. Syst.). $T_{1/2}$(calc)=0.25 s from Viola–Seaborg systematics for Q(α)=9.5 MeV. %α=? β_2(theory): 0.221 from 1995Mo29; 0.228 from 2003Mu26; 0.238 from 2005GaZX.

^{275}Mt α Decay: Tentative 2004Og03

Parent ^{275}Mt: E=x; Jπ=?; $T_{1/2}$=10 ms *+50–5*; Q(g.s.)=10480 *90*; %α decay≈100.
^{275}Mt–$T_{1/2}$: 9.7 ms *+460–44* (2004Og03).
^{275}Mt–Q(α): from 2004Og03.
See ^{275}Mt Adopted Levels for details.

^{271}Bh Levels

E(level)
x?

α radiations

Eα
10330 *90*

Adopted Levels

S(n)=6820 *SY*; S(p)=2250 *SY*; Q(α)=10899 *20* 2003Au03.
S(n): estimated uncertainty=310 keV.
S(p): estimated uncertainty=550 keV.
Q(α): from Eα=10738 keV *20* (1998Ho13); 10738 keV *3* (68% c.i.). 2003Au03 adopted 10870 keV *20* based on input values of 10870 keV *20* and 10899 keV *20* from the Eα's of 1998Ho13 and apparently used the level scheme proposed by 2000Fi12 who assigned the 69–ms state of ^{271}Ds as the g.s.
2000Fi12 cite 1996He07 which does not contain any information on ^{271}Ds. The evaluators believe this was a preliminary result of the work finally reported in 1998Ho13 and cited as a private communication, reference 20 in 1995La20.
1998Ho13: GSI/SHIP cold fusion experiment, ^{208}Pb(^{64}Ni,n) at a detection efficiency of 100% for α–decay and fission events. Nine position and time correlated chains of α particles were observed: two at a beam energy of 311.7 MeV, six at 313.0 MeV, and one at 315.5 MeV. The cross–sections at these energies were 7.4 pb *+94–48*, 15 pb *+9–6*, and 3.6 pb *+68–3* respectively. A total number of 38 α–decays were measured and assigned to nine decay chains. Determined α energies and time intervals between successive particles. Assigned to decay of ^{271}Ds by consistency of lower chain member energies and lifetimes with known ^{255}No, ^{259}Rf, and ^{263}Sg data. The measured α energies and emission times are grouped as follows: five events with an average energy of E1=10738 keV *20*, two events with an average energy of E2=10682 keV *20*, and one escape and one event with energy E3=10709 keV *20* with a long life–time of 81 ms corresponding to $T_{1/2}$=56 ms *+270–26*. The emission times for the first two groups were 0.2–4.4 ms and 81 ms for the last event which 1998Ho13 take as being a sign of an isomeric state in ^{271}Ds. The second member of each chain corresponds to decay of ^{267}Hs. Analysis by 2000Sc26 confirms the assignment. 1998Ho13 also suggest the existence of two ^{267}Hs daughter states.
2003Gi05: confirmation of ^{271}Ds was reported by experiments done at LBNL with the Berkeley Gas Filled Separator (BGS) at the 88–inch cyclotron facility. The BGS was incorporated to enhance the collection of EVR's produced by the reaction. The same production reaction, ^{208}Pb(^{64}Ni,n), was studied at energies of 306.7, 309.2 and 312.8 MeV at the center of the target. A cross–section of 8.3 pb *+11–5* was deduced at a beam energy of 309.2 MeV in agreement with data of 1998Ho13. Two position and time correlated event chains were assigned to ^{271}Ds. No such event sequences were seen at the other two beam energies. The two corresponding ^{267}Hs α decay energies originating from 1.6–ms ^{271}Ds were 9.89 MeV (following α decay) and 9.88 MeV (following an escape event). Both these states decay to 0.12–s ^{263}Sg with life–times of 15 ms and 32 ms, respectively. Uncertainties of energy and time measurements are not given; strip detectors had an average energy resolution of 70 keV for 5 to 9 MeV α's.
2004Fo08: ^{271}Ds was studied at LBNL with the Berkeley Gas Filled Separator (BGS) at the 88–inch cyclotron facility as part of an experiment to produce ^{272}111 *via* the ^{208}Pb(^{65}Cu,n) reaction and and compare the resultant cross section with that of the ^{209}Bi(^{64}Ni,n) reaction (2002Ho11,2004Mo14) and confirm the assignment of ^{272}111 by 1995Ho04. ^{208}Pb(^{64}Ni,n) at 317.0 MeV (7.7 pb *+100–52*) and 319.8 MeV (20 pb *+15–11*) using a 98.4% enriched ^{208}Pb target. Estimated uncertainties for Eα were ≈20 keV for α's fully stopped in the focal plane and ≈45 keV for α particle events "reconstructed" from the sum of focal plane and upstream detector events. Data are in good agreement with 1998Ho13, 2003Gi05, and 2004Mo40. Seven chains observed; average energy of α's assigned to ^{271}Ds in three chains was 10753 keV and assigned to known transition of 10738 keV. 10688 keV *45* from one chain may be either the known 10682 or 10738 keV α's.
2004Mo40,2004Mo27: ^{271}Ds was studied at the RIKEN Linear Accelerator (RILAC) using the Gas Filled Recoil Separator (GARIS) with efficiency estimated to be 80% *15*. Production reaction: ^{208}Pb(^{64}Ni,n) at E=310, 313, 316 and 320 MeV using a 98.4% enriched ^{208}Pb target. The cross–sections at these energies (laboratory frame) were 1.8 pb *+41–15*, 8.0 pb *+60–40*, 17 pb *+7–6*, and <3.7 pb, respectively. The maximum cross–section was observed at a primary beam energy of 316 MeV. The difference of about 3 MeV from the result of 1998Ho13 is not considered significant due to statistical uncertainties in the estimation. A total of 14 decay chains attributed to the decay of ^{271}Ds over three experiments. The position resolution was better than ±0.9 mm for an energy deposit >2 MeV. 13 decays detected as second generation decays were attributed to ^{267}Hs and the results are in agreement with 1998Ho13. Method proposed by 2000Sc26 used in analysis. The energy centroids in the α spectra were deduced to be at 10.45 and 10.73 MeV; the latter is in good agreement with 10.73 MeV from 1998Ho13. Measured lifetimes of the α's from ^{271}Ds could be divided into two groups; one with decay times less than 10 ms (11 events) and another with decay times greater than 10 ms (3 events). The mean lifetimes for both groups agree with the results of 1998Ho13 as do the number ratios of the two groups: 11/3 (2004Mo40) and 11/2 (1998Ho13). Note that Q(β^-)values corresponding to their average $T_{1/2}$'s were not presented by 2004Mo40. See also 2004Mo43.
Theory: see Nuclear Science References.
Assignment: ^{208}Pb(^{64}Ni,n), E=311.7 MeV, 313.0 MeV, and 315.5 MeV; great grandparent of ^{259}Rf (Eα=8.80 MeV *2*, $T_{1/2}$=2.6 s), ^{255}No (Eα=8.10 MeV *2*, $T_{1/2}$=110 s) from 1998Ho13. Assignment accepted in IUPAP/IUPAC JWP assessment (2001Ka70).

Adopted Levels (continued)

^{271}Ds Levels

Level scheme from 1998Ho13 and 2004Mo40. 2000Fi12 adopted a level scheme with the 69–ms state as the ground state. $T_{1/2}$(calc)=0.41 ms from Viola–Seaborg systematics supports conclusion that the 69–ms state is less likely to be the g.s.

E(level)	$T_{1/2}$	Comments
0.0	1.63 ms *+44–29*	Jπ: 1998Ho13 propose 9/2+[615] based on theory which predicts that the 9/2[615] Nilsson orbital lies closer to the Fermi level in ^{271}Ds. 2003Au02 suggest 9/2+ based on systematics; Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$: mean value from 2004Mo40 based on τ=2.9 ms *+13–7* (2004Mo40) and and τ=1.8 ms *+8–4* (1998Ho13). Other: 1.6 ms *+9–5* (2004Fo08; calculated using MLDS code). $T_{1/2}$(calc)=0.41 ms from Viola–Seaborg systematics for Q(α)=10.90 MeV. %α≈100 (1998Ho13). %α: no SF events observed. Predicted β (1997Mo25; finite–range droplet model, folded–Yukawa single particle potential) and SF (1995Ho27, systematics, and 1997Sm03, macroscopic–microscopic model) half–lives much longer than those predicted and observed for α emission. $β_2$(theory): 0.221 from 1995Mo29; 0.230 from 2003Mu15; 0.248 from 2005GaZX.
x	69 ms *+56–21*	Jπ: 1998Ho13 suggest 13/2– as a suitable candidate for the assignment of the 69–ms state; in ^{267}Hs the 13/2– state is predicted to be high in energy and, therefore, hindrance of α transitions to states closer to g.s. could be expected and are in agreement with the data. 2003Au02 suggest 11/2– based on systematics. $T_{1/2}$: mean value from 2004Mo40 based on τ=124 ms *+169–45* (2004Mo40) and τ=65 ms *+120–26* (1998Ho13). %α>0; %IT=? (1998Ho13,2004Mo40). %α,%IT: to explain the decay properties of ^{271}Ds, 2004Mo40 suggest that this level decays by an isomeric transition to the g.s. of ^{271}Ds and also α decays to the possible isomeric state in ^{267}Hs. No SF events observed (1998Ho13). Predicted β (1997Mo25; finite–range droplet model, folded–Yukawa single particle potential) and SF (1995Ho27, systematics, and 1997Sm03, macroscopic–microscopic model) half–lives much longer than those predicted and observed for α emission.

Adopted Levels: Tentative

Q(β⁻)=–950 *SY*; S(n)=5410 *SY*; S(p)=3040 *SY*; Q(α)=9150 *60* 2003Au03,2004Og03.
Q(β⁻): estimated uncertainty=840 keV.
S(n): estimated uncertainty=830 keV.
S(p): estimated uncertainty=890 keV.
Q(α): from Eα=9.02 MeV *6* (2004Og03). Other: 9.30 MeV *30* (2003Au03. Syst).
2003OgZY and 2004Og03: identification of new nuclides: ^{288}115, ^{284}113, ^{280}Rg, ^{276}Mt, ^{272}Bh, and ^{268}Db. ^{272}Bh observed as α–decay daughter of parent ^{276}Mt and α–decay grand–daughter of ^{280}Rg. Reaction: ^{243}Am(^{48}Ca,3n) E=248 MeV corresponding to an excitation energy of 38.0 to 42.5 MeV at the target center. Experiments performed by the Dubna–LLNL collaboration. ^{288}115 was formed at a cross–section of 2.7 pb *+48–16*.
Experiments were done at the U400 cyclotron with the Dubna gas–filled recoil seperator (DGFRS) at FLNR–JINR. The evr's recoiling from the target were separated by DGFRS in flight from the ^{48}Ca beam ions, scattered particles and transfer–reaction products with a transmission efficiency of 35% for 115 nuclei.
Detection system: multiwire proportional counter for tof measurement; semi–conductor focal–plane detector array with 12 vertical position– sensitive strips, which measured the decay of the implanted recoils. This detection system surrounded by eight side detectors with no position sensitivity. The α spectrum was measured in the range 9.6 to 11.0 MeV. The resolution of the detector system was FWHM=60–100 keV for α particles absorbed in the focal–plane detector; 140–200 keV for α's escaping the focal–plane detector and registered by the side detectors.
Three similar decay chains with five consecutive α decays were detected in a time interval of 20 s (in the beam–off mode following the first recoil expected to belong to Z=115) terminated by an SF event with a release of total kinetic energy of ≈220 MeV. These events were assigned to the (^{48}Ca,3n) channel with the production of the parent nuclide ^{288}115; the fifth and penultimate event in the chain was assigned to ^{272}Bh. Properties of ^{272}Bh from the three chains are listed below by event.
Event #1: Energy of the evaporation residue=10.4 MeV
E_α=9230 keV t=24.0 s – assigned to ^{272}Bh
Event #2: Energy of the evaporation residue=11.0 MeV
E_α=9020 keV t=2.964 s – assigned to ^{272}Bh
Event #3: Energy of the evaporation residue=9.1 MeV
E_α=8970 keV t=15.388 s – assigned to ^{272}Bh
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: descendent of ^{288}115 produced by ^{243}Am(^{48}Ca,3n) E=248 MeV (2003OgZY,2004Og03) and E=243 MeV, chem (2004DmZZ). The evaluators suggest that 2004DmZZ offers independent support to the synthesis of ^{288}115 (2004Og03) having precisely determined the atomic number for Z=105 by isolation of Group V elements. The properties are in agreement with ^{268}Db measured in the three chains seen earlier by 2004Og03, thereby providing evidence in favor of the synthesis of ^{288}115 and daughters. However, since the identification relies on the measurement of SF fragments, the possibility that the observed nucleus is actually ^{268}Rf following (undetected) ε from the parent ^{268}Db, cannot be excluded.

^{272}Bh Levels

Cross Reference (XREF) Flags

A ^{276}Mt α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	10 s *+12–4*	Jπ: Ω(p)=1/2–; Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$: from 9.8 s *+117–35* (2004Og03). $T_{1/2}$(calc)=2.8 s from Viola–Seaborg systematics for Q(α)=9.15 MeV. %α≈100. %α: assumed from one event. β_2(theory): 0.221 from 1995Mo29; 0.224 from 2003Mu26; 0.224 from 2005GaZX.

^{276}Mt α Decay: Tentative 2004Og03,2003OgZY

Parent ^{276}Mt: E=x; Jπ=?; $T_{1/2}$=0.72 s *+87–25*; Q(g.s.)=9850 *60*; %α decay≈100.
^{276}Mt–$T_{1/2}$: from 2004Og03.
^{276}Mt–Q(α): from 2004Og03.
See ^{276}Mt Adopted Levels for details.

^{276}Mt α Decay: Tentative 2004Og03,2003OgZY (continued)

^{272}Bh Levels

E(level)	$T_{1/2}$	Comments
x?	10 s *+12–4*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
9710 *60*	x?	Eα: from 2004Og03.

Adopted Levels

S(p)=250 *SY*; Q(α)=11150 *35* 2003Au03,2004Mo26.
S(p): estimated uncertainty=350 keV.
Q(α): from Eα=10986 keV *35* (2004Mo26. Unweighted average of all events). Other: 11.44 MeV *10* (2003Au03. Syst.).
1995Ho04: GSI/SHIP cold fusion experiment. ^{209}Bi(^{64}Ni,n) E=5.0 MeV/A. Three beam energies were employed: 316.1 MeV (0 event observed), 318.1 MeV (1 event observed) and 320.0 MeV (2 events observed). A total of 2.2×10^{18} projectile particles yielded a total of three position and time correlated chains of α particle events. Determined α energies and time intervals between successive particles. Assigned to decay of ^{272}Rg by consistency of lower chain member energies and lifetimes with known Db and Lr data. The measured α energies and emission times for the three events were:

Event #1: 8–Dec–1994

$E_{\alpha 1}$= 533 keV (esc+155–keV X–ray)	t_1=3.600 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10259 keV	t_2=71 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9475 keV	t_3=98 ms	– assigned to	^{264}Bh
$E_{\alpha 4}$= 1969 keV (esc)	t_4=1.969 s	– assigned to	^{260}Db

Event #2: 13–Dec–1994

$E_{\alpha 1}$= 4612 keV (esc)	t_1=0.696 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10097 keV	t_2=171 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9618 keV	t_3=334 ms	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9146 keV	t_4=953 ms	– assigned to	^{260}Db

Event #3: 17–Dec–1994

$E_{\alpha 1}$=10820 keV	t_1=2.042 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10221 keV	t_2=72 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9621 keV	t_3=1.452 s	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9200 keV	t_4=573 ms	– assigned to	^{260}Db
$E_{\alpha 5}$= 8463 keV	t_5=66.3 s	– assigned to	^{256}Lr

These are consistent with one parent state and one daughter state. Identification of other daughter states prevented by the missing α energies in two of the three events due to escape of α from detector.
1998Ho13 also summarize results from previous experiments and observe that the upper limit cross–section for E*=11.1 MeV (no events) was 2.9 Pb (68% c.i.). Cross–sections for events measured at 318 MeV (1 event) and 320 MeV (2 events) were 1.7 Pb 33–14 and 3.5 Pb +46–23, respectively.
IUPAC/IUPAP JWP assessment (2001Ka70): insufficient internal redundancy to warrant conclusive observations.
2002Ho11: experiments repeated at GSI/SHIP, using the UNILAC with the same reaction ^{209}Bi(^{64}Ni,n) at a beam energy of 320 MeV. The irradiation proceeded over 13 days with a total beam dose of 2.2×10^{18} ions. Three events were observed:

Event #1: Energy of the evaporation residue=41.76 MeV

$E_{\alpha 1}$= 3503 keV (esc)	t_1=3.36 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$=10294 keV	t_2=4.23 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9385 keV	t_3=944 ms	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9156 keV	t_4=364 ms	– assigned to	^{260}Db
$E_{\alpha 5}$= 8465 keV	t_5=55.8 s	– assigned to	^{256}Lr

Event #2: Energy of the evaporation residue=36.55 MeV

$E_{\alpha 1}$=11008 keV	t_1=1.38 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$= 6953 keV	t_2=7.32 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9514 keV	t_3=2.99 s	– assigned to	^{264}Bh
$E_{\alpha 4}$= 1706 keV (esc)	t_4=14.98 s	– assigned to	^{260}Db
$E_{\alpha 5}$= 877 keV (esc)	t_5=47.0 s	– assigned to	^{256}Lr

Event #3: Energy of the evaporation residue=39.19 MeV

$E_{\alpha 1}$=11046 keV	t_1=2.70 ms	– assigned to	^{272}Rg
$E_{\alpha 2}$= 765 keV (esc)	t_2=37.14 ms	– assigned to	^{268}Mt
$E_{\alpha 3}$= 9113 keV	t_3=3.01 s	– assigned to	^{264}Bh
$E_{\alpha 4}$= 9129 keV	t_4=4.06 s	– assigned to	^{260}Db
$E_{\alpha 5}$= 8423 keV	t_5=20.6 s	– assigned to	^{256}Lr

5 event average (including data points from 1995Ho04) for t_1=2.3 ms. Two event average (two data points indicating redundancy within current experiment) for Eα=11027 keV. At a beam energy of 320 MeV, a total of 3.3×10^{18} projectiles were delivered over 5 events from both experiments corresponding to an average cross–section of 2.9 pb *+19–13*.
IUPAC/IUPAP JWP assessment (2003Ka71): priority of discovery of Z=111 by 1995Ho04 is now confirmed owing to additional convincing observations reported in 2002Ho11.
2004Fo08: cold fusion experiment done at LBNL using the ^{208}Pb(^{65}Cu,n) reaction. The cross–section was estimated to be 1.7 pb *+39–14*. The $^{65}Cu^{5+}$ beam was provided by the 88–inch cyclotron at a beam energy of 326.9 MeV corresponding to an energy of 321.1 MeV (E*=13.2 MeV) at target center. Recoil products were separated by the BGS. Two runs lasting 5 days each resulted in a total beam dose of 6.6×10^{17} ions. One EVR–α1–α2–α3–α4–α5... Event was observed and attributed to the decay of ^{272}Rg with the following properties:

Continued on next page

Adopted Levels (continued)

Energy of evaporation residue=28.58 MeV

$E_{\alpha 1}$=11042 keV *20* t_1=0.263 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10114 keV *20* t_2=12.6 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 993 keV (esc) t_3=1.16 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9416 keV *20* t_4=1.45 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8613 keV *20* t_5=3.16 s – assigned to ^{256}Lr

ΔE assumed by the evaluators.

2004Mo26 (in a collaboration with French and Chinese scientists): the RILAC was upgraded and the gas filled recoil seperator GARIS was installed for heavy element research. Using the reaction ^{209}Bi(^{64}Ni,n), as in the GSI experiment. Three beam energies were employed: 323 MeV (9 events), 326 MeV (no event at a beam dose of 2.5×10^{18} ions), 320 MeV (3 events), and repeat runs at 323 MeV (2 more events). A total of 14 correlated decay sequences were observed. The cross–sections at each of these energies were 2.6 pb *+23–15* (320 MeV); 2.5 pb *+12–9* (323 MeV); 0.0 pb *+11–0* (326 MeV). The total beam time was 50 days with a beam intensity of 5×10^{12}/s from RILAC. The reaction products were separated in–flight by GARIS filled with He at a pressure of 86 Pa, after which they were guided into a detector system consisting of 2 foil detectors with micro–channel plates (MCP's) and a Si semi–conductor (SSD) box. The detectors were used for the dual purpose of tof and in anti–coincidence mode as a veto for signals coming from the MCP's. The largest probability for accidental signals was determined to be 2.3×10^{-8} with estimates given for different types of events.

Event 1: Feb. 17, 2003; E=(323 MeV); tof=48.3 ns; E(EVR)=33.1 MeV

$E_{\alpha 1}$=11.08 MeV t_1=11.0 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.36 MeV t_2=9.20 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.81 MeV t_3=1.38 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.17 MeV t_4=1.93 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.39 MeV t_5=11.9 s – assigned to ^{256}Lr

Event 2: Feb. 17, 2003; E=(323 MeV); tof=45.8 ns; E(EVR)=33.0 MeV

$E_{\alpha 1}$=11.04 MeV t_1=4.42 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.68 MeV t_2=13.0 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.60 MeV t_3=1.45 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.05 MeV t_4=10.9 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.37 MeV t_5=21.9 s – assigned to ^{256}Lr

Event 3: Feb. 20, 2003; E=(323 MeV); tof=46.5 ns; E(EVR)=33.2 MeV

$E_{\alpha 1}$=11.56 MeV t_1=14.9 ms – assigned to ^{272}Rg
$E_{\alpha 2}$= 1.12 MeV (esc) t_2=122 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.85 MeV t_3=21.8 ms – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.34 MeV t_4=0.505 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.65 MeV t_5=33.5 s – assigned to ^{256}Lr

Event 4: Feb. 26, 2003; E=323 MeV; tof=47.3 ns; E(EVR)=30.5 MeV

$E_{\alpha 1}$=11.25 MeV t_1=1.42 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.43 MeV t_2=36.6 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.66 MeV t_3=1.87 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.40 MeV t_4=1.52 s – assigned to ^{260}Db
$E_{\alpha 5}$= 3.12 MeV (esc) t_5=46.8 s – assigned to ^{256}Lr

Event 5: Feb. 26, 2003; E=323 MeV; tof=46.3 ns; E(EVR)=31.6 MeV

$E_{\alpha 1}$=10.82 MeV t_1=7.11 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.29 MeV t_2=0.715 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.57 MeV t_3=0.543 s – assigned to ^{264}Bh
E_{SF}=231 MeV t_4=1.71 s – assigned to ^{260}Db

Event 6: Apr. 8, 2003; E=323 MeV; tof=47.5 ns; E(EVR)=32.7 MeV

$E_{\alpha 1}$=11.31 MeV t_1=2.82 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.78 MeV t_2=44.0 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.58 MeV t_3=0.442 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 8.81 MeV t_4=48.5 s – assigned to ^{260}Db

Event 7: Apr. 15, 2003; E=323 MeV; tof=47.5 ns; E(EVR)=32.7 MeV

$E_{\alpha 1}$=10.58 MeV t_1=1.17 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.35 MeV t_2=38.3 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.31 MeV t_3=3.6 ms – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.01 MeV t_4=4.87 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.50 MeV t_5=45.8 s – assigned to ^{256}Lr

Event 8: Apr. 15, 2003; E=323 MeV; tof=46.0 ns; E(EVR)=31.1 MeV

$E_{\alpha 1}$=10.96 MeV t_1=8.89 ms – assigned to ^{272}Rg
$E_{\alpha 2}$= 2.76 MeV (esc) t_2=26.2 ms – assigned to ^{268}Mt
E_{SF}=208 MeV t_3=0.967 s – assigned to ^{264}Bh

Event 9: Apr. 16, 2003; E=323 MeV; tof=47.0 ns; E(EVR)=31.1 MeV

$E_{\alpha 1}$=11.06 MeV t_1=5.11 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.43 MeV t_2=19.1 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.50 MeV t_3=1.34 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.10 MeV t_4=3.69 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.41 MeV t_5=48.5 s – assigned to ^{256}Lr

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Adopted Levels (continued)

Event 10: Apr. 30, 2003; E=320 MeV; tof=47.5 ns; E(EVR)=31.0 MeV
$E_{\alpha 1}$=10.21 MeV t_1=1.00 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.03 MeV t_2=8.81 ms – assigned to ^{268}Mt
E_{SF}=206 MeV t_3=4.93 s – assigned to ^{264}Bh
Event 11: May 6, 2003; E=320 MeV; tof=47.8 ns; E(EVR)=32.2 MeV
$E_{\alpha 1}$=10.85 MeV t_1=0.773 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.34 MeV t_2=32.4 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 8.87 MeV t_3=1.91 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 8.50 MeV t_4=21.0 s – assigned to ^{260}Db
Event 12: May 8, 2003; E=320 MeV; tof=47.0 ns; E(EVR)=32.4 MeV
$E_{\alpha 1}$=11.00 MeV t_1=6.92 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.58 MeV t_2=35.5 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.34 MeV t_3=1.00 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.14 MeV t_4=1.14 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.47 MeV t_5=38.6 s – assigned to ^{256}Lr
Event 13: May 8, 2003; E=323 MeV; tof=44.8 ns; E(EVR)=28.9 MeV
$E_{\alpha 1}$=11.01 MeV t_1=6.84 ms – assigned to ^{272}Rg
$E_{\alpha 2}$= 9.40 MeV t_2=37.2 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.56 MeV t_3=1.23 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 8.29 MeV t_4=0.334 s – assigned to ^{260}Db
Event 14: May 12, 2003; E=323 MeV; tof=47.8 ns; E(EVR)=33.0 MeV
$E_{\alpha 1}$=11.08 MeV t_1=4.46 ms – assigned to ^{272}Rg
$E_{\alpha 2}$=10.28 MeV t_2=3.35 ms – assigned to ^{268}Mt
$E_{\alpha 3}$= 9.63 MeV t_3=0.81 s – assigned to ^{264}Bh
$E_{\alpha 4}$= 9.13 MeV t_4=2.42 s – assigned to ^{260}Db
$E_{\alpha 5}$= 8.63 MeV t_5=6.85 s – assigned to ^{256}Lr
Projectile energies in parentheses are uncertain due to target deterioration.

Theory: see Nuclear Science References.

Assignment: ^{209}Bi(^{64}Ni,n) E=318 and 230 MeV (1995Ho04), 320 MeV (2002Ho11), and 320, 323, and 326 MeV (2004Mo26). ^{208}Pb(^{65}Cu,n) E=321 MeV (2004Fo08). IUPAC/IUPAP JWP assessment (2003Ka71): priority of discovery of Z=111 by 1995Ho04 is now confirmed owing to additional convincing observations reported in 2002Ho11. The work of 2004Fo08 and 2004Mo26 provide further support to ^{272}Rg through its decay to the previously unknown daughters ^{268}Mt and ^{264}Bh to the known nuclides ^{260}Db and ^{268}Lr (evaluators).

^{272}Rg Levels

E(level)	$T_{1/2}$	Comments
x	3.8 ms *+14–8*	Jπ: Ω(p)=9/2–; Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$: from average t_1=5.5 ms (14 events. 1 σ. 2004Mo26). Others: 1.6 ms *+11–5* from average t_1=2.3 ms (5 events. 1 σ. 2002Ho11); 3.0 ms *+9–6* from average t_1=4.3 ms (21 events. 1 σ. Evaluators). $T_{1/2}$(calc.)=0.20 ms from Viola–Seaborg systematics for Q(α)=11.15 MeV. An assignment to g.s. is possible; however, being an odd–odd nucleus long–lived isomeric states are likely as may be seen from the variation in half–lives from the data. Redundancy in α energies has been achieved in the case of 5 events (chains 2, 9, and 12–14). The average value for these events was Eα=11045 keV *35* in agreement with the average from 2002Ho11 for two redundant events of 11027 keV *20*. %α≈100. %α: 21 α–decay events observed in four experiments; no SF decay reported. β_2(theory): 0.221 from 1995Mo29; 0.227 from 2003Mu15; 0.240 from 2005GaZX.

Adopted Levels: Not Observed

Q(β^-)=−2730 *SY*; S(n)=5340 *SY*; S(p)=3610 *SY*; Q(α)=9900 *SY* 2003Au03.
Q(β^-): estimated uncertainty=970 keV.
S(n): estimated uncertainty=1010 keV.
S(p): estimated uncertainty=1030 keV.
Q(α): estimated uncertainty=500 keV.
The data of 1999Ni03 cited by 2000Fi12 have been retracted (2002Ni10) and have not been confirmed in a repeated experiment at LBNL (2003Gr26). Also, 2001MoZU and 2000HoZZ found no evidence for ^{293}118 in ^{208}Pb(^{86}Kr,n) reaction at 457.6 MeV (2001MoZU) and at 453.9 and 456.7 MeV (2000HoZZ). The statistical analysis of 2000Sc26 also indicate that the data of 1999Ni03 do not originate from radioactive decays with an error probability of less than 5%.
2003Au02 suggest Jπ=3/2+ based on systematics.

Adopted Levels

Q(β⁻)=–4490; S(n)=5700 *SY*; S(p)=2520 *SY*; Q(α)=11370 *50* 2003Au03.
Q(β⁻): estimated uncertainty=620 keV.
S(n): estimated uncertainty=660 keV.
S(p): estimated uncertainty=500 keV.
Q(α): from Eα=11.20 MeV *2* (2002Ho11) assuming g.s. to g.s. transition.
1996Ho13: daughter of ^{277}112 produced by ^{208}Pb(^{70}Zn,n), E=343.8 MeV (E*=10.1 MeV; σ=1.0 pb +*18*–*4*) at GSI/SHIP. Two α–decay chains observed; first event (dated 1st feb 1996) retracted by 2002Ho11; σ revised to 0.4 pb +*9*–*3*. See ^{277}112 Adopted Levels for details.
1996La12: ^{273}Ds produced by ^{244}Pu(^{34}S,5n) E=190 MeV at Dubna using DGFRS in collaboration with LLNL. 15 candidate α chains of the ^{273}Ds type were observed.
Final candidate α chains reported were:
Chain 1: Energy of evaporation residual=6.39 MeV (FWHM of α's 140 keV)
E(α1)=11.35 MeV *6* t_1=394 μs – ^{273}Ds candidate
– ^{269}Hs not detected
E(α3)= 8.63 MeV *6* t_3=158 s – ^{265}Sg candidate
E(α4)= 8.22 MeV *6* t_4=384 s – ^{261}Rf candidate
Chain 2: Energy of evaporation residual=3.81 MeV (FWHM of α's 120 keV)
E(α1)=11.72 MeV *6* t_1=13.2 ms – ^{273}Ds candidate
– ^{269}Hs not detected
E(α3)= 8.86 MeV *6* t_3=43 s – ^{265}Sg candidate
Chain 3: Energy of evaporation residual=5.65 MeV
E(α1)=10.57 MeV *6* t_1=94.4 ms – ^{273}Ds candidate
– ^{269}Hs not detected
E(α3)= 8.71 MeV *6* t_3=31 s – ^{265}Sg candidate
Chain 4: Energy of evaporation residual=4.78 MeV
E(α)= 10.72 MeV *6* t=125 μs – Unidentified
E(α)= 6.72 MeV *6* t=532 s – Unidentified
E(α)= 8.27 MeV *6* t=442 μs – Unidentified
Chain 5: Energy of evaporation residual=3.72 MeV
E(α1)=10.85 MeV *6* t_1=1.3 ms – ^{273}Ds candidate
E(α2)= 9.81 MeV *6* t_2=1.7 s – ^{269}Hs candidate
E(α3)= 8.51 MeV *6* t_3=73 s – ^{265}Sg candidate
E(α4)= 8.20 MeV *6* t_4=117 s – ^{261}Rf candidate
E(α5)= 8.29 MeV *6* t_5=146 s – ^{257}No candidate
Chain 1 best fit the expected implantation pattern in the position–sensitive detector array and was assigned to ^{273}Ds by 1996La12 based on various considerations (see paper for details). A conservative estimate of the expected number of random four–fold correlations with similar properties is 0.006; this very small but non–zero value allows for possibility that the observed event sequence is of random origin.
Chain 2 also displayed the ^{273}Ds implantation/decay pattern but had several problems associated with it.
1998Ho13: from Q(α) systematics and comparison to theoretical binding calculations, 1998Ho13 conclude that ^{277}112 of chain 2 (1996Ho13) was produced in the deformed ground state and populates the deformed ground state of the daughter. See ^{277}112 Adopted Levels for details.
IUPAC/IUPAP 2001 JWP findings: 1996La12 included for illustrative purposes. See ^{277}112 Adopted Levels for conclusions regarding 1996Ho13.
2002Ho11: daughter of ^{277}112. The experiment of 1996Ho13 was redone at GSI/SHIP. The ^{208}Pb(^{70}Zn,n) reaction was again used at projectile energies of 346.1 MeV (E*=12.0 MeV; σ=0.5 pb +*11*–*4*; 1 event) and 343.8 MeV (E*=10.1 MeV; σ<2.6 pb; 0 events). One EVR–α1–α2–α3–α4–SF event observed. Retracted first observed by 1996Ho13. See ^{277}112 Adopted Levels for details.
IUPAC/IUPAP 2003 JWP (2003Ka71): although the referenced chain's (1996La12) ^{273}112 α energy agrees with that seen by 2002Ho11, the two α's have delay times at sharp variance with the literature values for ^{265}Sg and ^{261}Rf. See also ^{277}112 Adopted Levels for conclusions for Z=112.
2004MoZU: daughter of ^{277}112. Confirmatory experiments performed by the Japanese group at RIKEN with ^{208}Pb(^{70}Zn,^{1}n), E=345.9 MeV (σ=0.44 pb +*59*–*29*). Two EVR–α1–α2–α3–α4–SF events observed. Confirmed results of 2002Ho11. See ^{277}112 Adopted Levels for details.
Other: 2000OgZS.
Theory: see Nuclear Science References.
Assignment: daughter of ^{277}112 produced by ^{208}Pb(^{70}Zn,n) E=343.8 MeV (1996Ho13), 346.1 MeV (2002Ho11), 345.9 MeV (2004MoZU). The ^{277}112 decay chain seems to be well established through ^{265}Sg; see ^{277}112 Adopted Levels for details. In the ^{273}Ds decay chain reported by 1996La12, the ^{269}Hs daughter was not observed and the lifetimes of ^{265}Sg and ^{261}Rf seem unusually long.

Adopted Levels (continued)

^{273}Ds Levels

2000Fi12 adopted a 0.18–ms state as the possible g.s. of ^{273}Ds and an ≈120–ms state based on the α chains reported by 1996Ho13. 2003Au02 adopted a 0.32 ms *28* g.s. (Jπ=13/2– from syst) a possible 198 keV *20* isomeric state ($T_{1/2}$≈120 ms. Jπ=3/2+ from syst), and a possible state at 290 keV *40* based on 2000Fi12. However, the first of the two chains reported by 1996Ho13 was subsequently retracted by 2002Ho11.

Cross Reference (XREF) Flags

A ^{277}112 α Decay

E(level)	XREF	$T_{1/2}$	Comments
0.0	A	0.17 ms *+17–6*	1998Ho13 conclude that the ^{277}112 parent was produced in the deformed ground state and populates the deformed ground state of the daughter. Jπ: 2003Au02 suggest 13/2– based on systematics. $T_{1/2}$: from τ=0.245 ms (arithmetic mean of 0.110 ms (1996Ho13), 0.310 ms (2002Ho11), and 0.52 ms and 0.040 ms (2004MoZU)); uncertainty estimated by the evaluators. $T_{1/2}$(calc)=31.4 μs from Viola–Seaborg systematics for Q(α)=11.370 MeV. Other: τ=0.394 ms (1996La12). %α≈100. %α: from 5/5 events. β_2(theory): 0.222 from 1995Mo29; 0.221 from 2003Mu15; 0.227 from 2005GaZX.
283? *58*	A		

^{277}112 α Decay 1996Ho13,2002Ho11,2004MoZU

Parent ^{277}112: E=0; Jπ=?; $T_{1/2}$=0.69 ms *+69–24*; Q(g.s.)=11594 *55*; %α decay≈100.
^{277}112: 1998Ho13 conclude that the ^{277}112 parent was produced in the deformed ^{273}Ds: ground state and populates the deformed ground state of the daughter.
^{277}112 –J: 2003Au02 suggest 3/2+ based on systematics.
See ^{277}112 Adopted Levels for details.

^{273}Ds Levels

E(level)	$T_{1/2}$	Comments
0.0	0.17 ms *+15–6*	1998Ho13 conclude that the ^{277}112 parent was produced in the deformed ground state and populates the deformed ground state of the daughter. $T_{1/2}$: from the adopted levels.
283? *58*		E(level): from ΔE(α).

α radiations

Eα[†]	E(level)	Comments
11164[§] *22*	283?	Eα: weighted av (ext) of 11.17 MeV *2* (2002Ho11) and 11.09 MeV *7* (2004MoZU).
11427 *54*	0.0	Eα: weighted av (ext) of 11454 keV *20* (1996Ho16) and 11.32 MeV *4* (2004MoZU).

[†] From the energy difference of 284 keV *28* between the data of 1996Ho13 and 2002Ho11 and a similar difference between the two transitions reported by 2004MoZU, the evaluators suggest that two transitions have been observed.
[§] Existence of this branch is questionable.

Adopted Levels: Tentative

S(n)=6180 *SY*; S(p)=910 *SY*; Q(α)=11320 *70* 2003Au03,2004Mo42.
S(n): estimated uncertainty=860 keV.
S(p): estimated uncertainty=630 keV.
Q(α): from Eα=11.15 MeV *7* (2004Mo42). Other: 11.6 MeV *3* (2003Au03. Syst.).
2004Mo42: cold fusion experiment done at RIKEN in collaboration with Chinese scientists in 2003/2004. Reaction: ^{209}Bi(^{70}Zn,n) at a beam energy of 352.6 MeV provided by RILAC corresponding to an energy at target center of 349 MeV. The absolute accuracy of the beam energy was ±0.6 MeV. The production cross–section was 55 fb *+150–45*.
See ^{278}113 Adopted Levels for experimental details.
Event #1: Energy of the evaporation residue=36.75 MeV
$E_{\alpha 1}$=11.68 MeV *4* t_1=344 μs – assigned to ^{278}113
$E_{\alpha 2}$=11.15 MeV *7* t_2=9.26 ms – assigned to ^{274}Rg
$E_{\alpha 3}$=10.03 MeV *7* t_3=7.16 ms – assigned to ^{270}Mt
$E_{\alpha 4}$= 9.08 MeV *4* t_4=2.47 s – assigned to ^{266}Bh
E(SF)=204.1 MeV t(SF)=40.9 s – assigned to ^{262}Db
Other: see 1998Ho13, 1999GrZM, and 1999HoZV for experiments producing Z=113.
Theory: see Nuclear Science References.
Assignments: the assignments are the *most probable* ones for the reaction. Also, the identification of the parent as ^{278}113, α–decay daughter ^{274}Rg, and grand–daughter ^{270}Mt, are all rendered plausible following a consistent comparison of the 4th and 5th events with known descendents. The observation of each isotope in the sequence should be considered as tentative and pending confirmation.

^{274}Rg Levels

Cross Reference (XREF) Flags

A ^{278}113 α Decay: Tentative

E(level)	XREF	Comments
x?	A	Jπ: Ω(p)=3/2–; Ω(n)=13/2– from 1997Mo25 (theory). $T_{1/2}$=6.4 ms *+307–29*. $T_{1/2}$: from Δt=9.26 ms; uncertainty estimated by the evaluators. $T_{1/2}$(calc)=79 μs from Viola–Seaborg systematics for Q(α)=11.315 MeV. %α≈100. %α: assumed from 1/1 event. β_2(theory): 0.222 from 1995Mo29; 0.226 from 2003Mu15; 0.222 from 2005GaZX.

^{278}113 α Decay: Tentative 2004Mo42

Parent ^{278}113: E=x; Jπ=?; $T_{1/2}$=0.2 ms *+12–2*; Q(g.s.)=11850 *40*; %α decay≈100.
^{278}113 –$T_{1/2}$: 0.24 ms *+114–11* (2004Mo42).
^{278}113 –Q(α): from 2004Mo42.
See ^{278}113 Adopted Levels for details.

^{274}Rg Levels

E(level)	Comments
x?	$T_{1/2}$=6.4 ms *+307–29*. E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
11680‡ *40*	x?	Eα: from 2004Mo42.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=–3290 *SY*; S(n)=5540 *SY*; S(p)=4020 *SY*; Q(α)=9440 *70* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=740 keV.
S(n): estimated uncertainty=960 keV.
S(p): estimated uncertainty=1060 keV.
Q(α): from Eα=9.30 MeV *7* (2004Og12). Other: 9.2 MeV *3* (2003Au03. Syst.).
2004Og12,2004OgZZ: as α decay product of ^{287}114 (15 events) and ^{283}112 (7 events). See for ^{287}114 and ^{283}112 Adopted Levels for details. ^{287}114 was synthesized using ^{242}Pu+^{48}Ca at beam energies of 235, 238 and 244 MeV with 5 measurements made at each energy. ^{283}112 was observed using ^{238}U+^{48}Ca at 230 and 234 MeV. One special case attributed to ^{287}114 in the ^{242}Pu reaction at a beam energy of 244 MeV, lasting for 6.5 min, of the type EVR–α1–α2–α3–α4–SF warrants mention. Generally, α decay is blocked below ^{279}Ds which fissions rather than α decays (%α≈10). The evaluators suggest that this longer chain which terminates with ^{271}Sg may, if confirmed, be one incidence of this 10% branch. The α energy for ^{279}Ds from this event is 9.7 MeV *6* with a lifetime of 0.2831 s. Another exception to the fissioning of ^{279}Ds appears in the case of a similar EVR–α1–α2–α3–α4–SF event originating from ^{283}112 in the ^{238}U reaction at 234 MeV. Here, the sequence ends with the fission of ^{267}Rf. The α energy for ^{279}Ds from this event is 9.8 MeV *3* with a lifetime of 0.2775 s. Although both exceptions require further investigation, their radioactive properties agree well with each other and the evaluators suggest that if confirmed, they could represent the 10% α decay branch for ^{279}Ds.
2005Gr19, 2002Lo15: no EVR–α–α correlations with Δt(EVR–α)<20 s or Δt(α–α)<20 s were observed in any of the ^{48}Ca + ^{238}U irradiations. See ^{283}112 Adopted Levels for details.
Theory: see Nuclear Science References.
Assignment: the assignments for Z=112, Z=114 (and Z=116) and their daughters are based on measured excitation functions and in some cases consistency of observed properties produced by cross–bombardments. In particular, the decay properties of ^{283}112 are consistent through the various measurements using the DGFRS, independent of whether they were observed as primary nuclei or as α decay daughters of parents one (Z=114) or two (Z=116) 'levels' up. In the case of ^{287}114, the second α in the decay chain has an energy of 9.54 MeV *6* which agrees well with the four measured α's (2004Og07, 2004Og12) in 11 out of 14 cases. The other three α energies are 8.94, 9.36 and 9.32 MeV which the experimenters suggest may be indicative of transitions to different excited states in the daughter nucleus ^{279}Ds. These two papers are identical in most respects. 2004OgZZ report more statistics in a few cases. Note that 2005Gr19 did not observe any SF decays or EVR–α–α correlations in any ^{48}Ca + ^{238}U irradiations.

^{275}Hs Levels

Cross Reference (XREF) Flags

A ^{279}Ds α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.15 s *+27–6*	Jπ: Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$: from 2 half–lives/2 α events (2004Og12). $T_{1/2}$(calc)=0.81 s from Viola–Seaborg systematics for Q(α)=9.44 MeV. %α≈100. %α: assumed from 2/2 events. β_2(theory): 0.183 from 1995Mo29; 0.211 from 2003Mu26; 0.195 from 2005GaZX.

^{279}Ds α Decay: Tentative 2004Og12

Parent ^{279}Ds: E=x; Jπ=?; $T_{1/2}$=0.18 s *+5–3*; Q(g.s.)=9840 *60*; %α decay≈10.0.
^{279}Ds–$T_{1/2}$: from 2004Og12.
^{279}Ds–Q(α): from 2004Og12.

^{275}Hs Levels

E(level)	$T_{1/2}$	Comments
x?	0.15 s *+27–6*	E(level),$T_{1/2}$: from the Adopted Levels.

^{279}Ds α Decay: Tentative 2004Og12 (continued)

α radiations

Eα	E(level)	Comments
9700‡ *60*	x?	Eα: from 2004Og12.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=−3290 *SY*; S(n)=7000 *SY*; S(p)=2150 *SY*; Q(α)=10480 *90* 2003Au03,2004Og03.
Q(β⁻): estimated uncertainty=740 keV.
S(n): estimated uncertainty=810 keV.
S(p): estimated uncertainty=880 keV.
Q(α): from Eα=10.33 MeV *9* (2004Og03). Other: 10.12 MeV *20* (2003Au03. Syst).
2003OgZY, 2004Og03: identification of new nuclides: ^{287}115, ^{288}113, ^{279}Rg, ^{275}Mt and ^{267}Db. Reaction: ^{243}Am(^{48}Ca,4n) E=253 MeV corresponding to an excitation energy of 42.4 to 46.5 MeV at the target center. ^{287}115 was formed at a cross–section of 0.9 pb *+32–8*. The target was 99% enriched ^{243}Am. Experiments were done at the U400 cyclotron with the DGFRS at FLNR, JINR in collaboration with LLNL, USA. The evaporation residues recoiling from the target were separated by DGFRS in flight from the ^{48}Ca beam ions, scattered particles and transfer–reaction products.
Detection system: multiwire proportional counter for tof measurement; semi–conductor focal–plane detector array with 12 vertical position– sensitive strips, which measured the decay of the implanted recoils. This detection system surrounded by eight side detectors with no position sensitivity. The α spectrum was measured in the range 9.6 to 11.0 MeV. Resolution: FWHM=60–100 keV for α particles absorbed in the focal–plane detector. 140–200 keV for α's escaping the focal–plane detector and registered by the side detectors.
Results: one decay chain with four consecutive α decays detected in a time interval of 0.5 s (in the beam–off mode) terminated by an SF event with a release of kinetic energy of 206 MeV. This event was assigned to ^{243}Am(^{48}Ca,4n) channel with the production of the parent nuclide ^{287}115. The fourth event in the sequence was ^{275}Mt whose properties appear below.
Energy of the evaporation residue=12.2 MeV
E_α=10330 keV t=14 ms – assigned to ^{275}Mt
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: the identification of Z=115 and 113 and all associated nuclides in the chain should be treated as tentative until confirmed by independent experiments.

^{275}Mt Levels

Cross Reference (XREF) Flags

A ^{279}Rg α Decay: Tentative

E(level)	XREF	Comments
x?	A	Jπ: Ω(p)=11/2+ from 1997Mo25 (theory). $T_{1/2}$=9.7 ms *+460–44* (2004Og03). $T_{1/2}$: $T_{1/2}$(calc)=2.3 ms from Viola–Seaborg systematics for Q(α)=10.48 MeV. %α≈100. %α: assumed from one event. β_2(theory): 0.212 from 1995Mo29; 0.215 from 2003Mu26; 0.202 from 2005GaZX.

^{279}Rg α Decay: Tentative 2003OgZY,2004Og03

Parent ^{279}Rg: E=x; Jπ=?; $T_{1/2}$=0.17 s *+81–8*; Q(g.s.)=10520 *160*; %α decay≈100.
^{279}Rg–$T_{1/2}$: from 2004Og03.
^{279}Rg–Q(α): from 2004Og03.
See ^{279}Rg Adopted Levels for details.

^{275}Mt Levels

E(level)	Comments
x?	$T_{1/2}$=9.7 ms *+460–44*. E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
10370 *160*	x?	Eα: from 2004Og03.

Adopted Levels: Tentative

Q(β⁻)=–1750 *SY*; S(n)=5730 *SY*; S(p)=2440 *SY*; Q(α)=9850 *60* 2003Au03,2004Og03.
Q(β⁻): estimated uncertainty=910 keV.
S(n): estimated uncertainty=900 keV.
S(p): estimated uncertainty=990 keV.
Q(α): from Eα=9.71 MeV *6* (2004Og03). Other: 9.8 MeV *3* (2003Au03. Syst.).
2003OgZY and 2004Og03: identification of new nuclides: ^{288}115, ^{284}113, ^{280}Rg, ^{276}Mt, ^{272}Bh, and ^{268}Db. ^{276}Mt observed as great–granddaughter of 288115.
Reaction: ^{243}Am(^{48}Ca,3n) E(lab)=248 MeV corresponding to an excitation energy of 38.0 to 42.5 MeV at the target center. Experiments performed by the Dubna–LLNL collaboration. Z=115 was formed at a cross–section of 2.7 pb *+48–16*.
Experiments were done at the U400 cyclotron with the Dubna gas–filled recoil seperator (DGFRS) at FLNR–JINR in collaboration with LLNL, USA. The EVR's recoiling from the target were separated by DGFRS in flight from the ^{243}Am+^{48}Ca beam ions, scattered particles, and transfer–reaction products with a transmission efficiency of 35% for Z=115 nuclei.
Detection system: multiwire proportional counter for tof measurement; semi–conductor focal–plane detector array with 12 vertical position–sensitive strips, which measured the decay of the implanted recoils. This detection system surrounded by eight side detectors with no position sensitivity. The α spectrum was measured in the range 9.6 to 11.0 MeV. The resolution of the detector system was FWHM=60–100 keV for α particles absorbed in the focal–plane detector; 140–200 keV for α's escaping the focal–plane detector and registered by the side detectors.
Three similar decay chains with five consecutive α decays were detected in a time interval of 20 s (in the beam–off mode following the first recoil expected to belong to Z=115) terminated by an SF event with a release of total kinetic energy of ≈220 MeV. These events were assigned to the (^{48}Ca,3n) channel with the production of the parent nuclide ^{288}115; the fourth event in the chain was assigned to ^{276}Mt. Properties of ^{276}Mt from the three chains are listed below by event.
Event #1: Energy of the evaporation residue=10.4 MeV
E_α=9650 keV t=1.055 s – assigned to ^{276}Mt
Event #2: Energy of the evaporation residue=11.0 MeV
E_α=9800 keV t=0.249 s – assigned to ^{276}Mt
Event #3: Energy of the evaporation residue=9.1 MeV
E_α=9740 keV t=1.834 s – assigned to ^{276}Mt
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: descendent of ^{288}115 produced by ^{243}Am(^{48}Ca,3n) E=248 MeV (2003OgZY,2004Og03) and E=243 MeV, chem (2004DmZZ). The evaluators suggest that 2004DmZZ offers independent support to the synthesis of ^{288}115 (2004Og03) having precisely determined the atomic number for Z=105 by isolation of Group V elements. The properties are in agreement with ^{268}Db measured in the three chains seen earlier by 2004Og03, thereby providing evidence in favor of the synthesis of ^{288}115 and daughters. However, since the identification relies on the measurement of SF fragments, the possibility that the observed nucleus is actually ^{268}Rf following (undetected) ε from the parent ^{268}Db, cannot be excluded.

^{276}Mt Levels

Cross Reference (XREF) Flags

A ^{280}Rg α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.72 s *+87–25*	Jπ: Ω(p)=11/2+; Ω(n)=5/2+ from 1997Mo25 (theory). $T_{1/2}$: $T_{1/2}$(calc)=0.11 s from Viola–Seaborg systematics for Q(α)=9.85 MeV. %α≈100. %α: assumed from three events. β_2(theory): 0.202 from 1995Mo29; 0.211 from 2003Mu26; 0.193 from 2005GaZX.

^{280}Rg α Decay: Tentative 2004Og03

Parent ^{280}Rg: E=x; Jπ=?; $T_{1/2}$=3.6 s *+43–13*; Q(g.s.)=9870 *60*; %α decay≈100.
^{280}Rg–$T_{1/2}$: from 2004Og03.
^{280}Rg–Q(α): from 2004Og03.
See ^{280}Rg Adopted Levels for details.

^{280}Rg α Decay: Tentative 2004Og03 (continued)

^{276}Mt Levels

E(level)	$T_{1/2}$	Comments
x	0.72 s *+87–25*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
9750 *60*	x	Eα: from 2004Og03.

Adopted Levels: Not Observed

Q(β^-)=−2400 *SY*; S(n)=5620 *SY*; Q(α)=8400 *SY* 2003Au03.
Q(β^-): estimated uncertainty=1140 keV.
S(n): estimated uncertainty=1100 keV.
Q(α): estimated uncertainty=300 keV.
2000Fi12 tentatively adopted the Dubna data for ^{289}114 produced by ^{244}Pu(^{48}Ca,3n) as reported by 1999GhZZ (see 1999Og10, 2000Og07, and 2001Og11). The one chain of α events culminating in the SF decay of ^{277}Hs was reassigned to ^{290}114 by 2004Og10. Subsequent decay chains assigned to ^{289}114 terminated with the SF decay of ^{281}Ds.
2004Mo15: the evaluators believe that this report summarized data for two ^{289}114 chains prior to reassignment. Thus, the two events attributed to ^{277}Hs terminating the sequence have also been reassigned.
2003Au02 suggest Jπ=3/2+ based on systematics.

Adopted Levels: Not Observed

Q(β^-)=−3610 *SY*; S(n)=12910 *SY*; S(p)=5550 *SY*; Q(α)=10300 *SY* 2003Au03.
Q(β^-): estimated uncertainty=1150 keV.
S(n): estimated uncertainty=1070 keV.
S(p): estimated uncertainty=1200 keV.
Q(α): estimated uncertainty=500 keV.
The data of 1999Ni03 cited by 2000Fi12 have been retracted (2002Ni10) and have not been confirmed in a repeated experiment at LBNL (2003Gr26). Also, 2001MoZU and 2000HoZZ found no evidence for ^{293}118 in ^{208}Pb(^{86}Kr,n) reaction at 457.6 MeV (2001MoZU) and at 453.9 and 456.7 MeV (2000HoZZ). The statistical analysis of 2000Sc26 also indicate that the data of 1999Ni03 do not originate from radioactive decays with an error probability of less than 5%.
2003Au02 suggest Jπ=11/2+ based on systematics.

Adopted Levels

S(p)=2210 *SY*; Q(α)=11594 *55* 2003Au03.

S(p): estimated uncertainty=640 keV.

Q(α): from Eα=11427 keV *54* (weighted av (ext) of 11454 keV *20* (1996Ho16) and 11.32 MeV *4* (2004MoZU)) assuming transition is g.s. to g.s. Other: 11620 keV *30* (2003Au03) assuming 11454 keV *20* (1996Ho13) transition is g.s. to g.s.

1996Ho13: GSI/SHIP cold fusion experiment in collaboration with scientists from Russia, Slovakia and Finland. ^{208}Pb(^{70}Zn,n) at 4.91 MeV/nucleon. The beam energy chosen was 343.8 MeV corresponding to an excitation energy E*=10.1 MeV. Total of 3.4×10^{18} projectile particles. ^{70}Zn$^{(10+)}$ charge state delivered on a target 99% enriched. The measured cross–section for 1*n* channel was 1.0 pb *+18–4*. Observed position and time correlated chains of α particle events. Determined α energies and time intervals between successive particles. Assigned to decay of ^{277}112 by consistency of lower chain member energies and lifetimes with known Rf and Sg data. The experiments were carried out from January 26, 1996 to February 18, 1996. Event 1 was observed on February 1st with: E1=11649 keV *20*, t_1=400 μs. Event 2, characterized by E2=11454 keV *20*, t_2=280 μs was observed on February 9th. Average half–life quoted: $T_{1/2}$=240 μs *+430–90*.

First α–decay chain (1–Feb–1996) stands retracted (2002Ho11).

Event #2: 9–Feb–1996 (Energy of the evaporation residue=32.0 MeV)

$E_{\alpha 1}$=11454 keV *20* t_1=280 μs – assigned to ^{277}112
$E_{\alpha 2}$=11083 keV *20* t_2=110 μs – assigned to ^{273}Ds
$E_{\alpha 3}$= 9230 keV *20* t_3=19.7 s – assigned to ^{269}Hs
$E_{\alpha 4}$= 4600 keV (esc) t_4=7.4 s – assigned to ^{265}Sg
$E_{\alpha 5}$= 8520 keV *20* t_5=4.7 s – assigned to ^{261}Rf
$E_{\alpha 6}$= 8340 keV *20* t_6=15.0 s – assigned to ^{257}No

No spontaneous fission events observed in 1996Ho13.

1998Ho13: the calculated lifetime of 67 μs for Δ*l*=0 compares well with ^{273}112 110 μs (1996Ho13) indicating that the transition is unhindered and connects analagous states of the parent and daughter nuclei. The trend of Q(α) shows that the smooth dependence as a function of neutron number is broken for chain 2 (1996Ho13) when N=162 is crossed. Similar irregularities of the Q(α) systematics is observed near closed shells. From comparisons to theoretical binding energy calculations (1995Mo29, 1995Sm05), the observed properties of chain 2 (1996Ho13) are in good agreement with the calculated binding energies of the ground state. Therefore, 1998Ho13 conclude that ^{277}112 of chain 2 (1996Ho13) was produced in the deformed ground state and populates the deformed ground state of the daughter.

IUPAC/IUPAP 2001 JWP findings (2001Ka70) were that there was insufficient internal redundancy to warrant conviction especially with regard to known daughters.

2002Ho11: the experiment of 1996Ho13 was redone at GSI/SHIP from May 3–29, 2000. The ^{208}Pb(^{70}Zn,n) reaction was again used at projectile energies of 346.1 MeV (E*=12.0 MeV; σ=0.5 pb *+11–4*; 1 event) and 343.8 MeV (E*=10.1 MeV; σ<2.6 pb; 0 events). E*=12.0 MeV was expected to be the maximum cross–section. The total beam dose was 3.5×10^{18} ions. One new α decay chain was measured on may 5th, 2000 at a deduced cross–section of 0.5 pb *+11–4*. This new chain ends at ^{261}Rf by a previously unknown SF branch. No new decay sequence was observed when the experiment was repeated at the lower energy of 343.8 MeV as employed in the 1996Ho13. A reanalysis of raw data from the first experiment revealed inconsistencies between the binary files stored and the event–by–event text files, on the basis of which preliminary assignments were made in the case of the first decay chain (February 1, 1996). The chain was found to be spurious and was retracted. A revised mean value for the cross–section of the data point at E*=10.1 MeV is 0.4 pb *+9–3*. The third chain (current work) is in agreement with data from the second chain of 1996Ho13 (February 9, 1996):

Event # 3: 5–May–2000 (Energy of the evaporation residue=24.1 MeV)

$E_{\alpha 1}$=11170 keV *20* t_1=1406 μs – assigned to ^{277}112
$E_{\alpha 2}$=11200 keV *20* t_2=310 μs – assigned to ^{273}Ds
$E_{\alpha 3}$= 9180 keV *20* t_3=22.0 s – assigned to ^{269}Hs
$E_{\alpha 4}$= 200 keV (esc) t_4=18.8 s – assigned to ^{265}Sg
E_{SF}= 153 MeV t(SF)=14.5 s – assigned to ^{261}Rf

2002Ho11 state that unambiguous assignments are possible for the nucleus ^{277}112 and its daughter ^{273}Ds based on verification of the properties of ^{269}Hs, ^{265}Sg, ^{261}Rf, ^{257}No and ^{253}Fm from other independent experiments including chemical investigations (references in this paper), which have played a crucial role in determining the most probable identity of each of the nuclides in the series.

IUPAC/IUPAP 2003 JWP (2003Ka71) note that neither of the two chains are completely characterized on their own merit. Supportive, independent results on intermediates are not convincing.

2004MoZU: confirmatory experiments performed by the Japanese group at RIKEN using the reaction ^{208}Pb(^{70}Zn,n). The beam provided by RILAC had an energy of 349.5 MeV *6* corresponding to 345.9 MeV at target center. Typical beam intensity on target was 1.7×10^{12}/s with a total beam dose of 4.4×10^{18} ions. 16 targets were mounted on a wheel 30 cm in diameter rotating at 2000 rpm. The reaction products were separated by He–filled GARIS and guided into a detector module. Assuming an 80% transmission efficiency for GARIS, the production cross–section was deduced to be 0.44 pb *+59–29*. Two events were observed of the type EVR–α1–α2–α3–α4–SF:

Continued on next page

Adopted Levels (continued)

Event #1: Energy of the evaporation residue=34.25 MeV
$E_{\alpha 1}$=11090 keV *70* t_1=1.10 ms – assigned to ^{277}112
$E_{\alpha 2}$=11140 keV *40* t_2=0.52 ms – assigned to ^{273}Ds
$E_{\alpha 3}$= 9170 keV *40* t_3=14.2 s – assigned to ^{269}Hs
$E_{\alpha 4}$= 8710 keV *40* t_4=23.0 s – assigned to ^{265}Sg
E_{SF}= 197.3 MeV t(SF)=2.97 s – assigned to ^{261}Rf
Event #2: Energy of the evaporation residue=35.15 MeV
$E_{\alpha 1}$=11320 keV *40* t_1=1.22 ms – assigned to ^{277}112
$E_{\alpha 2}$=11150 keV *70* t_2=0.04 ms – assigned to ^{273}Ds
$E_{\alpha 3}$= 9250 keV *70* t_3=0.27 s – assigned to ^{269}Hs
$E_{\alpha 4}$= 8700 keV *70* t_4=79.9 s – assigned to ^{265}Sg
E_{SF}= 156.3 MeV t(SF)=8.30 s – assigned to ^{261}Rf

The highest probability for randomness was calculated to be 3×10^{-4} in the case of ^{265}Sg in the second decay chain.

Other: 2004Og12 and 2004OgZZ obtain an upper limit of 0.6 pb for ^{233}U(^{48}Ca,*2–4n*)$^{277-279}$112 at E_{lab}=240 MeV.

Theory: see Nuclear Science References.

Assignment: ^{208}Pb(^{70}Zn,n) E=343.8 MeV (1996Ho13), 346.1 MeV (2002Ho11), 345.9 MeV (2004MoZU). The decay properties of the one chain reported by 1996Ho13, one chain reported by 2002Ho11, and the two chains reported 2004MoZU are consistent and are also in agreement with the properties of the three ^{269}Hs chains reported by 2003Tu05 (^{248}Cm(^{26}Mg,5n) E=143.7–146.8 MeV; chem). Decay properties of these seven chains also appear consistent with literature data for ^{265}Sg but not for ^{261}Rf. Comparing their data, that of 1996Ho13, and preliminary results from 2003Tu05 to the available literature data, 2002Ho11 conclude that two states exist in ^{261}Rf with $T_{1/2}$'s of 78 s *+11–6* and 4.2 s *+34–13*. The first state decays by a 8.28–MeV α and the second, by 8.52–MeV α emission and spontaneous fission (≈40%). Based on a private communication from A.H. Wapstra, 2002Ho11 suggest that the 8.52–MeV α fits better the systematics of ground–state α energies and, therefore, tentatively assign the 4.2–s state as the ground state and the 78–s state could be a higher spin isomer since these are preferentially produced in heavy–ion fusion reactions. The data of 2004MoZU tend to support these conclusions although the estimate of the fission branching ratio may increase. In the ^{273}Ds chain reported by 1996La12 (^{244}Pu(^{34}S,5n) E=190 MeV), ^{269}Hs was not observed and the lifetimes of ^{265}Sg and ^{261}Rf seem unusually long. While there may still be problems with ^{261}Rf, the ^{277}112 decay chain seems to be well established through ^{265}Sg.

^{277}112 Levels

E(level)	$T_{1/2}$	Comments
0.0	0.69 ms *+69–24*	1998Ho13 conclude ^{277}112 was produced in the deformed ground state and populates the deformed ground state of the daughter. Jπ: 2003Au02 suggest 3/2+ based on systematics. $T_{1/2}$: from τ=1.00 ms (arithmetic mean of 0.28 ms (1996Ho13), 1.406 ms (2002Ho11), and 1.10 ms and 1.22 ms (2004MoZU)); uncertainty estimated by the evaluators. $T_{1/2}$(calc)=34 μs from Viola–Seaborg systematics for Q(α)=11.594 MeV. %α≈100. %α: from 4/4 events. Predicted β (1997Mo25) and SF (1995Ho27,1997Sm03) half–lives much longer than those predicted and observed for α emission. β_2(theory): 0.202 from 1995Mo29; 0.208 from 2003Mu15; 0.199 from 2005GaZX.

Adopted Levels: Not Observed

See ^{289}114 Adopted Levels for details of the experiments.

2004Og10: the reinterpretation of one long lived decay chain first observed in 1999Og10 at Dubna, and tentatively assigned to the decay of ^{289}114, is now proposed as possibly originating from the CN ^{290}114 *via* the 2*n* channel. The subsequent α–decays would then be: $^{286}112 \rightarrow ^{282}Ds \rightarrow ^{278}Hs$ (SF). The cross–section for this event was ≈0.2 picobarn in the reaction $^{244}Pu + ^{48}Ca$ at 236 MeV (E*=35 MeV). This event was not observed in later experiments done at energies of E*=41–53 MeV (2000Og05,2000Og07). The α particle energy of the first decay is ≈0.1 MeV less than that attributed to ^{289}114 from later work. An alternative interpretation based on calculations (1999Cw01) is that this chain may belong to a rare decay branch of ^{289}114 starting from an excited state and going to low lying levels in the daughter governed by the appropriate selection rules. 3 minute α–SF event observed in 1999Og07 at E*=32.6 MeV for ^{290}114 and assigned to ^{287}114 not seen by 2004Og10.

Assignment: IUPAP/IUPAC JWP assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays. The evaluators believe that there is too little data to support the assignment of this decay chain to either ^{290}114 or ^{289}114 and, therefore, ^{290}114, ^{286}112, ^{282}Ds and ^{278}Hs remain unobserved. See the General Comments for more details.

Theory: see Nuclear Science References.

Adopted Levels: Tentative

Q(α)=11850 *40* 2004Mo42.

Q(α): from Eα=11.68 MeV *4*.

1998Ho13: excitation functions for the production of odd–elements were undertaken. Cross sections measured at GSI/SHIP using ^{209}Bi targets. Results favored ^{70}Zn for the production of Z=113. Extensive systematics indicated a cross section limit of between 1 and 0.3 pb for ^{278}113 with the reaction ^{209}Bi(^{70}Zn,n) and between 1 and 0.1 pb for ^{283}114 with ^{208}Pb(^{76}Ge,n).

1999GrZM, 1999HoZV: experiments optimized to observe Z=113 at a cross section window of 0.3 to 1.0 pb in the reaction ^{209}Bi(^{70}Zn,n). Production runs were carried out in April/may 1998 over two periods with total beam doses of 4.5×10^{18} (25 days) and 3.0×10^{18} (21 days) of the ^{70}Zn projectile. Two beam energies were used: 4.97 AMeV and 5.0 AMeV resulting in CN excitation energies of 9.85 and 11.57 MeV, respectively. Cross section limits obtained were 0.9 and 1.4 pb for the two energies at the 68% confidence level. The quoted weighted average excitation energy was 10.54 AMeV for an effective cross– section of 0.6 pb (arrived at by combining the two measured cross–sections). No events were observed in either run.

2004Mo42: cold fusion experiment done at RIKEN in collaboration with Chinese scientists in 2003/2004. Reaction: ^{209}Bi(^{70}Zn,n) at a beam energy of 352.6 MeV provided by RILAC corresponding to an energy at target center of 349 MeV. The absolute accuracy of the beam energy was ±0.6 MeV. The production cross–section was 55 fb *+150–45*. Sixteen targets were mounted on a rotating wheel (2000 rpm) with a diameter of 30 cm. Products following the reaction were separated in–flight by GARIS (2004Mo40) filled with He gas, and guided into a focal plane detector consisting of a timing module with microchannel plates (MCP) and a SSD (Si semiconductor detector) box which included one detector with 16 position sensitive strips (PSD). EVR's were implanted in the PSD after they pass through the timing counters. A total of 1.7×10^{19} ions impinged on the target; transmission efficiency of GARIS was 0.8 (2004Mo26). The excitation energy of the ^{279}113 CN was calculated to be 14.1 MeV *20*. A single EVR–α1–α2–α3–α4–SF sequence was observed on 23 July 2004:

Event #1: Energy of the evaporation residue=36.75 MeV

$E_{\alpha 1}$=11.68 MeV *4* t_1=344 μs – assigned to ^{278}113
$E_{\alpha 2}$=11.15 MeV *7* t_2=9.26 ms – assigned to ^{274}Rg
$E_{\alpha 3}$=10.03 MeV *7* t_3=7.16 ms – assigned to ^{270}Mt
$E_{\alpha 4}$= 9.08 MeV *4* t_4=2.47 s – assigned to ^{266}Bh
E(SF)=204.1 MeV t(SF)=40.9 s – assigned to ^{262}Db

Theory: see Nuclear Science References.

Assigments: the assignments are the *most probable* ones for the reaction. Also, the identification of the parent as ^{278}113, α–decay daughter ^{274}Rg, and grand–daughter ^{270}Mt, are all rendered plausible following a consistent comparison of the 4th and 5th events with known descendents. The observation of each isotope in the sequence should be considered as tentative and pending confirmation.

^{278}113 Levels

E(level)	Comments
x?	Jπ: Ω(p)=3/2–; Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$=0.24 ms *+114–11*. $T_{1/2}$: from Δt=344 μs; uncertainty estimated by the evaluators. $T_{1/2}$(calc)=16.9 μs from Viola–Seaborg systematics for Q(α)=11.85 MeV. %α≈100. %α: assumed from 1/1 event. β_2(theory): 0.184 from 1995Mo29; 0.196 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=–3360; S(n)=5840 *SY*; S(p)=3520 *SY*; Q(α)=9840 *60* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=1000 keV.
S(n): estimated uncertainty=1010 keV.
S(p): estimated uncertainty=1120 keV.
Q(α): from Eα=9.70 MeV *6* (2004Og12). Other: 9.60 MeV *20* (2003Au03. Syst.).
2004Og07 (see also 2004Og05): terminates ER–α1–α2–α3–SF sequence from ^{291}116 (2 events) and EVR–α1–α2–SF chain from ^{287}114 (1 event). See ^{287}114 and ^{291}116 Adopted Levels for details of experimental set–up. Experiments were done at Dubna in collaboration with LLNL. The current and all subsequent investigations were carried out using the DGFRS. The synthesis of ^{287}114 was done using a ^{244}Pu target at a ^{48}Ca beam energy of 257 MeV in the 5*n* evaporation channel. In the case of ^{291}116 (1*n*), a ^{245}Cm target was used and bombarded with ^{48}Ca ions at an energy of 243 MeV. In all cases ^{279}Ds fissions spontaneously and its attributes were as follows:
E(tot)=206 MeV [176+30 MeV, focal plane and side detector], t(SF)=0.319 s as observed at the end of the single ^{287}114 chain;
E(tot)=205 MeV [188+17 MeV, focal plane and side detector], t(SF)=0.687 s (event 1) and E(tot)=177 MeV [one detector only] t(SF)=0.256 s (event 2) ending the ^{291}116 sequence.
The combined $T_{1/2}$(SF) from all 3 events was reported as 0.29 s *+35–10*.
2004Og12,2004OgZZ: as α decay product of ^{287}114 (15 events) and ^{283}112 (7 events). See for ^{287}114 and ^{283}112 Adopted Levels for details. ^{287}114 was synthesized using ^{242}Pu+^{48}Ca at beam energies of 235, 238 and 244 MeV with 5 measurements made at each energy. ^{283}112 was observed using ^{238}U+^{48}Ca at 230 and 234 MeV. One special case attributed to ^{287}114 in the ^{242}Pu reaction at a beam energy of 244 MeV, lasting for 6.5 min, of the type EVR–α1–α2–α3–α4–SF warrants mention. Generally, α decay is blocked below ^{279}Ds which fissions rather than α decays (%α≈10). The evaluators suggest that this longer chain which terminates with ^{271}Sg may, if confirmed, be one incidence of this 10% branch. The α energy for ^{279}Ds from this event is 9.7 MeV *6* with a lifetime of 0.2831 s. Another exception to the fissioning of ^{279}Ds appears in the case of a similar EVR–α1–α2–α3–α4–SF event originating from ^{283}112 in the ^{238}U reaction at 234 MeV. Here, the sequence ends with the fission of ^{267}Rf. The α energy for ^{279}Ds from this event is 9.8 MeV *3* with a lifetime of 0.2775 s. Although both exceptions require further investigation, their radioactive properties agree well with each other and the evaluators suggest that if confirmed, they could represent the 10% α decay branch for ^{279}Ds.
^{283}112 was created in the complete fusion reaction ^{238}U(^{48}Ca,4n) at Dubna using the DGFRS. A total of 8 decay sequences were observed assigned to Z=112: seven EVR–α–SF events spanning about 0.5–6 s observed at E(beam)=230–234 MeV assigned to ^{283}112 and a shorter EVR–SF sequence with $T_{1/2}$(SF)<1 ms observed at an energy of 240 MeV assigned to ^{282}112. The mean α energy was 9.54 MeV in agreement with 2004Og07. No events that could be assigned to Z=112 were found in the reaction ^{233}U+^{48}Ca at 240 MeV despite an accumulated beam dose of 8×10^{8} ions. See 2004Og12 and 2004OgZZ for a detailed discussion.
The evaluators note that the radioactive properties for the current nucleus as shown in this work, 2004Og12 and 2004Og07 all using the DGFRS, are in agreement with each other whereas they differ considerably from results obtained in experiments using the VASSILISSA separator. Further investigations may be warranted to resolve the existing ambiguities in the data.
2005Gr19, 2002Lo15: no EVR–α–α correlations with Δt(EVR–α)<20 s or Δt(α–α)<20 s were observed in any of the ^{48}Ca + ^{238}U irradiations. See ^{283}112 Adopted Levels for details.
Theory: see Nuclear Science References.
Assignment: the assignments for Z=112, Z=114 (and Z=116) and their daughters from recent experiments using DGFRS are based on measured excitation functions and in some cases consistency of observed properties produced by cross–bombardments. In particular, the decay properties of ^{283}112 are consistent through the various measurements using the DGFRS, independently of whether they were observed as primary nuclei or as α decay daughters of parents one (Z=114) or two (Z=116) 'levels' up. In the case of ^{287}114, the second α in the decay chain has an energy of 9.54 MeV *6* which agrees well with the four measured α's (2004Og07, 2004Og12) in 11 out of 14 cases. The other three α energies are 8.94, 9.36 and 9.32 MeV which the experimenters suggest may be indicative of transitions to different excited states in the daughter nucleus ^{279}Ds. Note that 2005Gr19 did not observe any SF decays or EVR–α–α correlations in any ^{48}Ca + ^{238}U irradiations.

^{279}Ds Levels

Cross Reference (XREF) Flags

A ^{283}112 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.18 s *+5–3*	Jπ: Ω(n)=15/2– from 1997Mo25 (theory). $T_{1/2}$: for 21 half–lives/2 α particle energies from 2004Og12. $T_{1/2}$(calc)=0.25 s from Viola–Seaborg systematics for Q(α)=9.84 MeV. %α≈10; %SF≈90. %α,%SF: from 2004Og12. β_2(theory): 0.127 from 1995Mo29; 0.197 from 2003Mu15; 0.177 from 2005GaZX.
x+2.7×10³? *10*	A		
x+3.1×10³? *9*	A		

Continued on next page

Adopted Levels: Tentative (continued)

^{279}Ds Levels (continued)

E(level)	XREF
x+6.9×10^3? *9*	A

^{283}112 α Decay: Tentative 2004Og12

Parent ^{283}112: E=x; Jπ=?; $T_{1/2}$=4.0 s *+13–7*; Q(g.s.)=9760 *60*; %α decay≥99.0.
^{283}112 –$T_{1/2}$: from 2004Og12.
^{283}112 –Q(α): from 2004Og12.
See ^{283}112 Adopted Levels for details.

^{279}Ds Levels

E(level)	$T_{1/2}$	Comments
x	0.18 s *+5–3*	E(level),$T_{1/2}$: from the Adopted Levels.
x+2.7×10^3?† *10*		
x+3.1×10^3?† *9*		
x+6.9×10^3?† *9*		

† From Q(α) and Eα (evaluators).

α radiations

Eα	E(level)	Iα‡
8940†§ *70*	x+6.9×10	†
9320†§ *60*	x+3.1×10	†
9360†§ *80*	x+2.7×10	†
9540 *60*	x	

† 2004Og12 note that the energies of these three α's differ enough from the average Eα that they are outside the experimental uncertainties in measuring α–energies with the focal–plane detector and, therefore, correspond to transitions to various excited states in ^{279}Ds. The estimated probability of such transitions is about 20%.
‡ For α intensity per 100 decays, multiply by ≥0.99.
§ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=–3800 *SY*; S(n)=7270 *SY*; S(p)=1700 *SY*; Q(α)=10520 *160* 2003Au03,2004Og03.
Q(β⁻): estimated uncertainty=830 keV.
S(n): estimated uncertainty=920 keV.
S(p): estimated uncertainty=950 keV.
Q(α): from Eα=10.37 MeV *16* (2004Og03). Other: 10.45 MeV *85* (2003Au03. Syst.).
2003OgZY, 2004Og03: identification of new nuclides: ^{287}115, ^{288}113, ^{279}Rg, ^{275}Mt and ^{267}Db. Reaction: ^{243}Am(^{48}Ca,4n) E=253 MeV corresponding to an excitation energy of 42.4 to 46.5 MeV at the target center. ^{287}115 was formed at a cross–section of 0.9 pb *+32–8*. The target was 99% enriched ^{243}Am. Experiments were done at the U400 cyclotron with the DGFRS at FLNR–JINR in collaboration with LLNL, USA. The evaporation residues recoiling from the target were separated by DGFRS in flight from the ^{48}Ca beam ions, scattered particles and transfer–reaction products.
Detection system: multiwire proportional counter for tof measurement; semi–conductor focal–plane detector array with 12 vertical position– sensitive strips, which measured the decay of the implanted recoils. This detection system surrounded by eight side detectors with no position sensitivity. The α spectrum was measured in the range 9.6 to 11.0 MeV. Resolution: FWHM=60–100 keV for α particles absorbed in the focal–plane detector. 140–200 keV for α's escaping the focal–plane detector and registered by the side detectors.
Results: one decay chain with four consecutive α decays detected in a time interval of 0.5 s (in the beam–off mode) terminated by an SF event with a release of kinetic energy of 206 MeV. This event was assigned to ^{243}Am(^{48}Ca,4n) channel with the production of the parent nuclide ^{287}115. The third event in the sequence was ^{279}Rg, with the properties listed below.
Energy of the evaporation residue=12.2 MeV
E_α=10370 keV t=170 ms – assigned to ^{279}Rg
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: the identification of Z=115 and 113 and all associated nuclides in the chain should be treated as tentative until confirmed by independent experiments.

^{279}Rg Levels

Cross Reference (XREF) Flags

A ^{283}113 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.17 s *+81–8*	Jπ: Ω(p)=9/2– from 1997Mo25 (theory). $T_{1/2}$: from 2004Og03. $T_{1/2}$(calc)=7.2 ms from Viola–Seaborg systematics for Q(α)=10.52. %α≈100. %α: assumed from one event. β_2(theory): 0.164 from 1995Mo29; 0.202 from 2003Mu15; 0.184 from 2005GaZX.

^{283}113 α Decay: Tentative 2004Og03

Parent ^{283}113: E=x; Jπ=?; $T_{1/2}$=0.10 s *+49–5*; Q(g.s.)=10260 *90*; %α decay≈100.
^{283}113 –$T_{1/2}$: 100 ms *+490–45* from 2004Og03.
^{283}113 –Q(α): from 2004Og03.
See 288313 Adopted Levels for details.

^{279}Rg Levels

E(level)	$T_{1/2}$
x?	0.17 s *+81–8*

α radiations

Eα	E(level)
10120 *90*	x?

Adopted Levels: Not Observed

$Q(\beta^-)$=–4360 *SY*; S(n)=7200 *SY*; S(p)=3930 *SY*; $Q(\alpha)$=9300 *SY* 2003Au03.
$Q(\beta^-)$,s(n) estimated uncertainty=1130 keV.
S(p): estimated uncertainty=1110 keV.
$Q(\alpha)$: estimated uncertainty=200 keV.
2000Og05, 2001Og01: in α–decay chain of ^{288}114, at Dubna with ^{244}Pu+^{48}Ca *via* the 4*n* evaporation channel with a cross–section of ≈1 picobarn. See ^{288}114 Adopted Levels for details. Two identical genetically correlated event sequences were recorded of the type EVR–α1–α2–SF; the two SF events were determined to be from ^{280}Ds with total energies of 221 (156+65) and 213 (171+42) MeV. The probability of randomness for the sequence was estimated to be 5×10^{-13}.
Theory: see also Nuclear Structure References.
Assignment: reassigned by 2004Og07.
2003Au02 adopted $T_{1/2}$=11 s *6* (from t=6.93 s, 14.3 s, and 7.4 s) and %SF=100 based on 2001Og01.

Adopted Levels: Tentative

Q(β⁻)=–2390 *SY*; S(n)=6200 *SY*; S(p)=2060 *SY*; Q(α)=9870 *60* 2003Au03,2004Og03.
Q(β⁻): estimated uncertainty=980 keV.
S(n): estimated uncertainty=1000 keV.
S(p): estimated uncertainty=1050 keV.
Q(α): from Eα=9.75 MeV *6* (2004Og03). Other: 9.98 MeV *30* (2003Au03):
2003OgZY and 2004Og03: identification of new nuclides: ^{288}115, ^{284}113, ^{280}Rg, ^{276}Mt, ^{272}Bh, and ^{268}Db. ^{280}Rg observed as grand–daughter of ^{288}115.
Reaction: ^{243}Am(^{48}Ca,3n) E(lab)=248 MeV corresponding to an excitation energy of 38.0 to 42.5 MeV at the target center. Experiments performed by the Dubna–LLNL collaboration. Z=115 was formed at a cross–section of 2.7 pb *+48–16*.
Three similar decay chains with five consecutive α decays were detected in a time interval of 20 s (in the beam–off mode following the first recoil expected to belong to Z=115) terminated by an SF event with a release of total kinetic energy of ≈220 MeV. These events were assigned to the (^{48}Ca,3n) channel with the production of the parent nuclide ^{288}115; the third event in the chain was assigned to ^{280}Rg. Properties of ^{280}Rg from the three chains are listed below by event.
Event #1: Energy of the evaporation residue=10.4 MeV
E_α=9720 keV t=3.146 s – assigned to ^{280}Rg
Event #2: Energy of the evaporation residue=11.0 MeV
E_α=9760 keV t=10.599 s – assigned to ^{280}Rg
Event #3: Energy of the evaporation residue=9.1 MeV
E_α=9760 keV t=1.793 s – assigned to ^{280}Rg
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: granddaughter of ^{288}115 produced by ^{243}Am(^{48}Ca,3n) E=248 MeV (2003OgZY,2004Og03) and E=243 MeV, chem (2004DmZZ). The evaluators suggest that 2004DmZZ offers independent support to the synthesis of ^{288}115 (2004Og03) having precisely determined the atomic number for Z=105 by isolation of Group V elements. The properties are in agreement with ^{268}Db measured in the three chains seen earlier by 2004Og03, thereby providing evidence in favor of the synthesis of ^{288}115 and daughters. However, since the identification relies on the measurement of SF fragments, the possibility that the observed nucleus is actually ^{268}Rf following (undetected) ε from the parent ^{268}Db, cannot be excluded.

^{280}Rg Levels

Cross Reference (XREF) Flags

A ^{284}113 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	3.6 s *+43–13*	Jπ: Ω(p)=13/2+; Ω(n)=15/2– from 1997Mo25 (theory). $T_{1/2}$: from 2004Og03. $T_{1/2}$(calc)=0.42 s from Viola–Seaborg systematics for Q(α)=9.87 MeV. %α≈100. %α: from three events. β_2(theory): 0.117 from 1995Mo29; 0.200 from 2003Mu15; 0.179 from 2005GaZX.

^{284}113 α Decay: Tentative 2004Og03

Parent ^{284}113: E=x; Jπ=?; $T_{1/2}$=0.48 s *+58–17*; Q(g.s.)=10150 *60*; %α decay≈100.
^{284}113 –$T_{1/2}$: from 2004Og03.
^{284}113 –Q(α): from 2004Og03.
See ^{284}113 Adopted Levels for details.

^{280}Rg Levels

E(level)	$T_{1/2}$	Comments
x?	3.6 s *+43–13*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
10000‡ *60*	x?	Eα: from 2004Og03.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=–3080 *SY*; S(n)=5960 *SY*; Q(α)≤9050 2003Au03,2004Og12.

Q(β⁻): estimated uncertainty=1180 keV.

S(n): estimated uncertainty=1120 keV.

Q(α): estimated by 2004Og12. Other: Q(α)≤9.00 MeV from 2004OgZZ; 2003Au03 adopted 8.96 MeV *5* based on the data of 1999Og10.

2000Fi12 cite 1999GhZZ. The evaluators believe that the data in this private communication corresponds to that published in 1999Og10.

1999Og10: in Dubna, using the U400 cyclotron and the DGFRS. This nucleus produced after two α–decays originating from parent ^{289}114 observed in a single event *via* the 3*n* channel in the reaction ^{244}Pu+^{48}Ca with a cross–section≈1 picobarn. The assignments are tentative as this particular decay sequence has not been reproduced in subsequent experiments to date. The event is characterized by an α emitted with E1=9.71 MeV, and a long lifetime of t1=30.4 s attributed to the ^{289}114 parent. The granddaughter, ^{281}Ds has the properties: E3=8.83 MeV; t3=1.6 min. The evaluators note that this is the only observation of α–decay from this isotope of Ds, which is otherwise expected to fission. 1999Og10 suggest that the entire chain, if verified, represents a rare (isomeric) α–decay mode of ^{289}114, possibly also of ^{281}Ds. The decay sequence and all constituent assignments are considered tentative by the evaluators.

2000Og05: experiments done at Dubna with ^{244}Pu+^{48}Ca at 236 MeV with improved sensitivity of >2 orders of magnitude over previous attempts, for picobarn cross–sections expected in the production of Z=114. The U400 cyclotron was used with DGFRS (2000OgZR, 1993LaZS). Observed two identical three–member decay sequences at a ^{48}Ca beam energy of 237.6 and 237.0 MeV at target–center corresponding to excitation energies of 33.6–39.7 MeV and 33.2–39.1 MeV of the ^{292}114 CN respectively. Parent initially assigned to ^{288}114 *via* the 4*n* channel, and reassigned to ^{289}114 in 2004Og07. ^{281}Ds terminates the α1–α2–SF chain with an average E(tot)=217 MeV for the fission fragments: E1(SF–tot)=221 MeV with t(SF)=14.26 s and E2(SF–tot)=213 MeV with t(SF)=7.44 s respectively. See also 2000Og07 for more details of this experiment.

2004Og07: Z=116 parent nuclei produced in the reaction ^{248}Cm+^{48}Ca and reported via 2001Og01, 2001Og06 and discussed in 2002Og09 are reassigned to ^{293}116 in the 3n channel. The SF events terminating the α–decay chain correspond to ^{281}Ds. Also observed here were three α–decay sequences originating from ^{289}114 produced in the reaction ^{244}Pu+^{48}Ca: two events at E=243 MeV and one event at E=250 MeV. ^{281}Ds terminates the EVR–α1–α2–SF chain with an average energy of 158 MeV. (see ^{289}114 adopted levels for details).

2004Og12: as α–decay grand–daughter of ^{289}114. Three α–decay sequences in the reaction ^{244}Pu(^{48}Ca,3n) were attributed to the nucleus ^{289}114; two events were recorded at a beam energy of 243 MeV (second assignment tentative) and one at 250 MeV (not conclusive). In all cases ^{281}Ds terminated the EVR–α1–SF sequence. (see ^{285}112 and ^{289}114 Adopted Levels for details). Experimenters quote $T_{1/2}$(SF)=9.6 s *+50–25* for a total of 8 events.

2004OgZZ: report two EVR–α1–α2–α3–SF chains spanning about 10 to 80 s produced in the reaction ^{248}Cm+^{48}Ca at E=247 MeV. The experimenters note that these chains are similar to those observed at a lower energy in 2001Og01, 2001Og06, and also discussed in 2002Og09. In both cases the parent was ^{293}116 and the ^{281}Ds terminated the sequence with SF. (see also ^{293}116 Adopted Levels for details). A total of 10 α decay events were considered in the estimation of the half–life of 11.1 s +5.0–2.7, revised over the value quoted in 2004Og12. Experimenters estimate Q(α)≤9.05 MeV for the unobserved α–decay branch. 2004Og12 and 2004OgZZ are identical in most respects. 2004OgZZ report more statistics in some cases.

Other: 1999Og07, 2000Og07, 2004Og10.

Theory: see Nuclear Science References.

Assignment: granddaughter of ^{289}114 produced by ^{244}Pu(^{48}Ca,3n) E=236 MeV (1999Og10)?, E=237, 238 MeV (2000Og05). Great–granddaughter of ^{293}116 ^{248}Cm(^{48}Ca,3n) E=240 MeV (2001Og01,2001Og06). The evaluators consider the assignments of ^{293}116 and ^{289}114 as tentative; see respective Adopted Levels for details.

^{281}Ds Levels

Cross Reference (XREF) Flags

A ^{285}112 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	9.6 s *+50–25*	Jπ: 3/2+ from 1997Mo25 (theory). $T_{1/2}$: from 8 SF events (2004Og12). Other: 11.1 s +5.0–2.7 for 10 events from 2004OgZZ. %SF≈100 (2004Og12). β_2(theory): 0.108 from 1995Mo29; 0.137 from 2003Mu15; 0.159 from 2005GaZX.

^{285}112 α Decay: Tentative 2004Og12

Parent ^{285}112: E=x; Jπ=?; $T_{1/2}$=34 s *+17–9*; Q(g.s.)=9290 *60*; %α decay=100.
^{285}112 –$T_{1/2}$: from 2004Og12.
^{285}112 –Q(α): from 2004Og12.
See ^{285}112 Adopted Levels for details.

^{281}Ds Levels

E(level)	$T_{1/2}$	Comments
x?	9.6 s *+50–25*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
9160‡ *60*	x?	Eα: from 2004Og12.

‡ Existence of this branch is questionable.

Adopted Levels: Not Observed

S(n)=5980 *SY*; S(p)=2810 *SY*; Q(α)=10280 *SY* 2003Au03.
S(n): estimated uncertainty=1180 keV.
S(p): estimated uncertainty=1230 keV.
Q(α): estimated uncertainty=200 keV.
The data of 1999Ni03 cited by 2000Fi12 have been retracted (2002Ni10) and have not been confirmed in a repeated experiment at LBNL (2003Gr26). Also, 2001MoZU and 2000HoZZ found no evidence for ^{293}118 in ^{208}Pb(^{86}Kr,n) reaction at 457.6 MeV (2001MoZU) and at 453.9 and 456.7 MeV (2000HoZZ). The statistical analysis of 2000Sc26 also indicate that the data of 1999Ni03 do not originate from radioactive decays with an error probability of less than 5%.
2003Au02 suggest 3/2+ based on systematics.

Adopted Levels: Not Observed

See ^{289}114 Adopted Levels for details of the experiments.

2004Og10: the reinterpretation of one long lived decay chain first reported in 1999Og10 at Dubna, and tentatively suggested as a *candidate* for the decay of ^{289}114, has since been proposed as possibly originating from the CN ^{290}114 *via* the 2*n* channel. The subsequent α–decays would then be: $^{286}112\rightarrow^{282}Ds\rightarrow^{278}Hs$ (SF). The cross–section for this event was ≈0.2 picobarn in the reaction $^{244}Pu+^{48}Ca$ at 236 MeV (E*=35 MeV). This event was not observed in later experiments done at energies of E*=41–53 MeV (2000Og05,2000Og07). The α particle energy of the first decay is ≈0.1 MeV less than that attributed to ^{289}114 from later work. An alternative interpretation based on calculations (1999Cw01) is that this chain may belong to a rare decay branch of ^{289}114 starting from an excited state and going to low lying levels in the daughter governed by the appropriate selection rules. 3 minute α–SF event observed in 1999Og07 at E*=32.6 MeV for ^{290}114 and assigned to ^{287}114 not seen by 2004Og10.

Assignment: IUPAP/IUPAC JWP Assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays. The evaluators believe that there is too little data to support the assignment of this decay chain to either ^{290}114 or ^{289}114 and, therefore, ^{290}114, ^{286}112, ^{282}Ds and ^{278}Hs remain unobserved. See the General Comments for more details.

Theory: see Nuclear Science References.

Adopted Levels: Tentative

S(n)=7630 *SY*; S(p)=3200 *SY*; Q(α)≤10820 2003Au03,2004Og12.
S(n): estimated uncertainty=1210 keV.
S(p): estimated uncertainty=1170 keV.
Q(α): estimated by 2004Og12 for α decay (not observed). Other: 9.96 MeV *20* (2003Au03. Syst.).
2004Og07(see also 2004Og05): as granddaughter of ^{290}116 from one event recorded from the single α–decay of ^{286}114. See Adopted Levels for ^{286}114 and ^{290}116 for details of experimental set–up. The α–decay of ^{286}114 or ^{281}112 was not observed in the ^{294}118 chain (2002OgZX, 2003OgZZ, 2004Og12, and also 2004OgZZ). This may be due to the fact that ^{286}114 decays by both SF and α emission with %α≈40 (2004Og12, 2004OgZZ).
2004Og12,2004OgZZ: By the complete fusion reaction ^{238}U(^{48}Ca,4n). A total of 8 decay sequences were observed assigned to Z=112: 7 EVR–α–SF events spanning about 0.5–6 s observed at E(beam)=230–234 MeV assigned to ^{283}112 and 1 shorter EVR–SF sequence with $T_{1/2}$(SF)<1 ms observed at an energy of 240 MeV assigned to ^{282}112. Maximum cross–section value in the 4n channel for this nucleus is 0.6 pb *+16–5* at E*=39.8 MeV (2004OgZZ).
No events that could be assigned to Z=112 were found in the reaction ^{233}U+^{48}Ca at 240 MeV despite an accumulated beam dose of 8×10^{8} ions. See 2004Og12 and 2004OgZZ for a detailed discussion. ^{282}112 was also produced as the α–decay daughter of ^{286}114 produced in the reaction ^{242}Pu(^{48}Ca,4n) (see ^{286}114 adopted levels for for details). Of the 9 events measured (7 at 244 MeV, 2 at 250 MeV) the α decay branch was in evidence in 4 of these events leading to ^{282}112 which fissioned in all 4 cases thus terminating the sequences.
The excitation functions and decay properties of the shorter chain members decaying by EVR–α–SF in the ^{242}Pu+^{48}Ca reaction when compared against EVR–SF correlations in the ^{238}U+^{48}Ca reaction show that they may originate from the even–even parents ^{286}114 (with ^{282}112 as the α–decay daughter) and ^{282}112 respectively.
6 new events in total attributed to ^{282}112 with the following half–life for SF decay: $T_{1/2}$=0.50 ms *+33–14*. Estimated Q(α)≤10.82 for α–decay branch, not observed. The two papers are identical in most respects. 2004OgZZ report more statistics in some cases.
Other: 2004Og10.
Theory: see Nuclear Science References.
Assignment: granddaughter of ^{290}116 produced by ^{245}Cm(^{48}Ca,3n) E=243 MeV (2004Og07). Daughter from α–decay branch of ^{286}114 synthesized in the ^{242}Pu(^{48}Ca,4n) at E=244 and 250 MeV (2004Og12,2004OgZZ) and also great–granddaughter of ^{294}118 produced by ^{249}Cf(^{48}Ca,3n) E=265 MeV (2002OgZX,2003OgZZ). The evaluators consider all the assignments for this nucleus tentative.

^{282}112 Levels

Cross Reference (XREF) Flags

A ^{286}114 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.50 ms *+33–14*	Jπ: 0+ if g.s. $T_{1/2}$: from 2004Og12. %SF≈100 (2004Og12). %SF: from 6 events. β_2(theory): 0.089 from 1995Mo29; 0.145 from 2003Mu15; 0.169 from 2005GaZX.

^{286}114 α Decay: Tentative 2004Og12

Parent ^{286}114: E=x; Jπ=?; $T_{1/2}$=0.16 s *+7–3*; Q(g.s.)=10345 *60*; %α decay≈40.0.
See ^{286}114 Adopted Levels for details.

^{282}112 Levels

E(level)	$T_{1/2}$	Comments
x?	0.50 ms *+33–14*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)
10200‡ *60*	x?

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=–4340; S(n)=6180 *SY*; S(p)=3280 *SY*; Q(α)=9670 *60* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=1060 keV.
S(n): estimated uncertainty=1040 keV.
S(p): estimated uncertainty=1170 keV.
Q(α): from Eα=9.54 MeV *60* (2004Og12). Other: 9260 keV *200* (2003Au03. Syst.).

1999Og05: using the reaction ^{238}U(^{48}Ca,xn) attempts to synthesize new isotopes of Z=112 were made at DUBNA/JINR in collaboration with GSI and RIKEN. An upgraded and improved set–up was necessary for the preparation of the ^{48}Ca beam extracted from the U400 cyclotron used with the detection system with the VASSILISSA separator. The key to synthesis of Z=112 was the production of an intense ^{48}Ca ion beam in this hot fusion reaction. The U400 cyclotron was modified for an axial injection of the beam from the ECR–4M ion source which lead to an increase in intensity of a factor of 2–3 over the previous pulsed mode; the intensity at target thus being 2.2×10^{12} per sec. Two beam energies were used, 255 MeV *3* and 262 MeV *3*, post extraction from the cyclotron. The 0.3 mg/cm^2 ^{238}U target was enriched to 99.999%. The EVR's were separated in–flight from other reaction products by the electrostatic recoil separator VASSILISSA (1997Ye07). tof detectors were used to register EVR's and a position sensitive strip detector was installed in the focal plane of the separator. The energy resolution for α particles with energies of 6 to 9 MeV, was 20 keV. An accuracy of 1 microsec was achieved for recording time signals from events. The estimated detection efficiency of ≈25% was enhanced by surrounding the strip detector by 4 Si detectors. The array had an efficiency of 85% of 4π. The high tof efficiency allowed for the observation of clean spectra. The calculated beam energies at the target center were 231 and 238 MeV corresponding to excitation energies of 33 and 39 MeV respectively. The irradiation started March 1998 and proceeded for 25 days at the lower energy with a total beam dose of 3.5e18 projectiles, and for a further 15 days at the higher energy with a beam dose of 2.2×10^{18} ions. Only two SF events were detected at the lower energy (231 MeV) not accompanied by a tof signal but the high energy indicative of an implanted recoil. The TKE values for the two events are 190 and 212 MeV. Time reversed reconstruction of events revealed the possibility of an α–SF type occurance at a measured cross–section of 5.0 pb *+63–32*. The mean half–life of the events was 81 s *+147–32*. The EVR's being far from the region of known isotopes, could not be identified more conclusively and the possibility that the parent may be ^{283}112 in the absence of any decay chains having been observed, is based on a variety of arguments including a comparison with expected theoretical cross–sections. The experimenters have observed that $T_{1/2}$(SF) of the new nuclide is ≈1.5 min based on these two events, 3×10^5 times longer than $T_{1/2}$(α) of the lighter nucleus ^{277}112 synthesized by the GSI group and reported in 1996Ho13 and 1999Og07.

1999Og07: as daughter of ^{287}114 in experiments done at Dubna, with five participating countries, from March 3 to April 5, 1999 using the reaction ^{48}Ca+^{242}Pu *via* the 3*n* channel with a cross–section of 2.5 pb *+33–16*. The ^{48}Ca beam was injected into the U400 cyclotron at Dubna using six rotating targets of ^{242}Pu enriched to 97%. EVR's were separated by VASSILISSA (1994Ye08) in a set–up similar to the one used in 1999Og05. The beam energy at the center of the target was 235 MeV *2*, over a period of 32 days. A total of 7.5e18 ions passed through the target. 4 events were recorded with E(SF)>100 MeV in the front detector: two were attributed to SF–isomers of ^{242mf}Pu. In the other events, SF was observed in two coincident signals with E(tot)=195 MeV for the first event and E(tot)=165 MeV in the other. Tentative assignment CN ^{290}114 post the evaporation of 3 neutrons to ^{287}114 with Eα=10.44 MeV *2* to ^{283}112 with $T_{1/2}$(SF)=180 s *+170–60* based on 4 events. No α decays observed.

2000Ar03 discount all data from 1999Og05 and 1999Og07 (including decay chain for ^{289}114 from 1999Og10), classifying the evidence as being "very weak", with no convincing supporting arguments for the possible production of SHE. 5 decay events described as being uncorrelated (see the General Comments for this evaluation).

2001Ya19: the first attempt to chemically study Z=112 which is expected to exhibit higher 'volatility' than Hg in gas chromatographic experiments with Au surfaces (2004Pe06). The investigations were prompted by the observation of the single 3 min, SF decay event observed in 1999Og05. The reaction used was ^{48}Ca+$^{nat}U_3O_8$ containing 100 μg of ^{nat}Nd to enable the simultaneous production of short–lived Hg nuclides, expected to be the lighter homologue of Z=112. Started in January 2000, a 10 day irradiation with ^{48}Ca ions at a beam energy of 262 MeV (corresponding to a center–of–target energy of 234 MeV) with a beam current of 0.2–0.4 pμA resulted in a total beam dose of 6.85×10^{17} ions. Following the bombardments, both Hg and Z=112 could be isolated and transported from the target, through gaseous He to a PIPS (passivated ion–implanted planar silicon) detector system which could detect both SF and α's. To ensure high efficiency adsorption on the PIPS surfaces, they were coated with Au (or Pd). Both the 3*n* and 4*n* ΔE–excitation channels were observed. Recoils were thermalized in pure He at atmospheric pressure and transported through a 25 min long polytetraflourethylene (PTFE) capillary to the detectors. Details of tests with carrier–free Hg nuclides also described. The adsorption of Hg atoms in ^{48}Ca(Nd,xn) reactions was measured by recording the known Eα=5.65 MeV (49 s) from ^{185}Hg. If indeed Z=112 behaved like Hg, 3.4 *+43–22* SF events could have been observed. No SF events were recorded although the attempt showed that chemical identification of SF nuclei produced with pb cross–sections is possible.

2002Lo15: experiment repeated with the ^{238}U(^{48}Ca,3n) reaction at Berkeley using the 88 inch cyclotron and the BGS (1998NiZR). The experimental apparatus was improved over 1998NiZR to include better detectors, data acquisition system *etc*. The $^{48}Ca^{10+}$ beam was provided at an energy of 243.5 MeV over a 5.5 day run. The EVR's with an expected magnetic rigidity of ≈39 MeV were separated by the BGS with a parallel plate avalanche detector (PPAC) at the focal plane. A thorough search of the data resulting from a beam dose of 1.1×10^{18} ions did not reveal any events of interest. No data was recorded at the "one–event" upper limit cross–section of 1.6 pb for EVR–SF events or at the corresponding cross section of 1.8 pb for EVR–α events. 2002Lo15 conclude that the cross–section for the production of this nucleus must be better determined since the small value or a possible weaker α–decay channel will contribute to the difficulty in measurement.

Continued on next page

Adopted Levels: Tentative (continued)

2003Ya22: the second experiment was an improved version of 2001Ya19. The set up extended to investigate the adsorption behavior of Z=112 in comparison with both Hg and Rn. Spanning November–December 2001 at FLNR/JINR using the U400 cyclotron for the same reaction but a much stronger flux of incident ^{48}Ca ions (0.6 pμA). The earlier arrangement was extended to include a 25 min long capillary tube connected to a detector array with 8 pairs of Au coated PIPS detectors to detect Hg–like Z=112. Following this was a 5000 cm**3 ionization chamber to observe the gaseous Rn–like behavior of Z=112. At the end of the experiment 8 SF events were detected in the ionization chamber with none in the PIPS detectors indicating that a metal–metal bond with Au was not formed. With an expected background of about 1 event, and with good arguments to rule out other SF sources, the SF events were attributed to ^{283}112 (2004Ya09,2005ScZZ). It was concluded that Z=112 behaves more like a noble gas similar to Rn. Based on the absence of any metal–like event, an upper limit for the adsorption enthalpy was deduced to be $-\Delta H_{ads}(112)\leq 60$ kJ/mol. Results are indicative but not conclusive.

2004Ga18 reports results from experiments carried out at GSI in 2003. Done by a large international collaboration consisting of 5 countries, 10 institutes. The reaction ^{238}U(^{48}Ca,3n) was studied with a 1.2 pμA beam supplied by UNILAC. The beam energy was 239 MeV and a total flux of 2.8×10^{18} ions. Employing the IVO (in–situ volatilization and on–line detection) (2002Du22) technique with COLD (cryo on–line detector) successfully used in Hs experiments, seven ≥40 MeV SF events were seen which could be ^{283}112 (assuming $T_{1/2}$=3.0 min) at a cross–section of a few pb. These were observed in the same detectors that registered isotopes of Rn. Results are indicative but not conclusive. Imperfections in the experiment have been noticed and further experiments are planned.

2004Og02: further investigations for ^{283}112 undertaken at Dubna given that $T_{1/2}$(SF)≈3 min with the cross–section of ≈5 pb is quite large. Since the unambiguous identification of SF nuclei is difficult, VASSILISSA was upgraded for better mass resolution by incorporating a new dipole magnet with higher bending power (see description and references cited) resulting in a total geometric efficiency of 70% of 4π with an additional suppression of unwanted reaction products by a factor of ≈100. The ^{48}Ca beam impinged on the ^{238}U target with an incident energy of 242 MeV corresponding to an excitation energy, E*=33 MeV at the target center. During a period 29 days and a beam dose of 5.9×10^{18} ions no SF events were detected. During the analysis of data, lifetimes in the interval 5 μs to 1000 s and energies in the interval 8 MeV to 13 MeV were scanned. The upper limit of the cross–section was deduced to be 2.2 pb. A second run lasting 15 days was carried out at the higher beam energy of 245 MeV (E*=35.5 MeV) with a total beam dose of 4.7×10^{18} projectiles. Two SF signals were detected with lifetimes of 3.0 and 24.3 min respectively with no α decay events observed. Mean value $T_{1/2}$ for a total of six decays including two as daughters of ^{287}114 (1999Og07) is 5.1 min *+35–15*. The cross–section measured was 3.0 pb *+40–20*.

2004Og07 (see also 2004Og05): as granddaughter of ^{291}116 from one event recorded from the single α–decay of ^{287}114. See Adopted Levels for ^{287}114 and ^{291}116 for details of experimental set–up. Experiments were done at Dubna in collaboration with LLNL. The current and all subsequent investigations were carried out using the DGFRS. α energies attributed to the decay of ^{283}112 were as follows: Eα=9.54 MeV *7* as α decay daughter of ^{287}114; Eα=9.55 MeV *7* (event 1) and Eα=9.52 MeV *7* (event 2) as α decay grand–daughters of ^{291}116. The mean α energy (3 events) was 9.54 MeV and the estimated half–life was given as 6.1 s *+72–22*.

2004Og12,2004OgZZ: by the complete fusion reaction ^{238}U(^{48}Ca,3n) at Dubna using the DGFRS. A total of 8 decay sequences were observed and assigned to Z=112: 7 EVR–α–SF events spanning about 0.5–6 s observed at E(beam)=230–234 MeV assigned to ^{283}112 and 1 shorter EVR–SF sequence with $T_{1/2}$(SF)<1 ms observed at an energy of 240 MeV assigned to ^{282}112. The mean α energy was 9.54 MeV in agreement with 2004Og07. A special case at a beam energy of 234 MeV was recorded of the type EVR–α1–α2–α3–α4–SF ending with ^{267}Rf. α decay is blocked below ^{279}Ds which fissions rather than α decays (10%). The evaluators suggest that this longer chain which terminates with ^{267}Rf, if confirmed, may be one incidence of this 10% branch. The event requires further investigation. No events that could be assigned to Z=112 were found in the reaction ^{233}U+^{48}Ca at 240 MeV despite an accumulated beam dose of 8×10^{8} ions. See 2004Og12 and 2004OgZZ for a detailed discussion. These papers are identical in many respects. 2004OgZZ report more statistics some cases.

In the case of ^{287}114, the second α in the decay chain has an energy of 9.54 MeV *6* which agrees well with the 4 measured α's (2004Og07) in 11 out of 14 cases. The other 3 α energies are 8.94, 9.36 and 9.32 MeV which 2004Og12 suggest may be indicative of transitions to different excited states in the daughter nucleus ^{279}Ds.

2004OgZZ note that the maximum cross–section for the ^{48}Ca+^{238}U reaction in the 3*n* channel is 2.5 pb *+18–11* at E*=35 MeV corresponding to a beam energy of 231 MeV. They suggest that the non–observation of any events attributable to Z=112 by 2002Lo15 may be due to insufficient experimental sensitivity. The one–event upper cross–section limit set therein of 1.6 pb corresponds to a statistical upper limit of 2.9 pb with 84% confidence, assuming all parameters are chosen optimally.

2005Gr19 (includes results of 2002Lo15): attempt at independent confirmation of the production of ^{283}112 using the reaction ^{238}U(^{48}Ca,3n) at LBNL using the BGS. $^{48}Ca^{10+}$ accelerated by the LBNL 88–inch cyclotron to E=243.5 and 248.3 MeV (230.3 and 235.6 MeV center of target energies, respectively). Targets consisted of 0.58 mg/cm^2 Al foils with $^{238}UF_4$ evaporated on the downstream side. Nine targets on arc–shaped frames were arranged on the periphery of a 35–cm diameter wheel which rotated at ≈500 RPM. Beam intensities ≈3×10^{12} ions/s. BGS filled with He gas at 66 Pa (93 Pa for the 230.3–MeV irradiation). Efficiency for collecting ^{283}112 EVR estimated to be 49% at 230.3 MeV and 59% at 235.6 MeV. 10 cm×10 cm PPAC with 12 cm×6 cm Si strip array for 230.3–MeV irradiation; 16 cm×8 cm multiwire proportional counter(MWPC) with 18 cm×6 cm Si strip array for 235.6–MeV irradiation. ΔE_α(FWHM)=50 keV in the focal plane detector and ≈100 keV in upstream strips. α–particle detection efficiency ≈73–75%.

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Adopted Levels: Tentative (continued)

From theory (1995Sm05) and previous work, production of SHE in the region of ^{283}112 should result in SF decay of either the produced isotope or one of the daughter isotopes. The experiment of 2005Gr19 was sensitive to SF decays with lifetimes from 11 μs (15 μs at 230.3 MeV) to ≈1.0×10^6 s. No SF events were observed in any of the ^{48}Ca + ^{238}U irradiations (≤1.6 pb and ≤2.0 pb at 230.3 MeV and 235.6 MeV, respectively; 84% c.i.). Searches for possible Z=112 decay chains which are not terminated by SF decay (or where the SF lifetime is longer than the duration of the experiment) were also performed. No EVR–α–α correlations with Δt(EVR–α)<20 s or Δt(α–α)<20 s were observed in any of the ^{48}Ca + ^{238}U irradiations (limits≈1.19 larger than for SF decay). See 2005Gr19 for additional details.

Others: 2004Ma01, 2004Og06, 2004Og10, and 2002Og07. See also the General Comments section of this evaluation.

Theory: see Nuclear Science References.

Assignment: ^{238}U(^{48}Ca,3n) E=255, 262 MeV (1999Og05), E=245 MeV (2004Og02), and E=230–234 MeV (2004Og12,2004OgZZ). Daughter of ^{287}114 produced by ^{242}Pu(^{48}Ca,3n) E=235 MeV (1999Og07). Granddaughter of ^{291}116 produced by ^{245}Cm(^{48}Ca,2n) E=243 MeV (2004Og07). The evaluators note that the radioactive properties for the current nucleus as reported by 2004OgZZ, 2004Og12, and 2004Og07, all using the DGFRS, are in agreement with each other whereas they differ considerably from results obtained in experiments using the VASSILISSA separator. Further investigations may be warranted to resolve the existing ambiguities in the data. It cannot be ruled out that ^{283}112 may exhibit both SF and α decay modes although the probability of this appears to be small. However, if the data from both sets of experiments are taken together and analyzed, given a total of 17 α–decay events (2004Og07, 2004OgZZ) from the DGFRS data (no SF event) and a total of six SF events (1999Og05, 1999Og07, 2004Og02) from VASSILISSA (no α–decay event), the SF branch constitutes ≈35%. This ratio is clearly not observed in either data set, both being mutually exclusive to each other (*i.e.*, all SF or all α–decay). Since, however, in experiments using DGFRS, the assignments for Z=112, Z=114, and Z=116 are based on measured excitation functions and, in some cases, consistency of observed properties of decay daughters produced by cross–bombardments, greater internal consistency exists. In particular, the decay properties of ^{283}112 are consistent through the various measurements (following reassignments as suggested first in 2004Og07), independently of whether they were observed as primary nuclei or as α decay daughters of parents one (Z=114) or two (Z=116) 'levels' up. The evaluators have, therefore, tentatively adopted these radioactive properties here. Note that 2005Gr19 did not observe any SF decays or EVR–α–α correlations in any ^{48}Ca + ^{238}U irradiations.

IUPAC/IUPAP JWP assessment (2003Ka71): with respect to the Dubna experiments (1999Og05,1999Og07), although they have performed high quality studies, an acknowledgement of discovery of Z=112 is not warranted due to unsecured connections to descendents and unobserved elemental signatures; see also 2001Ka70.

^{283}112 Levels

E(level)	$T_{1/2}$	Comments
x?	4.0 s *+13–7*	Jπ: Ω(n)=7/2– from 1997Mo25 (theory). $T_{1/2}$: from 18/18 events half–lives/α particle energies (2004Og12). $T_{1/2}$(calc)=3.3 s from Viola–Seaborg systematics for Q(α)=9.67 MeV. %α≥99; %SF≤1. %α,%SF: from 2004Og12. Other %SF<4 (evaluators). β_2(theory): 0.089 from 1995Mo29; 0.135 from 2003Mu15; 0.165 from 2005GaZX.

^{287}114 α Decay: Tentative 2004Og12

Parent ^{287}114: E=x; Jπ=?; $T_{1/2}$=0.51 s *+18–10*; Q(g.s.)=10160 *60*; %α decay≈100.

^{287}114 –$T_{1/2}$: from 2004Og12.

^{287}114 –Q(α): from 2004Og12.

See ^{287}114 Adopted Levels for details.

^{283}112 Levels

E(level)	$T_{1/2}$	Comments
x?	4.0 s *+13–7*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
10020‡ *60*	x?	Eα: from 2004Og12.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

S(p)=1060 *SY*; Q(α)=10260 *90* 2003Au03,2004Og03.
S(p): estimated uncertainty=1020 keV.
Q(α): from Eα=10.12 MeV *9* (2004Og03). Other: 10.60 MeV *30* (2003Au03. Syst.).
2003OgZY and 2004Og03: identification of new nuclides: ^{287}115, ^{283}113, ^{279}Rg, ^{275}Mt and ^{267}Db. ^{283}113 observed as α–decay daughter of parent ^{287}115; see ^{287}115 Adopted Levels for experimental details.
Reaction: ^{243}Am(^{48}Ca,4n) E=253 MeV corresponding to an excitation energy of 42.4 to 46.5 MeV at the target center. ^{287}115 was formed at a cross–section of 0.9 pb *+32–8*.
One decay chain with four consecutive α decays was detected terminated by a fission event. The beam was switched off after the detection of an EVR signal followed by an α signal after 46.6 ms with E=10.59 MeV in the same strip attributed to ^{287}115. While in the beam–off mode 3 other α decays were recorded in within a time interval of about 0.4 s followed by an SF event after about 106 min with a sum energy of 206 MeV, all in the same position in the same strip detector. Three other SF events were also measured with fragment energies of 168 MeV, 154 MeV, and 151 MeV. The second event in the chain was assigned to the nucleus ^{283}113:
Energy of the evaporation residue=12.2 MeV
E_α=10120 keV t=100 MS – assigned to ^{283}113
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
The evaluators note that the identification of Z=115 and all associated nuclides in the chain should be treated as tentative until confirmed in independent experiments.

^{283}113 Levels

Cross Reference (XREF) Flags

A ^{287}115 α Decay: Tentative

E(level)	XREF	Comments
x?	A	Jπ: Ω(p)=7/2– from 1997Mo25 (theory). $T_{1/2}$=100 ms *+490–45* (2004Og03). $T_{1/2}$: $T_{1/2}$(calc)=140 ms from Viola–Seaborg systematics for Q(α)=10.26 MeV. %α≈100. %α: from one event. β_2(theory): 0.072 from 1995Mo29; 0.149 from 2003Mu15; 0.169 from 2005GaZX.

^{287}115 α Decay: Tentative 2004Og03

Parent ^{287}115: E=x; Jπ=?; $T_{1/2}$=0.03 s *+16–2*; Q(g.s.)=10740 *90*; %α decay≈100.
^{287}115 –$T_{1/2}$: 32 ms *+155–14* (2004Og03).
^{287}115 –Q(α): from 2004Og03.
See ^{287}115 Adopted Levels for details.

^{283}113 Levels

E(level)	Comments
x?	$T_{1/2}$=100 ms *+490–45*. E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
10590‡ *90*	x?	Eα: from 2004Og03.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=–5310 *SY*; S(n)=7520 *SY*; S(p)=3590 *SY*; Q(α)≤9850 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=1170 keV.
S(n): estimated uncertainty=1150 keV.
S(p): estimated uncertainty=1150 keV.
Q(α): from 2004Og12. Other: ≤9.80 MeV for 17 SF events from 2004OgZZ; 2003Au03 adopted 9.30 MeV *5* based on the data of 2001Og01 which was reassigned by 2004Og07.
Also as α decay daughter of ^{288}114.
2000Og05,2000Og07: at Dubna with ^{244}Pu+^{48}Ca. See ^{288}114 Adopted Levels for experimental details. These assignments for this nucleus (and parent) stand revised in 2004Og07.
2004Og07: see ^{288}114 Adopted Levels for details. Experiments done at Dubna with ^{244}Pu+^{48}Ca aimed at gaining improved sensitivity of >2 orders of magnitude over previous attempts, for picobarn cross–sections expected in the production of Z=114. At beam energies of 243 MeV (E*=41 MeV at target center, 7 events), 250 MeV (E*=47 MeV, 4 events) and 257 MeV (E*=53 MeV, 1 event) a total of 12 EVR–α–SF sequences were observed, occurring within a period of 1 second. The maximum yield for ^{288}114 corresponds to E*≈43 MeV with an expected cross–section of 5.3 pb *+36–21* in the 4*n* channel. t(SF)≈0.1 s was recorded for all 12 events though one α–decay chain had a missing α. Data from 11 events: Eα=9.95 MeV *8*, $T_{1/2}$(α)=0.63 s *+27–14* to ^{284}112 daughter ($T_{1/2}$(SF)=98 ms *+41–23*).
2004Og12,2004OgZZ: see ^{288}114 Adopted Levels for details. A series of experiments using more stringent methods (1992Ba77,2004Og05) were carried out since all these chains passed through and ended in hitherto unknown regions. Using the ^{242}Pu+^{48}Ca reaction at E(lab)=235 MeV a single EVR–α–SF chain was recorded. This event corresponded to the 2*n* evaporation channel with a cross–section of about 0.5 picobarn. The radioactive properties agreed well with the 12 chains measured in 2004Og07 using a ^{244}Pu target. The SF event corresponds to ^{284}112 in all cases with high probability. The evaluators note that these two papers are identical in most respects. 2004OgZZ report more statistics in some cases.
2004OgZZ: see ^{292}116 adopted levels for details. As α decay grand–daughter of ^{292}116 produced by ^{248}Cm(^{48}Ca,4n) at E=247 MeV. These 6 Er–α1–α2–SF events spanning 0.5–2.0 s were not observed in earlier experiments or described in 2004Og12. The results are consistent with previous measurements. The combined half life estimated from 17 events was revised to 97 ms *+31–19*. Estimated Q(α)≤9.80 MeV for α–decay branch, not observed.
Theory: 1997Sm03, 1997Mo25, 2004GaZU. See also Nuclear Science References.
Assignment: daughter of ^{288}114 produced by ^{244}Pu(^{48}Ca,4n) E=243, 250, 257 MeV (2004Og07) and ^{242}Pu(^{48}Ca,2n) E=235 MeV (2004Og12). IUPAP/IUPAC JWP assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays. These observations may still hold good even as the more recent cross bombardment and excitation function studies for ^{288}114 provide additional strong evidence for the assignment. Furthermore, due to the difficulties inherent to hot/warm fusion experiments, additional confirmation would be beneficial (see the General Comments section for details).

^{284}112 Levels

Cross Reference (XREF) Flags

A ^{288}114 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	101 ms *+41–22*	Jπ: 0+ if g.s. $T_{1/2}$: $T_{1/2}$(SF)=101 ms *+41–22* from 12 SF events observed (2004Og12). Other: 97 ms *+31–19* for 17 events from 2004OgZZ. %SF≈100. %SF: 100% observed; estimated 100% α–decay from 2003Au03 (syst.). β_2(theory): 0.089 from 1995Mo29; 0.129 from 2003Mu15; 0.000 from 2005GaZX.

^{288}114 α Decay: Tentative 2004Og12

Parent ^{288}114: E=0; Jπ=?; $T_{1/2}$=0.80 s *+32–18*; Q(g.s.)=10090 *70*; %α decay≈100.
^{288}114 –$T_{1/2}$: from 2004Og12.
^{288}114 –Q(α): from 2004Og12.
See ^{288}114 Adopted Levels for details.

^{284}112 Levels

E(level)	$T_{1/2}$	Comments
x?	101 ms *+41–22*	E(level),$T_{1/2}$: from the Adopted Levels.

^{288}114 α Decay: Tentative 2004Og12 (continued)

α radiations

Eα	E(level)
10080‡ *60*	x?

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

S(n)=6550 *SY*; S(p)=1430 *SY*; Q(α)=10150 *60* 2003Au03,2004Og03.
S(n): estimated uncertainty=1080 keV.
S(p): estimated uncertainty=1110 keV.
Q(α): from Eα=10.00 MeV *6* (2004Og03). Other: 10.25 MeV *30* (2003Au03. Syst.).
2003OgZY and 2004Og03: identification of new nuclides: ^{288}115, ^{284}113, ^{280}Rg, ^{276}Mt, ^{272}Bh, and ^{268}Db. ^{284}113 observed as α–decay daughter of parent ^{288}115; see ^{288}115 Adopted Levels for experimental details.
Reaction: ^{243}Am(^{48}Ca,3n) E(lab)=248 MeV corresponding to an excitation energy of 38.0 to 42.5 MeV at the target center. ^{288}115 was formed with a cross–section of 2.7 pb *+48–16*.
Three similar decay chains with five consecutive α decays were detected in a time interval of 20 s (in the beam–off mode following the first recoil expected to belong to Z=115) terminated by an SF event with a release of total kinetic energy of ≈220 MeV. These events were assigned to the (^{48}Ca,3n) channel with the production of the parent nuclide ^{288}115; the second event in the chain was assigned to ^{284}113. Properties of ^{284}113 from the three chains are listed below by event:
Event #1: Energy of the evaporation residue=10.4 MeV
E_α=10040 keV t=0.376 s – assigned to ^{284}113
Event #2: Energy of the evaporation residue=11.0 MeV
E_α=9480 keV *610* t=1.196 s – assigned to ^{284}113
Event #3: Energy of the evaporation residue=9.1 MeV
E_α=10000 keV t=0.517 s – assigned to ^{284}113
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: daughter of ^{288}115 produced by ^{243}Am(^{48}Ca,3n) E=248 MeV (2003OgZY,2004Og03) and E=243 MeV, chem (2004DmZZ). The evaluators suggest that 2004DmZZ offers independent support to the synthesis of ^{288}115 (2004Og03) having precisely determined the atomic number for Z=105 by isolation of Group V elements. The properties are in agreement with ^{268}Db measured in the three chains seen earlier by 2004Og03, thereby providing evidence in favor of the synthesis of ^{288}115 and daughters. However, since the identification relies on the measurement of SF fragments, the possibility that the observed nucleus is actually ^{268}Rf following (undetected) ε from the parent ^{268}Db, cannot be excluded.

^{284}113 Levels

Cross Reference (XREF) Flags

A ^{288}115 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.48 s *+58–17*	Jπ: Ω(p)=7/2–; Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$: from 20040g03. $T_{1/2}$(calc)=0.28 s from Viola–Seaborg systematics for Q(α)=10.15 MeV. %α≈100. %α: from three events. β_2(theory): 0.080 from 1995Mo29; 0.138 from 2003Mu15; 0.166 from 2005GaZX.

^{288}115 α Decay: Tentative 2004Og03

Parent ^{288}115: E=x; Jπ=?; $T_{1/2}$=0.09 s *+11–3*; Q(g.s.)=10610 *60*; %α decay≈100.
^{288}115 –$T_{1/2}$: 87 ms *+105–30* (2004Og03).
^{288}115 –Q(α): from 2004Og03.
See ^{288}115 Adopted Levels for details.

^{284}113 Levels

E(level)	$T_{1/2}$	Comments
x?	0.48 s *+58–17*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)	Comments
10460‡ *60*	x?	Eα: from 2004Og03.

‡ Existence of this branch is questionable.

Adopted Levels: Tentative

Q(β⁻)=–4310 *SY*; S(n)=6470 *SY*; Q(α)=9290 *60* 2003Au03,2004Og12.

Q(β⁻): estimated uncertainty=1220 keV.

S(n): estimated uncertainty=1120 keV.

Q(α): from Eα=9.16 MeV *6* (2004Og12). Other: 8.79 MeV *5* (2003Au03. Syst.); Eα=9.15 MeV *5*, Q(α)=9.28 MeV *5* (2004OgZZ).

As daughter nucleus of ^{289}114: see ^{289}114 Adopted Levels.

All assignments for this nucleus as the α–decay daughter of Z=114 stand revised in 2004Og07. The evaluators present results prior to 2004Og07 with the original nomenclature.

1999Og10: Z=114 produced by the Dubna group in the 3*n* evaporation channel using ^{244}Pu+^{48}Ca at 236 MeV provided by the U400 cyclotron in November–December 1998. EVR's were separated by the DGFRS (1993LaZS). 40% of the recoiling Z=114 nuclei expected to be implanted in the focal plane detector. Three SF events seen: one event assigned to 0.9 ms ^{244mf}Am, the product of transfer reactions. Second event: information was lost. Third SF event was resolved into a position–correlated decay chain with E1=9.71 MeV, t1=30.4 s; ^{285}112: E2=8.67 MeV, t2=15.4 min; ^{281}Ds: E3=8.83 MeV, t3=1.6 min followed by the two SF fragments with E(tot)=172 MeV from ^{277}Hs. Hindrance factors of 1–10 were assumed for α–decays of odd–n nuclei. Tentative assignment of parent ^{289}114 made in agreement with calculations by Smolanczuk (1997Sm03) and corresponding to a cross–section of 1 pb. This decay sequence and all constituent assignments are considered tentative by the evaluators.

2000Og05: experiments continued at Dubna with ^{244}Pu+^{48}Ca at 236 MeV as before but improved sensitivity of >2 orders of magnitude over previous attempts, for picobarn cross–sections expected in the production of Z=114. These experiments were done from June to October 1999 incorporating an upgraded data acquisition system which allowed for a correlation between the target sector giving rise to a specific recoil and the excitation energy at target center for the same event. The U400 cyclotron was used with DGFRS (2000OgZR, 1993LaZS). Observed two identical three–member decay sequences corresponding to two SF events at a ^{48}Ca beam energy of 237.6 and 237.0 MeV at target–center corresponding to excitation energies of 33.6–39.7 MeV and 33.2–39.1 MeV of the ^{292}114 CN, respectively. Two SF events were recorded as coincident signals with energies E1(tot)=221 MeV and E2(tot)=213 MeV. Upon the time–reversed reconstruction of all data, two α decay chains, consistent with each other were reported and thought to originate from ^{288}114 *via* the 4*n* channel. These were reassigned to ^{289}114 in 2004Og07 and 2004Og12. The decays proceed as follows: E1(α)=9.87 MeV, t1=0.77 s; E2(α)=9.21 MeV, t2=10.34 s; E3(SF–tot)=221 MeV, t(SF)=14.26 s for the first chain and E1(α)=9.80 MeV, t1=4.58 s; E2(α)=9.13 MeV, t2=18.01 s; E3(SF–tot)=213 MeV, t(SF)=7.44 s for the second chain respectively. The second event in each chain is ^{285}112. It was observed that life–times of nuclei Z≥Ds were considerably increased over predictions with increasing neutron number. The experiments were collectively offered as proof of enhanced stability in the region around Z=114 and N=184, where shell closure has been theorized to exist.

2001Og01, 2001Og06: report α decay chains initially assigned to the even–even nucleus ^{292}116 and daughters from the ^{248}Cm+^{48}Ca reaction thought to be *via* the 4*n* evaporation channel. These were subsequently reassigned to ^{293}116 hence α–decay grand–daughter is ^{285}112. See ^{293}116 Adopted Levels for details.

IUPAP/IUPAC JWP assessment (2003Ka71): discovery of Z=112 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays.

2004Og07, 2004Og12: see ^{289}114 Adopted Levels for details. A series of experiments using more stringent methods (1992Ba77,2004Og05) were carried out since all these chains passed through and ended in hitherto unknown regions. Bombarding energies of ^{48}Ca on ^{244}Pu were higher than those used earlier. At 243 MeV two decay chains were observed of the type α–α–SF. A tentative (due to the high randomness probability of about 40%) assignment of ^{289}114 was made; tentative α–decay daughter ^{285}112 (beam off condition) with Eα=9.16 MeV *6*. Three other similar events with a smaller probability of randomness of 18%, 2% and 6% were detected at this energy. Two such identical decay chains had previously been seen in 2000Og05 and 2000Og07 at the lower energy of 236 MeV (see the ^{293}116 Adopted Levels) with the reaction ^{248}Cm+^{48}Ca. At an energy of 250 MeV, one more such event was observed; none at 257 MeV.

Assignments: shorter α–SF chain to ^{288}114 *via* the 4*n* channel; two different α–α–SF chains to the E–O isotopes ^{289}114 and ^{287}114 *via* the 3*n* and 5*n* channels respectively. In the longer chains α–α–SF (8 events) all ^{285}112 daughter nuclei α decay with $T_{1/2}$(α)=34 s *+17–9*.

2004OgZZ report two EVR–α1–α2–α3–SF chains spanning about 10 to 80 s produced in the reaction ^{248}Cm+^{48}Ca at E=247 MeV. The experimenters note that these chains are similar to those observed at a lower energy in 2001Og01, 2001Og06, and also discussed in 2002Og09. In both cases the parent was ^{293}116 and α3 was attributed to ^{285}112. A total of 10 (α) decay events were considered in the estimation of the half–life of $T_{1/2}$=29 s *+13–7*. 2004Og12 and 2004OgZZ are identical in most respects. 2004OgZZ report more statistics in some some cases.

Other: 1999Og07, 2000Og07, 2004Og10.

Theory: 1995SmZY, 1997Sm03, 1997Mo25, 1996My01, 1999Cw01, 2000Be04, and 2004Ro03. See also Nuclear Science References.

Revised assignments: previously observed α decay daughters from 2000Og05, also mentioned in 2000Og07, as seen in the reaction ^{244}Pu+^{48}Ca are believed to be ^{285}112.

Assignment: daughter of ^{289}114 produced by ^{244}Pu(^{48}Ca,3n) E=236 MeV (1999Og10, 2000Og05) and E=243 and 250 MeV (2004Og07, 2004Og12). Granddaughter of ^{293}116 produced by ^{248}Cm(^{48}Ca,3n) E=240 MeV (2001Og01, 2001Og06). The evaluators consider the assignments of ^{293}116 and ^{289}114 and daughters as tentative. See respective Adopted Levels for details.

Adopted Levels: Tentative (continued)

^{285}112 Levels

Cross Reference (XREF) Flags

A ^{289}114 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	34 s *+17–9*	Jπ: 5/2+ from 1997Mo25 (theory) and 2003Au02 (systematics). $T_{1/2}$: from 8/8 events (2004Og12). Other: 29 s *+13–7* per 10/10 events (half–lives/α energies) from 2004OgZZ. $T_{1/2}$(calc)=48 s from Viola–Seaborg systematics for Q(α)=9.28 MeV. %α≈100. %α: from 8/8 events. β_2(theory): 0.089 from 1995Mo29; 0.122 from 2003Mu15; 0.143 from 2005GaZX.

^{289}114 α Decay: Tentative 2004Og12

Parent ^{289}114: E=x; Jπ=?; $T_{1/2}$=2.7 s *+14–7*; Q(g.s.)=9960 *60*; %α decay≈100.
^{289}114 –$T_{1/2}$: from 2004Og12.
^{289}114 –Q(α): from 2004Og12.
See ^{289}114 adopted levels for details.

^{285}112 Levels

E(level)	$T_{1/2}$	Comments
x?	34 s *+17–9*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)
9820‡ *60*	x?

‡ Existence of this branch is questionable.

Adopted Levels: Not Observed

S(p)=2060 *SY*; Q(α)=11000 *SY* 2003Au03.
S(p): estimated uncertainty=1300 keV.
Q(α): estimated uncertainty=200 keV.
The data of 1999Ni03 cited by 2000Fi12 have been retracted (2002Ni10) and have not been confirmed in a repeated experiment at LBNL (2003Gr26). Also, 2001MoZU and 2000HoZZ found no evidence for ^{293}118 in ^{208}Pb(86Kr,n) reaction at 457.6 MeV (2001MoZU) and at 453.9 and 456.7 MeV (2000HoZZ). The statistical analysis of 2000Sc26 also indicate that the data of 1999Ni03 do not originate from radioactive decays with an error probability of less than 5%.
2003Au02 suggest 3/2+ based on systematics.

Adopted Levels: Not Observed

See ^{289}114 Adopted Levels for details of the experiments.

2004Og10: the reinterpretation of one long lived decay chain first observed in 1999Og10 at Dubna, and tentatively assigned to the decay of ^{289}114, is now proposed as possibly originating from the CN ^{290}114 *via* the 2*n* channel. The subsequent α–decays would then be: $^{286}112\rightarrow^{282}Ds\rightarrow^{278}$Hs (SF). The cross–section for this event was ≈0.2 picobarn in the reaction ^{244}Pu+^{48}Ca at 236 MeV (E*=35 MeV). This event was not observed in later experiments done at energies of E*=41–53 MeV (2000Og05,2000Og07). The α particle energy of the first decay is ≈0.1 MeV less than that attributed to ^{289}114 from later work. An alternative interpretation based on calculations (1999Cw01) is that this chain may belong to a rare decay branch of ^{289}114 starting from an excited state and going to low lying levels in the daughter governed by the appropriate selection rules. 3 minute α–SF event observed in 1999Og07 at E*=32.6 MeV for ^{290}114 and assigned to ^{287}114 not seen by 2004Og10.

Assignment: IUPAP/IUPAC JWP assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays. The evaluators believe that there is too little data to support the assignment of this decay chain to either ^{290}114 or ^{289}114 and, therefore, ^{290}114, ^{286}112, ^{282}Ds and ^{278}Hs remain unobserved. See the General Comments for more details.

Theory: see Nuclear Science References.

Adopted Levels: Tentative

S(n)=7930 *SY*; S(p)=2520 *SY*; Q(α)=10345 *60* 2003Au03,2004Og12.

S(n): estimated uncertainty=1290 keV.

S(p): estimated uncertainty=1250 keV.

Q(α): from Eα=10.20 MeV *6* (2004Og12, 2004OgZZ). Others: Q(α)=10.70 MeV *30* (2003Au03. Syst); Q(α)=10.86 MeV *17* from Eα=10.71 MeV *17* (2004Og07).

2002OgZX, 2003OgZZ: by complete fusion reaction ^{249}Cf(^{48}Ca,3n) at an energy of 265 MeV. ^{286}114 is the α–decay granddaughter of ^{294}118 in this reaction which ends the decay chain by SF. See for ^{294}118 Adopted Levels for other experimental details. The optimal cross–section and the highest yield of EVR's is expected for the above channel by theory (2002Za19,2002Za16,2002Za01) and systematic extrapolations from the radioactive properties of neighbouring even–even nuclei such as ^{292}116, ^{288}114, ^{284}112, and ^{280}Ds created with ^{244}Pu and ^{248}Cm targets. The beam of ^{48}Ca ions was provided by the JINR U400 cyclotron and EVR's were separated by DGFRS. A fission fragment calibration was performed using SF fragments from ^{252}No with a known average energy release of about 176 MeV. 18 SF events observed separable into two groups by energy: 16 events with an average total E=158 MeV (125≤E(tot)≤175 MeV) and two events with E(tot)=207 MeV and 223 MeV. Corresponding lower limit of half–life for the group of 16 events was estimated to be $T_{1/2}$(SF)>0.5 h ascribed to long lived nuclides in the Cf–Fm region *via* incomplete fusion reactions suppressed by >5 orders of magnitude in DGFRS.

The other two fission events were preceded by recoil signals ascribed to α decay from a higher A–parent. In particular, the event with E(tot)=207 MeV points to a strong correlation of α decays in an EVR–α1–α2–SF sequence with a probability of randomness estimated to be $<1.5\times10^{-6}$. The instantaneous beam energy was 245.6 MeV corresponding to an excitation energy of 29.8 MeV *20* in the compound system ^{297}118 (see ^{294}118 adopted levels for details). $E_{\alpha1}$=11.65 MeV *6*, t_1=2.55 ms; $E_{\alpha2}$=10.71 MeV *17*, t_2=42.1 ms, E_{tot}SF=207 MeV, t(SF)=0.52 s. The sequence ended with the SF of ^{286}114.

For the second event with E(tot)=223 MeV no α–like signals were detected during the EVR–SF event. Two coincident fragments seen with with energies of 137 MeV (focal plane detector) and 86 MeV (side detector). The instantaneous beam energy was 246.1 MeV corresponding to a compound nucleus excitation energy of 30.2 MeV *23*. A comparison of the excitation functions and decay properties of the shorter EVR–α–SF chain members from the ^{242}Pu reaction with the EVR–SF events in the ^{238}U reaction suggest that they originate from the neighbouring isotopes ^{286}114 and ^{282}112, respectively. Of the 13 decays observed in total for ^{286}114, only five α–decays were observed: b(α)≈0.4.

Q(α)≤10.4 MeV and $T_{1/2}$≥100 ms (95% c.i.) extrapolated values from neighbouring E–E isotopes.

^{286}114 is also the α decay granddaughter of ^{294}118 but with different properties. Assignments for daughters are also tentative and based on the assumption that the parent nucleus is ^{294}118 *via* the 3*n* channel from the CN ^{297}118. It is estimated that the subsequent α–decays are genetically linked with a probability p>87%. This is supported by the application of the Viola–Seaborg relationship as applied to even–even isotopes to calculate Z for the nuclides that undergo α–decay prior to SF.

2004Og07 at Dubna in the reaction ^{245}Cm(^{48}Ca,3n) at a beam energy of 243 MeV. This measurement, using the Ca beam initiated a new series of experiments which have resulted in the synthesis of new Z=116 isotopes. This nucleus (^{286}114) is also produced as the α–decay daughter of ^{290}116. The ^{48}Ca beam was accelerated by the U400 cyclotron at the FLNR/JINR. The typical beam intensity was 1.2 pμA. The target was enriched to 98.7%. The EVR's recoiling from the target were separated by the DGFRS with a transmission efficiency of 35–40% for Z=114 and 116 nuclei. EVR recoils passed through a tof system and were implanted in a semiconductor array. The position averaged detection efficiency for α–decays of implanted nuclei was 87% of 4π with an energy resolution of 60–90 keV for α's absorbed in the focal plane detector. Those that escaped registered a summed signal with a resolution of 140–200 keV in the side detector. All the correlated events observed in these experiments had position deviations corresponding to the given position resolutions: 0.8–1.3 mm for EVR–α signals and 0.5–0.8 mm for EVR–SF signals. Three decay sequences were recorded and attributable to parent ^{290}116. This nucleus was observed as the α–decay daughter of ^{290}116. Of the three events ^{286}114 undergoes SF in two cases and α–decay in one case: Eα=10.03 MeV (escaped α, recorded in side detector only), $T_{1/2}$=1.448 ms. The α–decay of this isotope was not observed in the decay chain originating from ^{294}118 (see 2002OgZX,2003OgZZ). The possibility that this nucleus undergoes α–decay along with SF cannot be ruled out as it is seen that $T_{1/2}$(α) is approximately equal to $T_{1/2}$(SF). The α–decay properties are considered tentative by the evaluators until better statistics are achieved. The two SF events had a total E(SF)=193 MeV and 176 MeV, where only the first event was recorded in both the focal plane and the side detectors which may account for the difference in energies between the two measurements. (see 2004Og05 for more details and discussion).

2004Og12, 2004OgZZ: directly synthesised in the ^{242}Pu(^{48}Ca,4n) reaction at Dubna using DGFRS. A total of 9 EVR–α/SF–SF chains measured: 7 at 244 MeV and 2 at 250 MeV. The second α/SF event was attributed to ^{286}114 which fissioned in 5 of the sequences. 2004Og12, 2004OgZZ discuss all assignments in detail. The two papers are identical in many respects. 2004OgZZ report more statistics in some cases.

Other: see also 2004Og10.

Theory: see Nuclear Science References.

Assignment: daughter of ^{290}116 produced by ^{245}Cm(^{48}Ca,3n) E=243 MeV (2004Og07). Granddaughter of ^{294}118 produced by ^{249}Cf(^{48}Ca,3n) E=265 MeV (2002OgZX,2003OgZZ). ^{286}114 produced by ^{242}Pu(^{48}Ca,4n) at 244 MeV and 250 MeV (2004Og12,2004OgZZ). In the case of the ^{294}118 and ^{290}116 chains, 2004Mo15 note that their assignment of mass based on the CN excitation energy may be off by single unit. The evaluators consider all the assignments for this nucleus tentative.

Adopted Levels: Tentative (continued)

^{286}114 Levels

Cross Reference (XREF) Flags

A ^{290}116 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.16 s +7–3	Jπ: 0+ if g.s. $T_{1/2}$: based on 11 events included in half–life computation/5 α–energies respectively from 2004Og12 and 2004OgZZ. $T_{1/2}$(calc)=0.018 s if Q(α)=10.70 MeV, 0.007 s if Q(α)=10.86 MeV, and 0.16 s if Q(α)=10.345 MeV from Viola–Seaborg systematics. %α≈40; %SF≈60 (2004Og12,2004OgZZ). $β_2$(theory): –0.096 from 1995Mo29; 0.086 from 2003Mu15; 0.161 from 2005GaZX.

^{290}116 α Decay: Tentative 2004Og12

Parent ^{290}116: E=0.0 *0*; Jπ=+; $T_{1/2}$=15 ms *+26–6*; Q(g.s.)=11000 *80*; %α decay≈100.
28016–$T_{1/2}$: from 2004Og12.
28016–Q(α): from 2004Og12.
See ^{290}116 adopted levels for details.

^{286}114 Levels

E(level)	$T_{1/2}$	Comments
x?	0.16 s +7–3	$T_{1/2}$: from the Adopted Levels.

α radiations

Branching: estimated from two events.

Eα	E(level)	Iα†
10850 *8*	x?	0.0

† For α intensity per 100 decays, multiply by ≈1.00.

Adopted Levels: Tentative

Q(β⁻)=–5200 *SY*; S(n)=6450 *SY*; S(p)=2520 *SY*; Q(α)=10160 *60* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=1100 keV.
S(n): estimated uncertainty=1090 keV.
S(p): estimated uncertainty=1210 keV.
Q(α): from Eα=10.020 MeV *6* (2004Og12). Other: 10440 keV *50* (2003Au03. Syst.).
1999Og07: the experiment was performed 3 March to 5 April 1999 at JINR/Dubna with the reaction ^{242}Pu+^{48}Ca. ^{287}114 expected to be produced *via* the 3*n* channel with a cross–section of 2.5 pb *+33–16* as against an expected cross–section of ≈1 pb for this nucleus in an earlier attempt to synthesize Z=114 (1999Og10. See ^{289}114 Adopted Levels). The ^{48}Ca^{5+} beam was delivered to the U400 cyclotron so that E(lab) at target–center was 235 MeV *2*. Six such targets were mounted on a disk rotating at 2500 rpm with a beam chopper that stopped the beam for 0.6 ms. The EVR's were separated in–flight by the VASSILISSA electrostatic recoil separator (1994Ye08). Detection of full–energy α's was 85% of 4π with a time registration accuracy of ≈1 μs. Two position correlated α–SF sequences for this nucleus were observed following ^{290}114 CN decay. Deduced decay properties of the parent ^{287}114: Eα=10.29 MeV *2* MeV (Q(α)=10.44 MeV *2*), $T_{1/2}$=5.5 s *+10–2*, from one event only due to second escaped α with partial energy deposited. $T_{1/2}$(SF)=180 s *+170–60* deduced for ^{283}112 which ended the decay sequence.
2004Og07: see ^{286}114 Adopted Levels for experimental details of set up. ^{287}114 identified at a higher beam energy than before at Dubna with ^{244}Pu+^{48}Ca at an energy of 257 MeV corresponding to an E*=40.2 MeV. This nucleus is also created as the α–decay daughter of ^{291}116 in the reaction ^{245}Cm+^{48}Ca at an energy of 243 MeV. The beam was delivered by the U400 cyclotron at the FLNR. The EVR's were separated by the DGFRS (2000OgZR,2002Su35). The position averaged detection efficiency of α–decays of implanted products was 87% of 4π. Excitation function measurements were done with higher beam energies than before in similar experiments. At the maximum energy of 257 MeV (E*=53 MeV) a single new α–α–SF decay chain was observed with E(α1)=10.03 MeV *7* attributed to ^{287}114, E(α2)=9.54 MeV *7* from ^{283}112, followed by an SF event with E(tot)=206 MeV from 279Ds, all within a time interval of about 10 s. The production cross–section of ^{287}114 at this energy was 1.1 pb *+26–9*. Events following the first α–decay were detected with the beam off to reduce the background. The properties compare well with the two chains assigned to ^{291}116 (where 28114 is the daughter) from the ^{245}Cm+^{48}Ca reaction at 243 MeV.
2004Og12,2004OgZZ: experiments done at Dubna with a ^{242}Pu target during the period Sept–Nov 2003 using the ^{48}Ca beam from the U400 cyclotron at four bombarding energies: E(beam)=235, 238, 244, and 250 MeV. The EVR's were separated in–flight by DGFRS with the transmission efficiency estimated to be 35–40% for Z=114 and 116 (2000OgZR,2002Su35). The synthesis of Z=114 was achieved in the reaction ^{242}Pu(^{48}Ca,xn)$^{290-x}$114. The cross–section for ^{287}114 *via* the 3*n* channel was 3.6 pb *+34–17*. The target was 99.98% enriched. The transmission efficiency for Z=112 and 114 was approximately 40%. The beam was switched off after a recoil signal was detected within the implantation energy and tof parameters expected for Z=114, followed by an α–like signal of 9.9 MeV≤Eα≤10.35 MeV in the same strip within a 1.4–1.9 mm wide position window and a time interval of Δt=4 s. For α energies ≥9.3 MeV, only 22 events were detected and 6 were assigned to ^{287}114. 33 α–decays were seen. The 25 chains detected and assigned to Z=114 may be divided into three groups, of which the ER–α1–α2–SF sequences (15 measurements) are attributed to ^{287}114 in agreement with the observations from 2004Og07 (see also 2004Og05 for more details). The evaluators note that the two papers are identical in many respects. 2004OgZZ report more statistics in a few cases.
Theory: see Nuclear Science References.
Assignment: ^{242}Pu(^{48}Ca,3n) E=235 MeV (1999Og07); ^{244}Pu(^{48}Ca,5n) E=243 MeV; ^{242}Pu(^{48}Ca,3n) E=235, 238, 244, 250 MeV (2004Og12,2004OgZZ). Daughter of ^{291}116 produced by ^{245}Cm(^{48}Ca,2n) E=243 MeV (2004Og12).
IUPAC/IUPAP JWP assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of elemental signatures such as x–rays. Although the excitation function measurements of 2004Og12 (and 2004OgZZ) lend further support to these assignments, they are regarded as tentative by the evaluators.

^{287}114 Levels

Cross Reference (XREF) Flags

A ^{291}116 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.51 s *+18–10*	Jπ: 3/2+ from 1997Mo25 (theory). $T_{1/2}$: based on 15 events included in half–life computation/15 α–energies, respectively, from 2004Og12 (also 2004OgZZ). $T_{1/2}$(calc)=0.53 s from Viola–Seaborg systematics for Q(α)=10.16 MeV. %α≈100 (2004Og12,2004OgZZ). %α: from 15/15 events. β_2(theory): –0.078 from 1995Mo29; 0.088 from 2003Mu15; 0.153 from 2005GaZX.

^{291}116 α Decay: Tentative 2004Og12

Parent ^{291}116: E=x; Jπ=?; $T_{1/2}$=6 ms *+12–3*; Q(g.s.)=10890 *70*; %α decay≈100.
^{291}116 –$T_{1/2}$: 6.3 ms *116*–25.
^{291}116 –Q(α): from 2004Og12.
See ^{291}116 Adopted Levels for details.

^{287}114 Levels

E(level)	$T_{1/2}$	Comments
x?	0.51 s *+18–10*	E(level),$T_{1/2}$: from the Adopted Levels.

α radiations

Eα	E(level)
10740 *70*	x?

Adopted Levels: Tentative

S(p)=460 *SY*; Q(α)=10740 *90* 2003Au03,2004Og03.
S(p): estimated uncertainty=1100 keV.
Q(α): from Eα=10.59 keV *9* (2004Og03). Other: 11.3 MeV *3* (2003Au03. Syst.).
2003OgZY and 2004Og03: identification of new nuclides: ^{287}115, ^{283}113, ^{279}Rg, ^{275}Mt and ^{267}Db.
Reaction: ^{243}Am(^{48}Ca,4n) E=253 MeV corresponding to an excitation energy of 42.4 to 46.5 MeV at the target center. ^{287}115 was formed at a cross–section of 0.9 pb *+32–8*. 2004Og03 have noted that these correspond to the maximum cross–sections measured in 2004Og07 in the ^{244}Pu+^{48}Ca reactions used to synthesise Z=116 and Z=114 where the 4*n* channel had a maximum of 5 pb, 3*n*=2 pb and 5*n*=1 pb. The target was 99% enriched ^{243}Am. Experiments were done at the U400 cyclotron with the DGFRS at FLNR–JINR in collaboration with LLNL, USA. The evaporation residues recoiling from the target were separated by DGFRS in flight from the ^{48}Ca beam ions, scattered particles and transfer–reaction products.
Detection system: multiwire proportional counter for tof measurement; semi–conductor focal–plane detector array with 12 vertical position– sensitive strips, which measured the decay of the implanted recoils. This detection system surrounded by eight side detectors with no position sensitivity. The α spectrum was measured in the range 9.6 to 11.0 MeV.
Resolution: FWHM=60–100 keV for α particles absorbed in the focal–plane detector. 140–200 keV for α's escaping the focal–plane detector and registered by the side detectors.
Results: one decay chain with four consecutive α decays detected in a time interval of 0.5 s (in the beam–off mode) terminated by an SF event with a release of kinetic energy of 206 MeV. This event was assigned to (^{48}Ca,4n) channel with the production of the parent nuclide ^{287}115; the successive nuclides are listed below for event #1.
Energy of the evaporation residue=12.2 MeV

$E_{\alpha 1}$=10590 keV	t_1=46.6 ms	– assigned to	^{287}115
$E_{\alpha 2}$=10120 keV	t_2=0.147 s	– assigned to	^{283}113
$E_{\alpha 3}$=10370 keV	t_3=0.245 s	– assigned to	^{279}111
$E_{\alpha 4}$=10330 keV	t_4=14.0 ms	– assigned to	^{275}Mt
$E_{\alpha 5}$=? (not observed)		– assigned to	^{271}Bh (?)

^{271}Bh α decay not observed; but it probably decays to ^{267}Db which decays by SF (total kinetic energy=206 MeV); 105.96 min
Theory: see Nuclear Science References.
Assignment: the evaluators note that the identification of Z=115 and all associated nuclides in the chain should be treated as tentative until confirmed in independent experiments.

^{287}115 Levels

E(level)	Comments
x?	Jπ: Ω(p)=5/2– from 1997Mo25 (theory). $T_{1/2}$=32 ms *+155–14* (2004Og03). $T_{1/2}$: $T_{1/2}$(calc)=28 ms from Viola–Seaborg systematics for Q(α)=10.74 MeV. %α≈100. %α: assumed from one event. β_2(theory): –0.096 from 1995Mo29; 0.066 from 2003Mu15; 0.005 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=–6340 *SY*; S(n)=7990 *SY*; S(p)=2960 *SY*; Q(α)=10090 *70* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=1210 keV.
S(n): estimated uncertainty=1150 keV.
S(p): estimated uncertainty=1190 keV.
Q(α): from Eα=9.95 MeV *7* (2004Og12). Other: 9970 keV *50* (2003Au03. Syst.).
All assignments for this nucleus stand revised in 2004Og07. The evaluators present results prior to 2004Og07 with the original nomenclature.
Also produced as α–decay daughter of ^{292}116. See ^{292}116 Adopted Levels for ^{292}116.
2000Og05: at Dubna with ^{244}Pu+^{48}Ca in the 4*n* evaporation channel with a cross–section of ≈1 picobarn. The experimental set–up is similar to that used in the synthesis of ^{289}114 (2001Og01) with an improved data aquisition system allowing a narrower range of excitation energies to be assigned to each recoil. At a beam energy of ≈236 MeV the excitation energy of the ^{292}114 CN was estimated to be 31.5–39 MeV. Two identical genetically correlated event sequences were recorded of the type EVR–α–α–SF; the two events from ^{280}Ds had total energies of 221 and 213 MeV. The probability of randomness for the sequence was estimated to be 5×10^{-13}.
2004Og07: see Adopted Levels for ^{293}116 for experimental set–up. Experiments done at Dubna with ^{244}Pu+^{48}Ca aimed at gaining improved sensitivity of >2 orders of magnitude over previous attempts, for picobarn cross–sections expected in the production of Z=114. At a beam energies of 243 MeV (E*=41 MeV at target center, 7 events) 250 MeV (E*=47 MeV, 4 events) and 257 MeV (E*=51 MeV, 1 event) a total of 12 EVR–α–SF events observed in sequence over a period of 1 second. *via* this 4*n* channel, the maximum yield for ^{288}114 corresponds to about 43 MeV with an expected cross–section of 5.3 pb *+36–21*. t(SF)≈0.1 s was recorded for all 12 events though one α–decay chain had a missing α. Data from 11 events: E(α)=9.95 MeV *8*, t(α)=0.63 s *+27–14* to ^{284}112 daughter: t(SF)=98 ms *+41–23*.
2004Og12,2004OgZZ: a comprehensive study of excitation functions, and cross–bombardments using more stringent methods (1992Ba77,2004Og05) were undertaken at Dubna revisiting the synthesis of Z=112, Z=114, and Z=116 using fusion reactions with a ^{48}Ca beam and ^{233,238}U, ^{242}Pu and ^{248}Cm targets. Previous (re)assignments are confirmed and ^{292}116 directly measured. The decay properties of four Z=114 (A=286–289) isotopes provide consistent mass identification for heavier Z=116 (A=290,291,293) isotopes synthesized in ^{245,248}Cm reactions and also for the one Z=118 chain. Using the ^{242}Pu+^{48}Ca reaction at E(lab)=235 MeV a single EVR–α–SF chain was recorded. The assignment to ^{288}114 via the 2*n* evaporation channel with a cross–section of about 0.5 picobarn is suggested. The radioactive properties agree well with 11 chains measured earlier in 2004Og07 using a ^{244}Pu target in the reaction ^{244}Pu(^{48}Ca,4n). Properties of daughter are in agreement with the earlier observations of ^{284}112. A total of 12 events were taken into account for the the estimation of half–life adopted here (2004Og12). This nucleus was also synthesised as α–decay daughter from parent ^{292}116 produced in the reaction ^{248}Cm+^{48}Ca at E=247 MeV (see table 4, 2004OgZZ). Six new EVR–α1–α2–SF decay were reported by 2004OgZZ spanning about 0.5 to 2 seconds, which were not observed earlier. The evaluators note that these two papers are identical in many respects. 2004OgZZ report more statistics in some cases. See ^{292}116 Adopted Levels for details.
Others: 2000Og07, 2002Og03, 2002Og09, 2002Og13.
Theory: 1997Sm03, 1997Mo25, 2004GaZU. See also Nuclear Science References.
Assignment: IUPAP/IUPAC JWP assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays. These observations may still hold good even as the more recent cross bombardment and excitation function studies for ^{288}114 provide additional strong evidence for the assignment. Furthermore, due to the difficulties inherent to hot/warm fusion experiments, additional confirmation would be beneficial (see general comments section for details).

^{288}114 Levels

Cross Reference (XREF) Flags

A ^{292}116 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	0.80 s *+32–18*	Jπ: 0+ if g.s. $T_{1/2}$: per 12/11 events from 2004Og12. Other: 0.80 s *+27–16* from 16/16 events (half–lives/α energies) from 2004OgZZ. $T_{1/2}$(calc)=0.90 s from Viola–Seaborg systematics. %α≈100. %α: from 12/11 events. β_2(theory): 0.053 from 1995Mo29; 0.086 from 2003Mu15; 0.008 from 2005GaZX.

^{292}116 α Decay: Tentative 2004Og12

Parent ^{292}116: E=0.0; Jπ=0+; $T_{1/2}$=18 ms *+16–6*; Q(g.s.)=10800 *70*; %α decay=100.
^{292}116 –$T_{1/2}$: from 2004Og12.
^{292}116 –Q(α): from 2004Og12.

^{288}114 Levels

E(level)	$T_{1/2}$	Comments
x?	0.80 s *+32–18*	E(level),$T_{1/2}$: from the Adopted Levels.

Adopted Levels: Tentative

S(n)=6850 *SY*; S(p)=870 *SY*; Q(α)=10610 *60* 2003Au03,2004Og03.
S(n): estimated uncertainty=1160 keV.
S(p): estimated uncertainty=1150 keV.
Q(α): from Eα=10.46 MeV *6* (2004Og03). Other: 11.0 MeV *3* (2003Au03. Syst.).
2003OgZY and 2004Og03: identification of new nuclides: ^{288}115, ^{284}113, ^{280}Rg, ^{276}Mt, ^{272}Bh, and ^{268}Db. Reaction: ^{243}Am(^{48}Ca,3n) E=248 MeV corresponding to an excitation energy of 38.0 to 42.5 MeV at the target center. Experiments performed by the Dubna–LLNL collaboration. ^{288}115 was formed at a cross–section of 2.7 pb *+48–16*.
Reaction: ^{243}Am(^{48}Ca,3n) E=248 MeV corresponding to an excitation energy of 38.0 to 42.5 MeV at the target center. Experiments performed by the Dubna–LLNL collaboration. ^{288}115 was formed at a cross–section of 2.7 pb *+48–16*. 2004Og03 have noted that these correspond to the maximum cross–sections measured in 2004Og07 in the ^{244}Pu+^{48}Ca reactions used to synthesise Z=116 and Z=114 where the 4*n* channel had a maximum of 5 pb, 3*n*=2 pb and 5*n*=1 pb.
Experiments were done at the U400 cyclotron with the Dubna gas–filled recoil seperator (DGFRS) at FLNR–JINR. The EVR's recoiling from the target were separated by DGFRS in flight from the ^{48}Ca beam ions, scattered particles and transfer–reaction products with a transmission efficiency of 35% for 115 nuclei. If confirmed, it is possible that different states in the same nucleus ^{288}115 have been populated resulting in the differences between Q(α) and $T_{1/2}$ measurements of the three events.
Event #1: Energy of the evaporation residue=10.4 MeV
$E_{\alpha 1}$=10510 keV t_1=80.3 ms – assigned to ^{288}115
^{272}Bh α decay proceeds to ^{268}Db which decays by SF (total kinetic energy=205 MeV); 28.69 h
Event #2: Energy of the evaporation residue=11.0 MeV
$E_{\alpha 1}$=10380 keV t_1=18.6 ms – assigned to ^{288}115
^{272}Bh α decay proceeds to ^{268}Db which decays by SF (total kinetic energy=200 MeV); 23.54 h
Event #3: Energy of the evaporation residue=9.1 MeV
$E_{\alpha 1}$=10500 keV t_1=280 ms – assigned to ^{288}115
^{272}Bh α decay proceeds to ^{268}Db which decays by SF (total kinetic energy=140 MeV); 16.80 h
Theory: 1997Mo25, 2003Mu15, 2003Ge09, 2004Ba86, 2004GuZW and Nuclear Science References.
Assignment: produced by ^{243}Am(^{48}Ca,3n) E=248 MeV (2003OgZY,2004Og03) and E=243 MeV, chem (2004DmZZ). The evaluators suggest that 2004DmZZ offers independent support to the synthesis of ^{288}115 (2004Og03) having precisely determined the atomic number for Z=105 by isolation of Group V elements. The properties are in agreement with ^{268}Db measured in the three chains seen earlier by 2004Og03, thereby providing evidence in favor of the synthesis of ^{288}115 and daughters. However, since the identification relies on the measurement of SF fragments, the possibility that the observed nucleus is actually ^{268}Rf following (undetected) ε from the parent ^{268}Db, cannot be excluded.

^{288}115 Levels

E(level)	Comments
x?	Jπ: Ω(p)=5/2–; Ω(n)=3/2+ from 1997Mo25 (theory). $T_{1/2}$=87 ms *+105–30* (2004Og03). $T_{1/2}$: $T_{1/2}$(calc)=62 ms from Viola–Seaborg systematics for Q(α)=10.61 MeV. %α≈100. %α: from three events. β_2(theory): –0.087 from 1995Mo29; 0.072 from 2003Mu15; 0.017 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=–5060 *SY*; S(n)=6590 *SY*; Q(α)=9960 *60* 2003Au03,2004Og12.

Q(β⁻): estimated uncertainty=1260 keV.

S(n): estimated uncertainty=1120 keV.

Q(α): from Eα=9.82 MeV *6* (2004Og12). Other: 9850 keV *50* (2003Au03. Syst.); Eα=9.82 MeV *5*, Q(α)=9.96 MeV *5* (2004OgZZ, one more event).

Also observed as a daughter nucleus of ^{293}116: see ^{293}116 Adopted Levels.

All earlier assignments for this nucleus stand revised in 2004Og07. The evaluators present results prior to 2004Og07 with the original nomenclature and comments about the reassignments.

1999Og10: Z=114 produced by the Dubna group in the 3*n* evaporation channel using ^{244}Pu+^{48}Ca at 236 MeV provided by the U400 cyclotron in November–December 1998 over a period of 34 days. The excitation energy at target center expected for the 3*n* channel was about 35 MeV. The EVR's were separated by the DGFRS (1993LaZS). 40% of the recoiling Z=114 nuclei expected to be implanted in the focal plane detector. Three SF events seen: one assigned to 0.9 ms ^{244mf}Am, the product of transfer reactions with information lost for the second event. Third SF event was resolved into a position–correlated decay chain believed to start with ^{289}114: E1=9.71 MeV, t1=30.4 s; ^{285}112: E2=8.67 MeV, t2=15.4 min; ^{281}Ds: E3=8.83 MeV, t3=1.6 min followed by the two SF fragments with E(tot)=172 MeV from ^{277}Hs. Hindrance factors of 1–10 were assumed for α–decays of odd–N nuclei. Tentative assignment of parent ^{289}114 made in agreement with calculations by Smolanczuk (1997Sm03), corresponding to a cross–section of 1 pb. The chain starting with the rather long t=30.4 s decay and taking about 34 min in total for all 3 α–decays + SF, was considered a good *candidate* for ^{289}114 *via* the 3*n* evaporation channel. All five signals (EVR–α1–α2–α3–SF) appeared within a position interval of 1.6 mm indicating a correlation between the events. The experimenters suggest that the sequence represents a rare decay mode and thus cannot be ruled out. Since this event has only been observed once, this decay sequence and all constituent assignments are considered tentative by the evaluators.

2000Og05,2000Og07: experiments continued at Dubna with ^{244}Pu+^{48}Ca at 236 MeV as before but improved sensitivity of >2 orders of magnitude over previous attempts, for picobarn cross–sections expected in the production ofz=114. 2000Og05 reports experiments done from June to October 1999 incorporating an upgraded data acquisition system which allowed for a correlation between the target sector giving rise to a specific recoil and the excitation energy at target center for the same event. The U400 cyclotron was used with DGFRS (2000OgZR,1993LaZS). Observed two identical three–member decay sequences corresponding to two SF events at a ^{48}Ca beam energy of 237.6 and 237.0 MeV at target–center corresponding to excitation energies of 33.6–39.7 MeV and 33.2–39.1 MeV of the ^{292}114 CN, respectively. Two SF events were recorded as coincident signals with energies Z=1(tot)=221 MeV and E2(tot)=213 MeV. Upon the time–reversed reconstruction of all data, two α decay chains, consistent with each other were reported and thought to originate from ^{288}114 *via* the 4*n* channel. These were reassigned to ^{289}114 by 2004Og07 and 2004Og12.

The decays proceed as follows: E1(α)=9.87 MeV, t1=0.77 s; E2(α)=9.21 MeV, t2=10.34 s; E3(SF–tot)=221 MeV, t(SF)=14.26 s for the first chain and E1(α)=9.80 MeV, t1=4.58 s; E2(α)=9.13 MeV, t2=18.01 s; E3(SF–tot)=213 MeV, t(SF)=7.44 s for the second chain, respectively.

It is observed that life–times of nuclei Z≥110 were considerably increased over predictions with increasing neutron number. The experiments were collectively offered as proof of enhanced stability in the region around Z=114 and N=184, where spherical shell closure has been theorized to exist.

Other data: 2000Og07, in an attempt to double check the EVR–α1–α2–α3–SF event first reported in 1999Og10, performed another experiment in November and December 1999, with the same set–up but with higher excitation energies of 28.5–34.5 MeV for the expected CN ^{292}114, in an attempt to optimize this parameter over the previous range of 31.5–39 MeV (as in 1999Og10). Over 31 days, no SF event was observed that could be ascribed to the CN ^{292}116 or its daughters.

2001Og01,2001Og06: Z=114 (^{288}114) as α–decay daughter of Z=116 (^{292}116). Parent reassigned to ^{293}116 *via* the 3*n* channel by 2004Og07 and 2004Og12; hence daughter is ^{289}114. See ^{293}116 Adopted Levels for details (including 2002Og09).

2004Og07: a series of experiments using more stringent methods (see 1992Ba77,2004Og05) were carried out since all these chains passed through and ended in hitherto unknown regions. Bombarding energies of ^{48}Ca on ^{244}Pu were higher than those used earlier. The ^{48}Ca^{5} ions were delivered by the U400 cyclotron at FLNR–JINR operated with the ECR–4M ion source. The EVR's were separated in–flight from the scattered particles and reaction products by the DGFRS (2000OgZR, 2002Su35). The transmission efficiency for Z=114 and Z=116 nuclei was estimated to be 35–40%. The position averaged detection efficiency for the α–decays of implanted nuclei was 87% of 4π. At 243 MeV two decay chains were observed of the type α1–α2–SF. A tentative (due to the high randomness probability of about 40%) assignment of ^{289}114 was made for the event with Eα=9.9 MeV *9* and t=6.3 s. Three other similar events with a smaller probability of randomness of 18%, 2% and 6% were detected at this energy. Two such identical decay chains had previously been seen by 2000Og05 and 2000Og07 at the lower energy of 236 MeV then thought to originate from ^{288}114, and three such decay chains after the α–decay of the parent (Z=116) were seen in 2001Og01, 2001Og06 and 2002Og09 (see the ^{293}116 Adopted Levels) with the reaction ^{248}Cm+^{48}Ca previously ascribed to ^{292}116. In this work, at an energy of 250 MeV, one more such event was observed for which the assignment to ^{289}114 in not conclusive but cannot be excluded. No events were recorded at 257 MeV. These measurements were made within an energy interval of 235–250 MeV (E*=35–47 MeV) for the ^{48}Ca beam. Time intervals between implantation of mother nuclei in detectors and SF events varied from 1.5 to 3 minutes. In addition, at 243 MeV 7 new decay chains were seen not similar to any others seen earlier (^{288}114). These were of the type α–SF, detected within one second of the evr implantation. Also, four more such chains at 250 MeV (^{288}114) and one more at 257 MeV (^{287}114). Energy interval for these events: E*=41–53 MeV.

Continued on next page

Adopted Levels: Tentative (continued)

2004Og12,2004OgZZ: a comprehensive study of excitation functions, and cross–bombardments undertaken at DUBNA revisiting the synthesis of Z=112, Z=114 and Z=116 using fusion reactions with a ^{48}Ca beam and ^{233,238}U, ^{242}Pu, and ^{248}Cm targets. Previous (re)assignments are confirmed and ^{292}116 directly measured. 2004OgZZ is identical to 2004Og12 in most respects but includes more statistics for some of the decay chains. The decay properties of four Z=114 (A=286–289) isotopes provide consistent mass identification for heavier Z=116 (A=290,291,293) isotopes synthesized in ^{245,248}Cm reactions and also for the one Z=118 chain. Half–life for 8 events described in 2004Og12 was 2.7 s *+14–7* with a corresponding Q(α)=9.96 MeV *6*. One new measurement of ^{289}114 as α–decay daughter of ^{293}116 produced in the ^{248}Cm(^{48}Ca,3n) at E=247 MeV was reported in 2004OgZZ. The half–life for a total of 9 events was 2.6 s +1.2–0.7 with Q(α)=9.96 ± 0.05 MeV. Earlier reassignments are confirmed and the single new event was included in the analysis, although it had a lower α–decay energy.

Other: 1999Og07, 2000Og07 and 2004Og10. The evaluators believe that 2004Mo15 summarized data for two ^{289}114 α–decay chains before reassignment.

Theory: 1995SmZY, 1997Sm03, 1997Mo25, 1996My01, 1999Cw01, 2000Be04, and 2004Ro03. See also Nuclear Structure References.

Assignments: ^{244}Pu(^{48}Ca,3n), E=236 MeV (1999Og10,2000Og05,2000Og07) and E=243, 250, 257 MeV (2004Og07); shorter α–SF chain to ^{288}114 *via* the 4*n* channel; two different α1–α2–SF chains to the E–O isotopes ^{289}114 and ^{287}114 *via* the 3*n* and 5*n* channels, respectively. Excitation functions and cross–bombardment studies with ^{48}Ca on ^{233,238}U, ^{242}Pu, and ^{248}Cm (2004Og12,2004OgZZ). Daughter of ^{293}116 *via* ^{248}Cm(^{48}Ca,3n), E=240 MeV (2001Og01), E=247 MeV (2004Og12,2004OgZZ). IUPAP/IUPAC JWP Assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays. Subsequent work such as reported in 2004Og12 (2004OgZZ) and the larger volume of consistent data following reinterpretations lend support to these assignments. However, the evaluators consider the assignment for this decay chain as tentative.

Revised assignments: previously observed Z=114 isotopes from 2000Og05 and 2000Og07 (^{244}Pu+^{48}Ca) are ^{289}114. Previously observed Z=116 isotopes from 2001Og01, 2001Og06 and 2002Og09 are ^{293}116; their α–decay daughters are ^{289}114. The single event sequence starting with Eα=9.71 MeV, t=30.4 s seen and tentatively ascribed to ^{289}114 in 1999Og10 remains unconfirmed.

^{289}114 Levels

Cross Reference (XREF) Flags

A ^{293}116 α Decay: Tentative

E(level)	XREF	$T_{1/2}$	Comments
x?	A	2.7 s *+14–7*	Jπ: 5/2+ from 1997Mo25 (theory) and 2003Au02 (systematics). $T_{1/2}$: from 8/8 events reported in 2004Og12. Other: 2.6 s *+12–7* from 9/9 half lives/α–particle energies reported in 2004OgZZ. $T_{1/2}$(calc)=2.0 s from Viola–Seaborg systematics for Q(α)=9.96 MeV. Other: 2000Fi12 tentatively adopted 21 s *+94–10* from 1999GhZZ (^{244}Pu(^{48}Ca,3n)). %α≈100. %α: no SF decay reported. β_2(theory): –0.052 from 1995Mo29; 0.088 from 2003Mu15; 0.096 from 2005GaZX.

^{293}116 α Decay: Tentative 2004Og07,2004Og12

Parent ^{293}116: E=0.0; Jπ=?; $T_{1/2}$=53 ms *+62–19*; Q(g.s.)=10670 *60*; %α decay≈100.

^{293}116 –$T_{1/2}$: from 2004Og12.

^{293}116 –Q(α): from 2004Og12.

See ^{293}116 Adopted Levels for details.

^{289}114 Levels

E(level)	$T_{1/2}$	Comments
x?	2.7 s *+14–7*	E(level),$T_{1/2}$: from the Adopted Levels.

^{293}116 α Decay: Tentative 2004Og07,2004Og12 (continued)

α radiations

Branching: no SF events observed.

Eα	E(level)
10530‡ *60*	x?

‡ Existence of this branch is questionable.

Adopted Levels: Not Observed

Q(β⁻)=−6100 *SY*; S(p)=1360 *SY*; Q(α)=11300 *SY* 2003Au03.
Q(β⁻): estimated uncertainty=1220 keV.
S(p): estimated uncertainty=1380 keV.
Q(α): estimated uncertainty=350 keV.
The data of 1999Ni03 cited by 2000Fi12 have been retracted (2002Ni10) and have not been confirmed in a repeated experiment at LBNL (2003Gr26). Also, 2001MoZU and 2000HoZZ found no evidence for ^{293}118 in ^{208}Pb(^{86}Kr,n) reaction at 457.6 MeV (2001MoZU) and at 453.9 and 456.7 MeV (2000HoZZ). The statistical analysis of 2000Sc26 also indicate that the data of 1999Ni03 do not originate from radioactive decays with an error probability of less than 5%.
2003Au02 suggest Jπ=5/2+ based on systematics.

Adopted Levels: Not Observed

See ^{289}114 Adopted Levels for details of the experiments.

2004Og10: the reinterpretation of one long lived decay chain first observed in 1999Og10 at Dubna, and tentatively assigned to the decay of ^{289}114, is now proposed as possibly originating from the CN ^{290}114 *via* the 2*n* channel. The subsequent α–decays would then be: $^{286}112\rightarrow^{282}Ds\rightarrow^{278}$Hs (SF). The cross–section for this event was ≈0.2 picobarn in the reaction ^{244}Pu+^{48}Ca at 236 MeV (E*=35 MeV). This event was not observed in later experiments done at energies of E*=41–53 MeV (2000Og05,2000Og07). The α particle energy of the first decay is ≈0.1 MeV less than that attributed to ^{289}114 from later work. An alternative interpretation based on calculations (1999Cw01) is that this chain may belong to a rare decay branch of ^{289}114 starting from an excited state and going to low lying levels in the daughter governed by the appropriate selection rules. 3 minute α–SF event observed in 1999Og07 at E*=32.6 MeV for ^{290}114 and assigned to ^{287}114 not seen by 2004Og10.

Assignment: IUPAP/IUPAC JWP assessment (2003Ka71): discovery of Z=114 was not yet warranted due to unsecured connections to known descendents and the absence of further elemental signatures such as x–rays. The evaluators believe that there is too little data to support the assignment of this decay chain to either ^{290}114 or ^{289}114 and, therefore, ^{290}114, ^{286}112, ^{282}Ds and ^{278}Hs remain unobserved. See the General Comments for more details.

Theory: see Nuclear Science References.

Adopted Levels: Tentative

S(n)=8330 *SY*; S(p)=1820 *SY*; Q(α)=11000 *80* 2003Au03,2004Og12.
S(n): estimated uncertainty=1380 keV.
S(p): estimated uncertainty=1330 keV.
Q(α): from Eα=10.85 MeV *8* (2004Og12,2004OgZZ). Other: 11.30 MeV *35* (2003Au03. Syst.).
2002OgZX, 2003OgZZ: by the complete fusion reaction ^{249}Cf(^{48}Ca,3n) at an energy of 265 MeV. ^{290}116 is the expected daughter produced by the α–decay of Z=118 in this reaction. See the ^{294}118 Adopted Levels for details of experimental apparatus. The optimal cross–section and the highest yield of evr's is expected for the above channel by theory (2002Za19,2002Za16,2002Za01) and systematic extrapolations from the radioactive properties of neighboring even–even nuclei such as ^{292}116, ^{288}114, ^{284}112 and ^{280}Ds created with ^{244}Pu and ^{248}Cm targets. The beam of ^{48}Ca ions was provided by the JINR U400 cyclotron and EVR's were separated by DGFRS. A fission fragment calibration was performed using SF fragments from ^{252}No with a known average energy release of about 176 MeV.
18 SF events observed separable into two groups by energy: 16 events with an average total E=158 MeV (125≤E(tot)≤175 MeV) 1 event with E(tot)=207 MeV and 1 event with E(tot)=223 MeV. Corresponding lower limit of half–life for the group of 16 events was estimated to be $T_{1/2}$(SF)>0.5 h ascribed to long lived nuclides in the Cf–fm region via incomplete fusion reactions suppressed by >5 orders of magnitude in DGFRS.
The other two fission events were preceded by recoil signals ascribed to α decay from a higher A–parent. In particular, the event with E(tot)=207 MeV points to a strong correlation of α decays in a EVR–α1–α2–SF sequence. The probability of randomness for all 4 events in the sequence was calculated as being less than 1.5×10^{-6}. The instantaneous beam energy was 245.6 MeV corresponding to an excitation energy of 29.8 MeV *20* in the compound system ^{297}118.
E1=11650 keV *60*, t1=2.55 ms; E2=10710 keV *170*, t2=42.1 ms, E_{tot}(SF)=207 MeV, t(SF)=0.52 s. The second decay was attributed to ^{290}116. Extrapolated value for Q(α) from neighbouring E–E isotopes is 10.86 MeV ± 0.17 with an estimated $T_{1/2}$=29 ms *+140–33*.
For the second event with E(tot)=223 MeV. No α–like signals were detected during the EVR–SF event. Two coincident fragments seen with with energies of 137 MeV (focal plane detector) and 86 MeV (side detector). The instantaneous beam energy was 246.1 MeV corresponding to a compound nucleus excitation energy of 30.2 MeV *23*.
2004Og07: directly synthesised at Dubna in the reaction ^{245}Cm(^{48}Ca,3n) at a beam energy of 243 MeV (E*=30.9–35.0 MeV) optimized for the production of ^{290}116 and ^{291}116. The reaction cross–section was ≈1 pB and the accumulated beam dose was 1.2e19 ions. This measurement initiated a new series of experiments which resulted in the synthesis of new Z=116 isotopes. The ^{48}Ca beam was accelerated by the U400 cyclotron at the FLNR/JINR. The typical beam intensity was 1.2 pμA. The target was enriched to 98.7%. The EVR's recoiling from the target were separated by the DGFRS with a transmission efficiency of 35–40% for Z=114 and 116 nuclei. EVR recoils passed through a tof system and were implanted in a semiconductor array. The position averaged detection efficiency for α–decays of implanted nuclei was 87% of 4π with an energy resolution of 60–90 keV for α's absorbed in the focal plane detector. Those that escaped registered a summed signal of 140–200 keV in the side detector. All the correlated events observed in these experiments had position deviations corresponding to the given position resolutions: 0.8–1.3 mm for EVR–α signals and 0.5–0.8 mm for EVR–SF signals. Two EVR–α–SF and one EVR–α–a–SF events were seen although two α's were missed. The only α–decay recorded from the parent had: Eα=10.88 MeV *8*, t=0.233 ms following evaporation. Experimeters quote measured Eα=10.85 MeV *8*, $T_{1/2}$=15 ms *+26–6* for a total of two events measured to date. See also 2004Og05 and ^{293}116 and ^{286}114 Adopted Levels.
Other: see also 2004Og10.
2004Og12, 2004OgZZ discuss all assignments at length. These two papers are identical in most respects. 2004OgZZ report more statistics in some cases.
Theory: see Nuclear Science References.
Assignment: ^{245}Cm(^{48}Ca,3n), E=243 MeV (2004Og07). Daughter of ^{294}118 from ^{249}Cf(^{48}Ca,3n), E=265 MeV (2002OgZX,2003OgZZ). A total of two events, one each, taken into account for half–life estimation. 2004Mo15 note that their assignment of mass based on the CN excitation energy may be off by single unit. The evaluators consider all assignments for this decay chain as tentative.

^{290}116 Levels

Cross Reference (XREF) Flags

A ^{294}118 α Decay: Tentative

E(level)	Jπ	XREF	$T_{1/2}$	Comments
0.0	0+	A	15 ms *+26–6*	$T_{1/2}$: from two events (2004Og07). $T_{1/2}$(calc)=12 ms from Viola–Seaborg systematics for Q(α)=11.00 MeV. 2003Au02 suggest 50 ms based on systematics. %α≈100. %α: estimated from 2 events for half–life calculations/2 α–decays. β_2(theory): 0.072 from 1995Mo29; 0.076 from 2003Mu15; 0.003 from 2005GaZX.

^{294}118 α Decay: Tentative 2002OgZX,2003OgZZ,2004Og12

Parent ^{294}118: E=0.0; Jπ=0+; $T_{1/2}$=1.8 ms *+84–8*; Q(g.s.)=11810 *60*; %α decay≈100.
^{294}118 –$T_{1/2}$: from one event (2002OgZX,2003OgZZ. $\Delta T_{1/2}$ at 68% confidence level). 1.8 ms *+750–13* (2004Og12) if 95% confidence level used.
^{294}118 –Q(α): from 2002Og10 and 2004Og12.
See ^{294}118 Adopted Levels for details.

^{290}116 Levels

E(level)	Jπ	$T_{1/2}$	Comments
0.0	0+	15 ms *+26–6*	E(level),Jπ,$T_{1/2}$: from the Adopted Levels.

α radiations

Branching: 2004Mo15 indicate two events with Eα=11.64 MeV and E(SF)=213 MeV but give no additional details.

Eα	E(level)
11650 *60*	0.0

Adopted Levels: Tentative

Q(β⁻)=−6100 *SY*; S(n)=6750 *SY*; S(p)=1820 *SY*; Q(α)=10890 *70* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=1220 keV.
S(n): estimated uncertainty=1200 keV.
S(p): estimated uncertainty=1300 keV.
Q(α): from Eα=10.74 MeV *7* (2004Og12,2004OgZZ). Other: 11.00 MeV *35* (2003Au03. Syst).
2004Og05,2004Og07,2004Og10,2004Og12: experiments done at Dubna using the U400 accelerator with DGFRS (2000OgZR,2002Su35). Beam was switched off after initial recoil so that daughter products could be measured in the absence of beam related background. This nucleus deduced to occur in the complete fusion reaction ^{245}Cm(^{48}Ca,2n) at an energy of 243 MeV corresponding to an excitation energy at target center of 31–35 MeV. Maximized for 2*n*, 3*n* evaporation channels. Total beam dose was 1.2×10^{19} ions. Five new decay chains measured by 2004Og07. They could be divided into two types: three decay events comprising the first type, with EVR–α–SF or EVR–α–α–SF lasting ≈0.5 s and two decay events comprising the second type, with EVR–α–α–α–SF with a duration of ≈10 s. Of the three shorter events in the first category, the first α was not observed in two cases. Radioactive properties of longer lived chain compares well with Z=114 (following one α decay) from ^{245}Cm+^{48}Ca at E*=33 MeV with parent ^{293}116 and the single event from ^{244}Pu+^{48}Ca at E*=53 MeV assigned to the decay of ^{287}114 also reported here. The longer α–α–α–SF from ^{245}Cm+^{48}Ca at E*=33 MeV deduced to be ^{291}116. The evaluators note that 2004Og12 and 2004OgZZ are identical in most respects. 2004OgZZ report more statistics in some cases.
Theory: see Nuclear Science References.
Assignment: ^{245}Cm(^{48}Ca,2n), E=243 MeV. The evaluators hold that the deduced assignments are tentative, pending verification.

^{291}116 Levels

E(level)	Comments
x?	Jπ: 1/2+ from 1997Mo25 (theory). $T_{1/2}$=6.3 ms *+116–25*. $T_{1/2}$: per 2/2 events (half–lives/α energies) from 2004Og12 (also 2004OgZZ). $T_{1/2}$(calc)=22 ms from Viola–Seaborg systematics for Q(α)=10.89 MeV. 2003Au02 suggest 100 ms based on systematics. %α≈100. %α: estimated from 2/2 events for half–life calculations/a–decays. β_2(theory): 0.072 from 1995Mo29; 0.084 from 2003Mu15; 0.045 from 2005GaZX.

Adopted Levels: Tentative

Q(β⁻)=−7230 *SY*; S(n)=8280 *SY*; S(p)=2260 *SY*; Q(α)=10800 *70* 2003Au03,2004Og12.
Q(β⁻): estimated uncertainty=1270 keV.
S(n): estimated uncertainty=1200 keV.
S(p): estimated uncertainty=1230 keV.
Q(α): from Eα=10.66 MeV *7* (2004Og12,2004OgZZ). Other: 10.71 *5* (2003Au03. Syst.).
2001Og01, 2001Og06, 2001Og11: at DUBNA/JINR with ^{248}Cm+^{48}Ca at a beam energy of 240 MeV at the center of the target corresponding to an excitation energy of between 30.4 MeV and 35.8 MeV in the CN ^{296}116. The α decay daughters were expected to populate the Z=114 region studied prior to this experiment (see 1999Og10,2000Og05), thereby facilitating their identification. The beam was switched off after the first recoil so that sequential decays were measured without beam associated background. Following a beam dose of 6.6×10^{18} ions, on the 35th day of irradiation, one event sequence was seen attributed to ^{292}116. Probability of randomness was estimated to be $<<1\times10^{-6}$. E1(^{292}116)=10.56 MeV, t1=46.9 ms; E2(^{288}114)=9.81 MeV, t2=2.42 s; E3(^{284}112)=9.09 MeV, t3=53.9 s; E(tot)(SF)(^{280}Ds)=197 MeV. Assignment of parent on the basis of comparison with ^{288}114 supported by the Viola–Seaborg systematics. Reassigned to ^{293}116 *via* the 3*n* channel by 2004Og07 and 2004Og12; see ^{293}116 Adopted Levels for details.
2004Og12,2004OgZZ: by the complete fusion reaction ^{248}Cm(^{48}Ca,4n) at a beam energy of 247 MeV (higher than before) at the center of the target corresponding to an excitation energy of between 36.8 MeV and 41.1 MeV in the CN ^{296}116 which is about 3 MeV lower than the expected maximum cross–section for the 4*n* channel. At the current energy, the cross–section had already reached the value 3.3 pb *+25–14*. A total beam dose 0f 7.0×10^{18} ions was obtained. 2004OgZZ report 6 new EVR–α1–α2–SF decay spanning about 0.5 to 2 seconds, which were not seen earlier. Of the six events, in one case the signal from the EVR was not observed and in another instance α1 escaped. 4 of 5 events recorded in total were used in the estimation of the half–life adopted here (2004Og12 and 2004OgZZ). The evaluators note that the two papers are identical in many respects. 2004OgZZ report more statistics in a few cases.
Others: 2002Og03, 20020g09, and 2002Og13 summarize earlier work done at Dubna to synthesise Z=116. The events were later reassigned to ^{293}116.
Theory: See Nuclear Science References.
Assignment: ^{248}Cm(^{48}Ca,4n), E=247 MeV; parent of ^{288}114 (Eα=9.95 MeV, $T_{1/2}$=0.80 s) (2004Og12). IUPAP/IUPAC JWP assessment (2003Ka71): discovery of Z=116 (2000Og05, 2000Og07, 2001Og02, and 2001Og06) was not yet warranted due to unsecured connections to known descendents and the absence of elemental signatures such as x–rays; the evaluators note that the data considered were later reassigned to ^{293}116. The evaluators consider the current assignments as tentative for reasons applicable to hot fusion reactions relevant here.

^{292}116 Levels

E(level)	Jπ	$T_{1/2}$	Comments
0.0?	0+	18 ms *+16–6*	$T_{1/2}$: per 4/5 events (half–lives/α energies) from 2004Og12 (also 2004OgZZ). $T_{1/2}$(calc)=38.4 ms from Viola–Seaborg systematics for Q(α)=10.80 MeV. %α≈100. %α: estimated from 4 events for half–life calculations/5 α decays (2004Og12). β_2(theory): 0.070 from 1995Mo29; 0.056 from 2003Mu15; 0.044 from 2005GaZX.

Adopted Levels: Tentative

Q(α)=10670 *60* 2004Og12.

Q(α): from Eα=10.53 MeV *6* (2004Og12). Other: 10.69 MeV *6* from Eα=10.54 MeV *6* (2004OgZZ).

2001Og01 and 2001Og06 report α decay chains initially assigned to the even–even nucleus ^{292}116 and daughters from the ^{248}Cm+^{48}Ca reaction thought to be *via* the 4*n* evaporation channel. Further experiments using more stringent methods (2004Og07,2004Og12) prompted all of these decay chains to be reassigned to a ^{293}116 parent *via* the 3*n* channel. The original nomenclature is included here for experimental details and methodology leading up to a more conclusive assignment of ^{293}116 after the evaporation of 3 neutrons. See also 2002Og09 for overview of all experiments done until 2002.

The first decay event observed for Z=116 was reported from Dubna in 2001Og01 by the complete fusion of ^{248}Cm+^{48}Ca followed by the evaporation of 3 (or 4) neutrons and gammas to produce Z=116 with neutron number 177 (or 176) respectively. The energy chosen was 240 MeV corresponding to an excitation energy of 30.4–35.8 MeV in the ^{296}116 CN. The ^{48}Ca^{+5} ions were delivered by the U400 cyclotron at FLNR–JINR operated with the ECR–4M ion source. The EVR's were separated in–flight from the scattered particles and reaction products by the DGFRS (2000OgZR). The transmission efficiency for Z=116 nuclei estimated to be 35%. The detection efficiency for α–decays of implanted nuclei was 87% of 4π. The total counting rate (beam off conditions) for α–particles with E>8 MeV by the entire detector array was 2 per hour. Z=116 was expected to α–decay to Z=114 which had been produced by the same group with ^{244}Pu(^{48}Ca,*3–4*n)^{288,289}114 (1999Og10,2000Og05), thereby facilitating the identification of the isotopes. On the 35th day of irradiation following an accumulated beam dose of 6.6×10^{18} one event sequence was observed and tentatively assigned to parent ^{292}116: E1=10.56 MeV *5*, t1=46.9 ms; (beam off) ^{288}114: E2=9.81 MeV *5*, t2=2.42 s; ^{284}112: E3=9.09 MeV *46*; ^{280}Ds: E(SF)=197 (194+3) MeV; t(SF)=6.93 s.

The two SF events were recorded in both the focal plane and the side detectors. Assignments were consistent with energies and decay times of observed descendents of Z=114: ^{288}114 (1999Og10,2000Og05) and one chain starting with the t=1/2 min decay attributed to ^{289}114 *via* the 3*n* evaporation channel, seen only once with the ^{244}Pu target (1999Og10), still pending confirmation.

2001Og06 reports two further α–decay chains from experiments started on April 20, 2001. Preliminary assignments were made to ^{292}116 and its daughters as follows: ^{292}116: Q1=10.68 MeV *6*, $T_{1/2}$=53 ms *+63–19*; ^{288}114: Q2=9.96 MeV *6*, $T_{1/2}$=2.6 s *+20–8*; ^{284}112: Q3=9.28 MeV *6*, $T_{1/2}$=45 s *+34–14*; ^{280}Ds: $T_{1/2}$(SF)=7.6 s +5.8–2.3. 30 SF events were also seen during the 91 day bombardment of ^{248}Cm. 15 SF events observed over a subsequent 83–day off–line measurement. Origin of SF events attributed to ^{252,254}Cf and to ^{256}Fm as long lived products of transfer reactions with the ^{248}Cm target (see 1985Ho13).

2004Og07: measurements for a series of confirmatory experiments including a new search for Z=116 started at an energy of 243 MeV with ^{245}Cm(^{48}Ca,xn) were begun. See 2004Og05 for details of the methodology used and 2002Su35 for additional details on DGFRS. Cross–bombardments and excitation function measurements with ^{244}Pu(^{48}Ca,xn) were done to determine the number of neutrons evaporated, thereby allowing a more conclusive determination of isotopes where α decay chains terminate in unknown regions. Daughter nuclei produced in earlier experiments were confirmed. Based on convincing arguments, all earlier assignments of ^{292}116 from experiments employing a ^{248}Cm target stand reassigned to ^{293}116.

2004Og12, 2004OgZZ: comprehensive studies of excitation functions with a ^{48}Ca beam + ^{238}U and ^{242}Pu targets were carried out at Dubna. New measurements were begun at one energy each for reactions with ^{48}Ca on ^{233}U and ^{248}Cm. Cross–bombardments were also undertaken in an attempt to revisit the synthesis of Z=112, Z=114 and Z=116. Previous (re)assignments are confirmed and ^{292}116 directly measured. The evaluators note that these two papers are identical in most respects. 2004OgZZ report more statistics in a few cases.

Other: 2002Og09 report results of earlier experiments at Dubna and those with ^{244}Pu and ^{248}Cm rotating targets using a ^{48}Ca beam at incident energies of 236 MeV and 240 MeV respectively. The experiments were designed to produce Z=114 and Z=116 at the pb cross–section level with an increased sensitivity of over 2 orders of magnitude over previous attempts. 5 SF events were observed. Two SF events with total energies of 149 MeV and 153 MeV occurred within milliseconds following the implantation of the recoil. These events were assigned to 0.9 ms ^{244mf}Am, the product of transfer reactions. Three SF events terminated α decay sequences. Assigned to ^{288,289}114. Based on this previous assignments for ^{292}116 following the 10.53 MeV α, were retained as being reasonable in the *4n* channel, along with ^{284}112. It was observed that life–times of nuclei Z≥110 were considerably increased over predictions with increasing neutron number. The experiments were collectively offered as proof of enhanced stability in the region around Z=114 and N=184, where shell closure has been theorized to exist. Parents were subsequently reassigned in 2004Og07 with the corresponding changes for their daughters.

Theory: see Nuclear Science References.

Assignment: ^{248}Cm(^{48}Ca,3n), E=247 MeV (2004Og12). IUPAP/IUPAC JWP assessment (based on events originally assigned to ^{292}116. 2003Ka71): discovery of Z=116 was not yet warranted due to unsecured connections to known descendents and the absence of elemental signatures such as x–rays. The evaluators note that the cross–bombardment and excitation function measurements performed by 2004Og07 and 2004Og12 lend further support to the assignment.

Adopted Levels: Tentative (continued)

^{293}116 Levels

E(level)	$T_{1/2}$	Comments
0.0?	53 ms *+62–19*	Jπ: 1/2+ from 1997Mo25 (theory). $T_{1/2}$: from 2004Og12 for 3/3 events. Other: 61 ms *+57–20* per 4/4 events (half–lives/α energies) from 2004OgZZ. $T_{1/2}$(calc)=85 ms using Viola–Seaborg formalism for Q(α)=10.67 MeV. %α≈100. %α: assumed from lack of observed SF events. Eα=10.54 MeV *6* (2004OgZZ). Other: Eα=10.53 MeV *6*(2004Og07,2004Og12). It is probable that this is the ground state. The experimenters have observed that the transition is unhindered from the nearly spherical even–Z ^{292}116 nucleus, a fact which facilitated the initial assignment. That this may be the ground state in the presence of the extra neutron is further supported by the *unique* α–particle energy measured for this odd isotope at one bombarding energy for the three events reported in 2001Og01, 2001Og06, and 2002Og09. β_2(theory): –0.070 from 1995Mo29; 0.043 from 2003Mu15; 0.028 from 2005GaZX.

Adopted Levels: Not Observed

S(p)=660 *SY*; Q(α)=12300 *SY* 2003Au03.
S(p): estimated uncertainty=1520 keV.
Q(α): estimated uncertainty=500 keV.
The data of 1999Ni03 cited by 2000Fi12 have been retracted (2002Ni10) and have not been confirmed in a repeated experiment at LBNL (2003Gr26). Also, 2001MoZU and 2000HoZZ found no evidence for ^{293}118 in ^{208}Pb(^{86}Kr,n) reaction at 457.6 MeV (2001MoZU) and at 453.9 and 456.7 MeV (2000HoZZ). The statistical analysis of 2000Sc26 also indicate that the data of 1999Ni03 do not originate from radioactive decays with an error probability of less than 5%.
2003Au02 suggest Jπ=1/2+ based on systematics.

Adopted Levels: Not Observed

S(p)=13110 *CA*; Q(α)=6950 *CA* 1997Mo25.

1980St05 searched for naturally occurring ^{294}Ds using an FN Tandem accelerator as a sensitive mass spectrometer (placer platinum from Goodnews Bay, Alaska; tof). The observed background leads to an upper limit on ^{294}Ds in the platinum sample of less than one part in 10^{11}. This implies that ^{294}Ds has $T_{1/2}$ less than about 2×10^{8} y, was not produced in the amounts predicted by 1971Sc39, or did not follow its homolog platinum in the geophysical or chemical processing of the material.

Others: 1969We13, 1973Ge15, and 1974Be02.

1997Mo25 calculate $T_{1/2}(\alpha)$=296 y.

Theory: see Nuclear Science References.

Adopted Levels: Tentative

Q(α)=11810 *60* 2004Og10,2004Og12.

Q(α): from Eα=11.65 MeV *6* (2004Og10,2004Og12).

2003OgZZ, 2004Og10, 2004Og12: the Dubna group in a collaborative effort with LLNL, synthesized Z=118 by the complete fusion reaction ^{249}Cf(^{48}Ca,3n) at an energy of 265 MeV. The CN formed was ^{297}118. Experiments were performed from February through June 2002 totaling 2300 irradiation hours and an accumulated beam dose of 2.5×10^{19} ^{48}Ca ions. The optimal cross–section and the highest yield of EVR's is expected for the above channel by theory (2002Za19,2002Za16,2002Za01) and complemented by systematic realistic extrapolations from the radioactive properties of neighboring even–even nuclei such as ^{292}116, ^{288}114, ^{284}112 and ^{280}Ds created with ^{244}Pu and ^{248}Cm targets. Note: 2002OgZX and 2003OgZZ appear to be the same report.

The beam of ^{48}Ca ions was provided by the JINR U400 cyclotron and EVR's were separated by DGFRS with magnetic rigidity set to detect Z=118 EVR's extrapolated from experimental data for the region Z=89–116 (2001Og09). A rotating target (97.3% ^{249}Cf) with six separate target sectors, each with an area of 5.3 cm^2, was used. It was determined that the excitation energy of the ^{297}118 CN could vary from 26.6–31.7 MeV and subsequent analysis led to an accuracy of $\Delta E^*\approx4.3$ MeV. A tof detector with a 65 mm flight base was mounted ahead of the focal plane detector. X–y position correspondence provided genetic correlations between implanted recoils (α's or SF) and their subsequent decays. A fission fragment calibration was performed using SF fragments from ^{252}No with a known average energy release of about 176 MeV.

18 SF events observed were separable into two groups by energy: 16 events with an average total E=158 MeV ($125\leq E(tot)\leq175$ MeV), 1 event with E(tot)=207 MeV, and 1 event with E(tot)=223 MeV. The corresponding lower limit of half–life for the group of 16 events was estimated to be $T_{1/2}(SF)>0.5$ h ascribed to long lived nuclides in the Cf–Fm region via incomplete fusion reactions suppressed by >5 orders of magnitude in DGFRS. The other two fission events were preceded by recoil signals ascribed to α decay from a higher A parent.

Event 1 (19 March 2002): in particular, the event with E(tot)=207 MeV (TKE≈230 MeV) points to a strong correlation of α decays in a EVR–α1–α2–SF sequence. The probability of randomness for all 4 events in the sequence was calculated as being less than 1.5×10^{-6}. The instantaneous beam energy was 245.6 MeV corresponding to an excitation energy of 29.8 MeV *20* in the compound system ^{297}118. The events were:

E_1=11650 keV 60, t_1=2.55 ms

E_2=10710 keV 170, t_2=42.1 ms

E_3(SF)=188+19 MeV, t_{SF}=0.52 s.

E_1 and E_2 were assigned to the α decay of Z=118 (^{294}118) and Z=116 (^{290}116), respectively, and E3 to the two SF fragments of Z=114 (^{286}114).

Event 2 (16 April 2002): for this EVR–SF sequence with E(tot)=223 MeV no α–like signals were detected. Two coincident SF fragments were seen with energies of 137 MeV (focal plane detector) and 86 MeV (side detector). The instantaneous beam energy was 246.1 MeV corresponding to a compound nucleus excitation energy of 30.2 MeV *23*. The fissioning event was suggested to belong to the EVR ^{294}118 (t_1=3.16 ms) by 2004Og10. This event was not included in table IV of 2004Og12.

Other: see 2004OgZZ for further discussions.

Theory: see Nuclear Science References.

Assignment: ^{249}Cf(^{48}Ca,3n), E=265 MeV (2002OgZX,2003OgZZ,2004Og10,2004Og12). Additional experiments are underway and more detailed studies are required. The evaluators consider all assignments for this decay chain as tentative. Also, 2004Mo15 note that their assignment of mass based on the CN excitation energy may be off by single unit.

^{294}118 Levels

E(level)	Jπ	$T_{1/2}$	Comments
0.0?	0+	1.8 ms *+84–8*	$T_{1/2}$: from one event (2002OgZX,2003OgZZ. $\Delta T_{1/2}$ at 68% confidence level). 1.8 ms *+750–13* (2004Og12) if 95% confidence level used. $T_{1/2}$(calc)=0.44 ms from Viola–Seaborg systematics for Q=11.81 MeV. %α≈100. %α: estimated from one event. β_2(theory): –0.087 from 1995Mo29; 0.077 from 2003Mu15; 0.008 from 2005GaZX.

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