Adopted Levels

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	M. Gupta	ENSDF	1-Aug-2015

Q(β^-)=−2928 *SY*; S(n)=5958 *SY*; S(p)=4244 *SY*; Q(α)=8646 *50*

Q(β^-): estimated uncertainty=121 keV.

S(n): estimated uncertainty=206 keV.

S(p): estimated uncertainty=134 keV.

Q(α): From systematics, Eα=8646.42 keV ± 50.0 (2012Wa38). Other: QA=8409 keV 40 from 25 correlated α decay events corresponding to EA=8280 keV 40 (2013Mu08); Average EA=8280 keV 50 (QA=8409 keV 50) from 113 events (2011Ha13). Evaluators note that the Q(α)=8.409 MeV *40* from 2013Mu08 in agreement with Q(α)=8.411 MeV *28* (Eα=8.282 MeV *28*) from 2008Du09 could be the likely g.s. A second state with Q(α)=8.637 MeV *36* (Eα=8.505 MeV *36*) was also reported (2008Du09). The weighted average of both states from 2008Du09 for ^{261}Rf is Q(α)=8.615 MeV *67* (Eα=8.483 MeV *67*) by the normalised residual method.

1970Gh01: direct synthesis through the reaction ^{248}Cm(^{18}O,5n) at beam energies of 90-100 MeV. The ^{18}O beam was provided by the Berkeley heavy ion accelerator (HILAC). The yield of ^{261}Rf corresponded to a cross-section of 5 nb. The excitation function for the reaction was determined approximately. The bombarding energies were close to the calculated peak at 97 MeV. Recoils of interest were deposited via a He gas jet on a rotating wheel with a cycle rate of 48 s. α spectroscopy was performed using two stationery and two rotating Si-Au surface barrier detectors. Target impurities resulted in a host of contaminants in the observed spectra. The main α particle group was determined to be at 8.28 ± 0.02 MeV. The joint mother-daughter activity was 70 s ± 10. The combined half-life was 7% longer than of the mother activity alone resulting in the corrected $T_{1/2}$ of 65 s ± 10 for ^{261}Rf. No SF branch could be determined although an upper limit of 10% was estimated.

1994Lo27, 1994La22: produced as daughter nuclide in the reaction ^{248}Cm(^{22}Ne,5n) E=116, 121 MeV using the U400 cyclotron at Dubna and the H-gas filled separator DGFRS. See ^{265}Sg adopted data set for experimental details. Four α-α-(α) correlations at 121 MeV were attributed to parent ^{265}Sg with Eα=8.71-8.91 MeV at a production cross-section of 260 pb accurate to within an approximate factor of three. The Eα=8.16 to 8.17 MeV α-α correlation was attributed to the decay of ^{261}Rf to ^{257}No. The experimenters note that except for a single triple α correlation, ^{261}Rf could not be distinguished from ^{257}No with certainty due to the similarity in α energies. Experimenters suggest $T_{1/2}$=65 s, Eα≈8.29 MeV. Evaluators note that 4 α-SF events attributed to ^{266}Sg and ^{262}Rf are reassigned by 2006Dv01 to ^{265}Sg and ^{261}Rf^b (3 s state) which was unknown at the time. 1997Sc48 note that the half-lives of the Sg isotopes could not be measured due to the lack of an initial implantation signal in the Si detectors.

1996Ka66: direct synthesis through the reaction ^{248}Cm(^{18}O^{5-},5n) at LBL, E(lab)=117 MeV. Reaction cross-section was 5 nb. The purpose of this chemistry experiment was to study the relative volatility of tetrachlorides of the group 4 elements Zr, Hf and Rf using gas phase isothermal chromatography. Reaction products were transported through the heavy element volatility instrument (HEVI) described in 1992Ka57. Total transportation yield was 60% to 80%. Species leaving the chromatography column were transported to the merry-go-round (MG) detector system (1980Ho25) where 6 pairs of PIPS detectors were used to measure the kinetic energies of coincident fission fragments and α particles. The step time was 1 minute and the detection efficiency was about 60%. α spectra from all chemistry measurements in the energy window 8.15 to 8.38 MeV were analysed. A total of 170 α-α correlations were observed close to the expected value of 169. The suggested alpha decay half-life was $T_{1/2}$=78 s *+11−6* (68% c.i.) using the maximum likelihood method. The experimenters point out that a short component appears to exist in the observed SF events providing an upper limit of 11% corresponding to $T_{1/2}$(SF)>709 s assuming no other decay modes. The evaluators note that estimates for randomness are not provided for the α-α correlations making it difficult to distinguish true mother-daughter correlations from random events. However due to the improved ability of HEVI to seperate out non-volatile interfering activities prior to counting, the half-life arrived at in this work is expected to be better than the earlier value from 1970Gh01.

1996Ho13: descendent 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 in 2005Gu33 for details. One energy-time correlation recorded with one escaped particle for this nucleus with a time interval of 32.7 s (subsequently retracted by 2002Ho11) and one α decay with Eα=8.52 MeV ± 20 after a time interval of 4.7 s.

1996La12: descendant of ^{273}Ds using the hot fusion reaction ^{244}Pu(^{34}S,5n) E=190 MeV at Dubna using DGFRS in collaboration with LLNL. The cross-section was about 0.4 pb for ^{273}Ds. See ^{273}Ds Adopted Levels in 2005Gu33 for details. The energy window was set at 8.15 to 8.45 MeV for ^{261}Rf and ^{257}No with a time window of 1100 s following the emission of the first α. Suggested properties from the most likely single event in beam off conditions are Eα=8.20 MeV with a lifetime of 117 s corresponding to $T_{1/2}$=79 s. The assignment took into account the presence of a small ΔE signal from preliminary results, which was attributed at the time to a conversion electron accompanying the decay of the 8.63 MeV α (from ^{265}Sg) to ^{261}Rf and ^{257}No.

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1996La12 reason that this is consistent with odd-A ^{265}Sg decaying preferentially to an excited state in daughter ^{261}Rf.

1997Sc48, 1997Sc49: daughter of ^{265}Sg produced in the hot fusion reaction ^{248}Cm(^{22}Ne,5n) E=121 MeV at GSI using the UNILAC. See ^{265}Sg Adopted Levels for details. Two chemical separation techniques were used in these studies intended to study the chemical properties of Sg and α spectroscopy was done using a rotating wheel. The decay of ^{265}Sg was not seen although the presence of ^{261}Rf and ^{257}No as daughter products indicates the production of the parent. Three events were observed which could be attributed to ^{261}Rf and daughter ^{257}No: Eα=8.24, 8.26 and 8.52 MeV with τ=33.5, 22.7 and 142.0 s respectively (the last in 'parent-daughter' mode). Energy resolution was ± 60 keV (FWHM) for α particles between 5 and 12 MeV in the PIPS detectors with a detection efficiency of 33% (for α's) and 66% (SF fragment). The overall efficiency for an α-α correlation was 11% and for an α-SF correlation, 22%. A detailed analysis for random events is provided. The experimenters conclude that they have no evidence for the direct observation of ^{265}Sg α decay. 1997Sc49 report results from gas chromatography using the OLGA III (1996Tu05) setup. Three decay events attributable to ^{265}Sg were unambigiously measured. The following properties were attributed to ^{261}Rf: Eα=8.36, 8.15 and 8.34 MeV ± 6 (FWHM) corresponding to τ=31.0, 53.3 and 48.4 s respectively. Average Eα=8.28 MeV ± 6 with $T_{1/2}$=31 s *+42−11* (evaluators). The authors note that with about 90% probability, the isotopes of Rf and No were formed between the time taken for chemical separation and their measurement about 28 s later given the experimental set-up used. A random analysis is not provided. The evaluators note that ambiguities exist in both these experiments and the data from 1997Sc48, 1997Sc49 were not considered in the reanalysis by 2008Du09. See also 1998Sc50 and 1999Tu04 for chemistry.

1998Tu01: produced as the daughter of ^{265}Sg by the hot fusion reaction ^{248}Cm(^{22}Ne,5n) E=121, 123 MeV at the GSI UNILAC; see ^{265}Sg Adopted Levels for experimental details. See also ^{266}Sg Adopted Levels in 2005Gu33 for details. A total of 13 α-decay chains were attributed to ^{265}Sg (and daughter ^{261}Rf) and an additional three events attributed to ^{266}Sg (and daughter ^{262}Rf). Three more decay chains (events 14 to 16) with a higher degree of randomness were also suggested as belonging to the decay of ^{265}Sg.

Correlated decay chains with Eα(mother)=8.57-9.07 MeV (^{265}Sg) and Eα(daughter(s))=8.05-8.45 MeV (^{261}Rf, ^{257}No), and Eα(mother)=8.41-8.85 MeV (^{266}Sg) and E_{SF}(daughter) ≥ 20 MeV (^{262}Rf) within 6.3 s are shown below: see also ^{265}Sg Adopted Levels levels for details.

Note that Events 14-16 (assignments in parentheses) have a high degree of randomness and were not included in the re-evaluation by 2008Du09. Also, the three events (17 to 19) which were originally assigned to ^{266}Sg (^{262}Rg) through this work were reassigned to ^{265}Sg (^{261}Rf) via 2006Dv01 and considered as such in 2008Du09.

2000La34: direct synthesis through ^{244}Pu(^{22}Ne,5n)^{261}Rf at beam energies of 114 and 120 MeV with an estimated cross-section of 4 nb at both energies. 69 α-α correlations linking decays of ^{261}Rf and ^{257}No were observed. Experiments were conducted using the Dubna U400 cyclotron. Recoil products were separated by DGFRS described in 1993LaZS. At a beam energy of 120 MeV, 17 correlated α-α pairs were detected with the following properties: Eα_1=8.22-8.41 MeV, δt=0.4-181 s and Eα_2=8.07-8.37 MeV. At 114 MeV, 25 pairs of α events were observed with Eα_1=8.25-8.36 MeV, δt=0.2-129 s and Eα_2=8.21-8.40 MeV. The number of α-α correlations from genetically unrelated events was estimated to be less than 0.1 within the time window of 200 s over the total of 42 linked events observed. An α energy spectrum was measured for the first time centered around Eα=8.3 MeV with standard deviation σ=33 keV. A single α energy peak was observed at Eα=8.30 MeV ± 0.06 for 261Rf without any contribution from α decays originating from the daughter. An estimate of the half-life is not given. No α decays corresponding to the 8.52 MeV events ascribed to ^{261}Rf in 1996Ho13 or 1997Sc49 were seen.

2000Sy01: direct synthesis of ^{261}Rf in the reaction ^{248}Cm(^{18}O,5*n*) at a beam energy on target of 99 MeV, to study the relative volatility of group 4 tetrabromides. The chromatographic system HEVI (heavy element volatility instrument) with an improved temperature profile (1992Ka57) was used in which less volatile species are retained. Upon exiting the chromatography column, molecules of interest were transported to the MG wheel system (1980Ho25). α spectroscopy was performed by PIPS detectors allowing a solid angle detection efficiency of ≈60% for α and SF decays. The step time was set at 1 min since the experiment was designed to measure the known 78 s state in this nucleus. α decays were measured in energy window 8.12 − 8.38 MeV and $T_{1/2}$=74 s *+7−6* (68% c.i.) was suggested using a MLDS fit. The weighted average halflife when combined with 1996Ka66 was $T_{1/2}$=75.5 s ±6.6. The recommended value was $T_{1/2}$=75 s ± 7. The experimenters note that the half-life fit assumed the presence of the daughter ^{257}No and ^{211}Po^m. The energy resolution, reaction cross-section and estimates of randomness are not provided. In the absence of a random analysis, evaluators note that it is difficult to distinguish between true mother-daughter correlations and random events. However as with the work of 1996Ka66, due to the improved ability of HEVI to seperate out non-volatile interfering activities prior to counting, the half-life reported in this work is expected to be better than the earlier value from 1970Gh01. The experiment was not sensitive to detecting a shorter half-life state. The volatility temperature of $^{261}RfBr_4$ was 175° C and the adsorption enthalpy given as −87 ± 7 kJ/mol^{-1}.

2001Hu22:produced as daughter in the chemical study of seaborgium oxide hydroxide with the reaction ^{248}Cm(^{22}Ne,4*n*)^{266}Sg at a beam energy of 119 MeV provided by UNILAC, GSI. See ^{265}Sg Adopted Levels for details. The results of this experiment were

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reassigned to ^{265}Sg and ^{261}Rf in the analysis by 2008Du09 and are relevant here. Two α-SF events were measured in the energy window of 8.61 to 8.75 MeV attributed to ^{266}Sg and ^{262}Rf: Eα_1=8.66 MeV, τ_1=84.9 s and τ(SF)=7.0 s; Eα_2=8.70 MeV, τ_2=4.8 s, τ(SF)=3.7 s. From both events, probabilities of randomness were 0.82 (no random), 0.16 (one random) and 2% (both random). Evaluators note that the average Eα=8.680 MeV ± 28 corresponding to $T_{1/2}$=31 s *+57−12* (Sg). The two-event SF $T_{1/2}$(SF)=4 s *+7−2* (Rf).

2002Ho11: descendant 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 in 2005Gu33 for details. Two events were measured for this nucleus: Eα=8.52 MeV and $T_{1/2}$=4.7 s and a SF event with a lifetime of 14.5 s. The experimenters conclude that two states exist in ^{261}Rf with half-lives of 78 s *+11−6* and 4.2 s +3.4-1.3. The first state decays by the emission of an α particle with Eα=8.28 MeV. The second state decays either by an α particle with Eα=8.52 MeV or by SF with a branching of about 40%. It is suggested that the level with $T_{1/2}$=4.2 s and Eα=8.52 MeV offers a better agreement with ground state systematics. The state decaying with $T_{1/2}$=78 s is suggested as being an isomeric state. The possibility that ^{261}Rf may have two states was put forward here for the first time.

2003Tu05, 2003Du27, 2002Du21: descendent of ^{269}Hs in a chemical study. ^{269,270}Hs produced by ^{248}Cm(^{26}Mg,xn) at 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. Chemically separated Hs atoms were identified by observing genetically linked decay chains. See ^{269,270}Hs Adopted Levels in 2005Gu33 for details.

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. 2003Tu05 state that the first event with Eα=8.5 MeV *+7−3*, Δt=2.4 s is in good agreement with ^{261}Rf observed in the first decay chain in 2002Ho11. Taking into account all three events listed above, the experimenters suggest Eα=8.5 MeV *+7−3* (events 1 and 3 are energy redundant) and $T_{1/2}$=4.2 s *+34−13* (SF branch of 40%) for the ground state in ^{261}Rf. The previously known 78 s state is proposed as an isomer, in agreement with 2002Ho11. 2003Du27 suggest a randomness probability of ≤7×10^{-5} for decay sequences originating from ^{269}Hs. Two more possible candidates for ^{269}Hs are shown in 2002Du21 but not listed here since the parent (in the first event) and daughter (in the second event) were not observed. Tentative assignments of two decay chains initially made to ^{270}Hs in 2003Tu05 and 2002Du21 are reassigned to ^{269}Hs via 2006Dv01. All six events (three chains above, two tentative decays and one candidate for either ^{269}Hs or ^{270}Hs from 2002Du21) are taken into account by 2008Du09 in their reanalysis of ^{261}Rf data.

2004Vo24: descendent of ^{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). See ^{269}Hs Adopted Levels in 2005Gu33 for details. One correlated α-α-α chain and five α-SF chains observed; the last α-SF chain is a likely candidate for a random correlation.

α-α-α chain:

α-SF events:

Events 3 and 4 were included in the reevaluation by 2008Du09 and taken as originating from ^{269}Hs (undetected) decaying to ^{265}Sg and ending by SF from the ^{261}Rf^{b} state.

2006Dv01: grand daughter of ^{269}Hs produced by ^{248}Cm(^{26}Mg,5n) at GSI/UNILAC. This was the first campaign, with beam energies of 193 MeV and 185 MeV corresponding to E=145, 136 MeV at the center of target for the expected 5n and 4n channels respectively. Three arc-shaped segmented targets (95.8% ^{248}Cm, 4.2% ^{246}Cm); one segment contained 2% by weight of ^{152}Gd (30% enrichment) for simultaneous production of α-decaying Os isotopes, a chemical analog to Hs. See 2002Ki25, 2002Du21, and 2002Du22 for description of rapid chemical separation and on-line detection method used. Detection system consisted of a linear array of 2×32 PIPS detectors in two Invar profiles forming a vacuum tight gas channel. Energy resolution=50 keV (FWHM). The energy region of interest at Eα=8.0-9.5 MeV contained 145 events in the first 25 detectors. α decay chain was defined as an 8.0-9.5 MeV α-decay followed within 300s in the same or neighboring detector pair by an α-decay in the same energy window or by an SF. The search was repeated within the chain until no α-decay was registered. Data analysis revealed 15 correlated decay chains in the first 25 detector pairs; eight at E=145 MeV and seven at E=136 MeV. Based on the count rates, 3×10^{-5} random sequences can be for α-α-α-α, 5×10^{-3} for α-α-SF, and 1 for α-SF. Cross sections of ≈3 pb were measured for ^{270}Hs at 136 MeV and ≈7 pb for ^{269}Hs at 145 MeV within an estimated accuracy of a factor of ≈3.

Of the 7 events pertaining to the decay of ^{265}Sg and ^{261}Rf, one event with Eα=8.29 MeV and $T_{1/2}$=22 s was assigned to ^{261}Rf^{a} while the other 6 events were assigned to the SF branch of ^{261}Rf^{b} (states labelled in accordance with 2008Du09).

Evaluators Note: While the results from this experiment are contradictory to earlier reports, they also differ from the properties of ^{266}Sg and ^{270}Hs adopted in 2005Gu33. 2006Dv01 suggest that data pertaining to these nuclides from earlier studies are more

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consistent with decays from ^{265}Sg and ^{269}Hs and were erroneously assigned to ^{266}Sg and ^{270}Hs whose properties stand revised via their work. The quantities adopted in 2005Gu33 were in consonance with claims made by the various experimental groups, some of which cited 'unambigious' results for these nuclides. It is worthwhile to note that many of the early studies were designed primarily to measure chemical properties such as the greatly increased volatility of chlorides of trans-actinides (*i.e.* elements above Z=103). Hence, the experimental focus was mainly on the transmission of SF activity through a suitable detection system indicative of the presence of a specific nuclide and chemical species of interest (or its absence), rather than on the accurate measurement of a half-life. Additionally, the chemistry experiments employed hot fusion reactions with actinide targets which are known to lead to a relatively large SF background when compared to Pb-target based cold fusion reactions. The non-negligible SF background through most of the chemistry experiments may have interfered with the direct identification of ^{261}Rf^{b} as pointed out by 2008Du09. Finally, the presence of ^{212}Po (Eα=8.52 MeV, I$_{\alpha}$=2.05%) from transfer reactions caused by the projectile on Pb impurites in the target, could also have hindered the detection of the 'second' shorter lived state, ^{261}Rf^{b} with Eα=8.505 MeV, even if the energy gate had been adequate. Subsequent independent studies providing collateral information and improved characterisation and assignment properties, through both physical and chemical means were necessary in aiding more conclusive assignments and an accurate determination of physical properties.

2006Ni10: in a study of the reaction ^{238}U(^{30}Si,xn)^{268}Sg at GSI using the UNILAC and SHIP. The SHIP setup was similar to earlier work. See ^{265}Sg Adopted Levels for details. One event (number 8) was attributed to ^{265}Sg and daughter ^{261}Rf. The assignment was made taking into account an 'average' half-life for ^{265}Sg from 2003Tu05 (3 events) and 2002Ho11 (2 events). An SF event following an escaped α particle with a lifetime of 11.4 s was assigned to ^{261}Rf. The SF fragments were attributed to the presumed 100% SF mode as a result of α-decay from ^{265}Sg, populating the 3.6 s *+23−11* state in daughter ^{261}Rf. The TKE was not provided as one of the SF fragments was not measured. A single γ emission with energy 1172 keV was measured in coincidence with the SF decay in the clover detector. The experimenters suggest that the gamma ray originated from a 100% SF branch of the 3.2 s level in ^{261}Rf fed by the 15.2 s parent state with half life 10.5 s in ^{265}Sg. If confirmed, this may represent the proposed 20% branch from ^{265}Sg^{a} to ^{261}Rf^{b} (evaluators).

2007Mo09, 2005MoZT, 2005MoZQ: descendent of 27712. Confirmatory experiments performed by the Japanese group at RIKEN with ^{208}Pb(^{70}Zn,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 in 2005Gu33 for details. Randomness factors are provided in 2007Mo09. The revised half-life for ^{261}Rf from 4 events (including the two from GSI) is suggested as 5.3 s *+53−18*. 2007Mo09 note that while Eα of grand-parent ^{269}Hs from 2006Dv01 is somewhat low when compared to their results, the α energies for ^{265}Sg and decay properties of ^{261}Rf are consistent. 2007Mo09 suggest an α:SF branching of 1:3 from the fifth event chain.

2008Dv02: grand daughter of ^{269}Hs produced by ^{248}Cm(^{26}Mg,5n) at GSI/UNILAC. This was the second campaign with beam energies of 197 MeV, 189 and 181 MeV corresponding to E=150, 140 and 130 MeV at the target center. The experimental set-up was the same as used in 2006Dv01. Excitation functions were measured for the ^{248}Cm(^{26}Mg,3-5n)$^{269-271}$Hs reaction in this work. Five decay chains attributed to ^{269}Hs were observed:

Revised decay properties were deduced from all events including those from 2006Dv01:

^{269}Hs: α decay, Eα=9.13 MeV *5* with T$_{1/2}$=4 s (T$_{1/2}$ calculated using 2005Pa72) and 8.95 MeV *5*; ^{270}Hs: α decay, T$_{1/2}$=23 s (calculated using 2005Pa72 and Q(α) deduced from their experimental data), Eα=8.88 MeV *5*; ^{265}Sg: α decay, T$_{1/2}$=15 s *+7−4*, Eα=8.69 MeV *5*; and ^{266}Sg: SF decay, T$_{1/2}$=360 ms *+250−100*; ^{261}Rf^{a}: α decay, T$_{1/2}$=20 s *+110−10*, Eα=8.29 MeV *5*; and ^{261}Rf^{b}: α decay, T$_{1/2}$=3 s *+1−1*, Eα=8.51 MeV *5* with α:SF ratio 0.09:0.91.

2008Du09: reexamine all earlier data for ^{265}Sg and ^{261}Rf following reassignments via 2006Dv01. A comprehensive reevaluation of all data relevant to the production of ^{261}Rf in the reaction 248Cm(22Ne,*x*n)$^{270-x}$Sg was undertaken in an attempt to address existing ambiguities in deduced properties due to the varying quality of older data. Decay properties previously assigned to ^{266}Sg in 1994La22, 1996La12, 1998Tu01, 2001Hu22, 2003Tu05 and 2004Vo24 are reexamined together with new data from 2006Dv01 and 2008Dv02. Properties of ^{261}Rf from 1996Ka66 and 1996Ho13 are also examined. A total of 60 events were considered for ^{265}Sg and ^{261}Rf following reassignments. Strong indications for two states (a and b) in ^{261}Rf are suggested although it is not possible to conclusively deduce which (if any) is the ground state due to the poor quality of data.

Decay properties attributed to this nucleus are:

^{261}Rf^{a}: Eα=8.30 MeV; T$_{1/2}$=68 ± 3 s; b$_{SF}$<0.11.

^{261}Rf^{b}: Eα=8.51 MeV; T$_{1/2}$=3 ± 1 s; b$_{SF}$=0.91.

From available data on the direct production of ^{261}Rf the isomeric population ratio σ(^{261}Rf^{a})/σ(^{261}Rf^{b}) > 2 is deduced. In the case of the direct production of the grand-parent ^{269}Hs, the decays proceed preferentially to through 'b' states.

2008Ga08: ^{261}Rf produced as an EVR in ^{238}U(^{26}Mg^{6+},3n) reaction at the lowest excitation energy of 35.3 MeV corresponding to a centre of target beam energy of 121.8 MeV. Excitation functions are shown for the 4*n*, 5*n* and 6*n* channels and an analysis

Adopted Levels (continued)

provided. Noting that 2008Dv02 have observed a 3*n* channel from the ^{248}Cm+^{26}Mg reaction of comparable magnitude to the 4*n* channel in this work, a dedicated irradiation was performed to examine this. Experimenters used a $^{238}UF_4$ rotating target at the 88-Inch cyclotron facility at LBNL and with the Berkeley gas-filled recoil separator (BGS) filled with He gas. A pulsed beam was used for portions of the run to mimimise random correlations. A fast shut-off mode was used during the pulsed portion of this experiment, following the detection of an EVR during the beam pulse and the observed α within 300 s and ± 3.5 mm of the EVR. This enabled the detection of the 25 s daughter ^{257}No in nearly background free conditions. 280 such beam shut-offs lasting 100 s each were triggered by a potential EVR-α event. 8 α particles were measured in the energy range 8.0-8.7 MeV. Expected random EVR-α-α sequences numbered 7 x 10^{-3} during the entire irradiation. The probability of obtaining a random EVR-SF sequence was within five half-lives of ^{261}Rf^b (estimated to be 6%). A single correlated EVR-α-α event with properties Eα=8.34 MeV *5* attributed to ^{261}Rf^a decay and τ=103.2 s, followed by Eα=8.30 MeV *5*, τ=12.2 s from ^{257}No decay was observed corresponding to a cross-section of 28 pb *+92−26*. One EVR-SF event with SF energy of 173.3 MeV and lifetime of 9.4 s could belong to either state of Rf. Given that only a 6% chance of a random EVR-SF event exists within 5 half-lives of ^{261}Rf^b, if confirmed, the authors claim that this is the first observation of the "isomeric" state produced directly as an EVR rather than as the daughter of ^{265}Sg. The evaluators note that the assignment to the ^{261}Rf^b state is in agreement with 2008Du09 although any conclusion regarding whether this is an isomeric or ground state requires confirmation. The cross-section of the reaction in the 3n channel will increase by 14% to 32 pb *+93−26* including this event. Note that the evaluators adopt a nomenclature for states 'a' and 'b' consistent with 2008Du09.

2011Ha13: Direct synthesis via the reaction ^{248}Cm(^{18}O,5n)^{261}Rf at RIKEN. Though both states were populated, the purpose of the experiment was a detailed study of the isomeric state ^{261}Rf^b to determine its decay properties. Through this experiment, the decay properties of this state were directly measured for the first time. The ^{18}O beam was accelerated to energies of 95.1 and 93.1 MeV (middle of target) by the RIKEN Linear Accelerator (RILAC). Eight arc-shaped targets of 230 μg/cm^2 thick $^{248}Cm_2O_3$ enriched to 96.638% with 0.91 mg/cm^2 Ti backing foil rotated on a 100-mm diameter wheel at 1000 rpm. EVRs were separated in-flight by GARIS and extracted by a gas jet system. The thermalised ^{261}Rf ions were then attached to KCl aerosols and delivered to a shielded rotating wheel apparatus MANON for α-spectrometry. The gas jet transport efficiency was 52 ± 12% for ^{261}Rf^a. In MANON, the aerosol particles were deposited on Mylar foils, 40 of which were set on the periphery of the rotating wheel. The wheel was stepped to position the foils between 7 pairs of Si PIN photodiodes with 38% counting efficiency. Step intervals were set to 30.5 s and 2.0 s to enable the study of both the the 68 s ^{261}Rf^a and the 3 s ^{261}Rf^b respectively. Detector signals for alpha particles were set at 1-20 MeV and for SF fragments 5-150 MeV. FWHM for α detection was 50 keV in the top detectors and about 100 keV in the bottom ones. In the step interval of 30.5 s, 126 and 100 α events were registered with energy 8.0 to 8.41 MeV while 174 and 23 events were observed at a step interval of 2.0 s at beam energies of 95.1 and 93.1 MeV respectively. From a total of 120 α-α correlations, 113 decayed with an alpha energy of 8.01-8.37 MeV. The average energy was EA=8.28 ± 0.05 MeV with a half life deduced to be 24 ± 3 s. These decay properties were consistent with the parent-daughter pair ^{261}Rf^a-^{257}No. 6 α-α correlations were observed for the alpha group Eα=8.41-8.61 MeV at the 2.0 s time step. The average EA=8.52±0.05 MeV from the top detectors, with an α-decay half life of 2.4 ± 0.8 s consistent with ^{261}Rf^b. The number of random correlations was estimated to be 0.58 events. In addition to alpha decay, 5 and 8 SF events were measured respectively at 95.1 MeV and 93.1 MeV, 30.5 s time step, 77 and 9 SF events occured at 95.1 MeV and 93.1 MeV, 2.0 s time step. Assuming that all SF activity for the 30.5 s time step is from ^{261}Rf^a, a b_{SF}<13% (68% c.i.) is deduced. From 86 fission events at the 2.0 s time step, a SF halflife of 1.8 ± 0.4 s was deduced (Fig 3) and assigned to ^{261}Rf^b. Refitted data taking into account the sum of 8.5 MeV a-decays (9 events) and SF activity (77 and 9 events at beam energies of 95.1 MeV and 93.1 MeV respectively) yielded a half life of 1.9 ± 0.4 sec for ^{261}Rf^b. Data are insufficient for a conclusive determination of the ground state. Experimenters suggest that the SF half life of 2.1 ± 0.2 s attributed to ^{262}Rf by 1996La11, could possibly belong to ^{261}Rf^b. SF branch of b_{SF}=73 ± 6% is derived. An exceptional α-α correlation at the 2.0 s time step with parent EA=8.91 MeV, τ=4.05 s was tentatively proposed as belonging to ^{259}Rf. The deduced cross-section (sum of both states) was estimated to be 23 ± 4 nb. Cross-section for ^{261}Rf^b=11±2 nb at 95.1 MeV by comparing with ^{261}Rf^a=12±3 nb as reported by 2002Na37. Evaluators note that cross-sections reported by 2002Na37 for the same reaction are: 8±2 nb (E_{lab}=91 MeV), 13±3 nb (E_{lab}=94 MeV) and 8±2 nb (E_{lab}=99 MeV). The ratio of cross-section in the current work is provided as ^{261}Rf^a/^{261}Rf^b=1.1 ± 0.2.

2012Ha05: Daughter of ^{265}Sg produced using the reaction 248Cm(22Ne,5*n*)^{265}Sg at RIKEN. The ^{22}Ne projectiles were delivered on target by RILAC with E_{beam}=117.8 MeV at the centre of target. For experimental details see Adopted Levels for ^{265}Sg. A total of 18 and 24 observed events were attributed to parents ^{265}Sg^a and ^{265}Sg^b respectively. Their corresponding daughters were respectively populated by 16 and 4 α decays to ^{261}Rf^a and 2 and 20 decays to ^{261}Rf^b. The decay branching was calculated to be 91% (^{265}Sg^a to ^{261}Rf^a, 16 of 18 α decays) and 9% (^{265}Sg^b to ^{261}Rf^b, 4 of 24 α decays). A total of 25 decays from 18 SF

Adopted Levels (continued)

events and 7 α-decays, were attributed to $^{261}Rf^{b}$. E_{α}=8.51 ± 0.06 MeV from the 7 α decays. The corresponding α decay half-life is 10 s *+6−3* (evaluators). A SF half life of 2.6 s *+7−5* was deduced from the 22 fission events. Decay branching SF:α was b_{SF}=0.82±0.09 : b_{α}=0.18±0.09. In addition, a total of 15 lifetimes for $^{261}Rf^{a}$ were measured from triple α correlations from $^{265}Sg^{a\ or\ b}$ to $^{261}Rf^{a}$ to ^{257}No from which a half life of 59 ± 42 s was derived using an exponential decay curve analysis. Evaluators note the large uncertainty in this value. The average α energy was found to be 8.27 ± 0.06 MeV which agrees with the literature value.

2013Mu08: Direct synthesis using the reaction 248Cm(18O,5*n*)^{261}Rf at RIKEN using the RILAC facility to investigate the short lived SF components. Beam energies in the laboratory frame were 88.2, 90.2, 94.8 and 101.3 MeV at centre of target. EVRs were separated by GARIS and transported to a Si detector array at the focal plane. Decay events were detected in beam off conditions. To distinguish between short-lived SF activity and the decay of ^{262}Rf beam on-off periods were set to 6 s, 6 s, 0.1 s and 0.1 s. Following irradiations at each energy, background events were measured for several hours to estimate the contribution of long lived background SF events. Most of the events pertaining to $^{261}Rf^{a}$ and its alpha decay daughter ^{257}No were observed at a beam energy of 94.8 MeV as expected going by the calculations of 2004Ni10. 26 α-α correlations were observed with the following properties: 25 events at a beam energy of 94.8 MeV with Eα (average)=8.28 ± 0.04 MeV (68% c.i.) consistent with the α-decay of $^{261}Rf^{a}$; 1 event at a beam energy of 90.2 MeV with Eα=8.48±0.04 MeV. The single event was attributed to $^{261}Rf^{b}$ noting that the lifetime of the decay daughter was 11.8 s consistent with literature values for ^{257}No. Estimated total number of random events in the α- energy region 8.00 to 8.62 MeV was 0.14 suggesting true α-α correlations. Random α-SF sequences were estimated to be 0.09. Production cross-sections for $^{261}Rf^{a}$ were derived from the total events within the α-energy range 8.00 to 8.62 MeV at each beam energy: 0.47 ± 0.20 nb (E_b=88.92 MeV), 1.8 ± 0.6 nb (E_b=90.2 MeV), 12 ± 3 nb (E_b=94.8 MeV) and 4.1 ± 1.1 nb (E_b=101.3 MeV). Cross-sections for the SF nuclide $^{261}Rf^{b}$ were derived from the yields of $^{261}Rf^{a}$ although the SF event was observed only at a beam energy of 94.8 MeV, as follows:1.5 nb *+18−15* (E_b=88.92 MeV), 3.7 ± 3 nb (E_b=90.2 MeV), 12 ± 4 nb (E_b=94.8 MeV) and 0.9 nb *+26−9* (E_b=101.3 MeV). Total cross-sections for both states $^{261}Rf^{(a+b)}$ were 2.0 ± 1.8 nb (E_b=88.92 MeV), 5.5 ± 3.1 nb (E_b=90.2 MeV), 24 ± 5 nb (E_b=94.8 MeV) and 5.0 ± 2.9 nb (E_b=101.3 MeV). The experimenters concluded that the ratio of cross-sections $^{261}Rf^{a}$:$^{261}Rf^{b}$ depends on reaction employed.

2013Su04: Descendent of ^{277}Cn produced in the cold fusion reaction 208Pb(70Zn,n)^{277}Cn at RIKEN. Three beam energies were used: 347.5, 351.5 and 355.5 MeV. A single event was observed at 351.5 MeV. The fifth decay in the sequence with E(SF)=176 MeV and a decay time of 3.73 s was attributed to this nucleus. The corresponding half life of 4.7 s *+36−14* is in agreement within uncertainties with known values for $^{261}Rf^{b}$. Experimenters suggest that when ^{265}Sg and ^{261}Rf are produced as α-decay daughters, they form only one of the two isomeric states.

Other: 2002Na37, 2006Sc02, 2007Ha29, 2009HA49. See also 1996La11 wherein properties assigned to ^{262}Rf may belong to ^{261}Rf.

Theory: see Nuclear Science References.

Assignment: reassessment of all data from ^{248}Cm+^{22}Ne reaction (2008Du09); chem, ^{248}Cm(^{18}O,5n)^{261}Rf, E_{beam}=95.1, 93.1 MeV (2011Ha13); 248Cm(18O,5*n*)^{261}Rf, E_{lab}=88.2, 90.2, 94.8 and 101.3 MeV (2013Mu08).

Event #	E_1^a (MeV)	t_1^b (s)	E_2^c (MeV)	t_2^c (s)	Δt_2^d (MeV)	Δt_2^d (s)	E_3^e (°C)	Δt_3^f	Temp.	N_R^g
1	8.86	0.6	8.35	48.4		300	0.83[h]	^{265}Sg->^{261}Rf or ^{257}No		
2	8.76	1.4	8.39	151.8		350	[h,i]			
3	8.93	7.0	8.22	22.2		350	[h,i]			
4	8.82	27.3	8.15	53.3		300	[h]			
5	8.81	2.8	8.36	31.0	8.11	14.8 400	0.04	^{265}Sg->^{261}Rf->^{257}No		
6	8.69	1.4	8.18	56.0		300	1.90	^{265}Sg->^{261}Rf or ^{257}No		
7	8.85	5.6	8.41	40.2		350	[i]			
8	8.76	6.6	8.28	45.8		350				
9	8.77	6.8	8.22	25.5		350				
10	8.96	12.8	8.23	23.5		350				
11	8.85	19.1	8.35	0.5		400				
12	8.93	19.1	8.41	35.6		350	[i]			
13	8.86	21.7	8.37	31.6		300				
14	8.95	34.0	8.22	31.2		400	2.90	(^{265}Sg->^{261}Rf or ^{257}No)		
15	8.97	43.8	8.20	1.5		400				
16	8.83	52.1	8.42	1.3		400				
17	8.52	48.9	SF[j]	2.8		400	0.03[h]	^{266}Sg->^{262}Rf		

18	8.79	15.1	SF[j]	1.7	350	0.09[i]	
19	8.74	3.5	SF[j]	2.4	DC[k]	0.45	

[a] Energy of mother α particle (^{265}Sg or ^{266}Sg).
[b] decay time (since beginning of measurement).
[c] Energy of daughter α particle (^{261}Rf or ^{257}No).
[d] Time difference between decay of mother and daughter nuclei.
[e] Energy of granddaughter particle (^{257}No).
[f] Time difference between the decay of the daughter and the granddaughter (^{261}Rf and ^{257}No).
[g] Expected number of random correlations for decay chains 1 to 4, 5, 6 to 13, 14 to 16, 17, 18, and 19.
[h] Event was registered in daughter mode (DM).
[i] Event observed in the second series of experiments.
[j] Spontaneous fission (SF) with E_{SF} >20 MeV.
[k] Decay chain was observed during a direct catch (DC) experiment with the tape detection system.

TVEvent #1: 12-May-2001 at 09:55:03 hrs
$E_{\alpha1}$=9180 MeV +7-3 - assigned to ^{269}Hs
$E_{\alpha2}$=8.69 MeV +7-3 t2=4.4 s - assigned to ^{265}Sg
$E_{\alpha3}$=8.50 MeV +7-3 t3=2.4 s - assigned to ^{261}Rf
$E_{\alpha4}$=8.21 MeV +7-3 t4=55.6 s - assigned to ^{257}No
TVEvent #2: 12-MAY-2001 at 22:00:28 hrs
$E_{\alpha1}$=9.10 MeV +7-3 - assigned to ^{269}Hs
$E_{\alpha2}$=8.68 MeV +7-3 t2=9.3 s - assigned to ^{265}Sg
E_{SF}=179 MeV 6 t3=7.9 s - assigned to ^{261}Rf
TVEvent #3: 13-May-2001 at 10:02:07 hrs
$E_{\alpha1}$=8.88 MeV +7-3 (partial Eα) - assigned to ^{269}Hs
$E_{\alpha2}$=8.90 MeV +7-3 t2=17.1 s - assigned to ^{265}Sg
$E_{\alpha3}$=8.50 MeV +7-3 t3=0.846 s - assigned to ^{261}Rf

TVEvent: ^{269}Hs. October 30, 2002 (Probability to encounter this as random: $<4\times10^{-3}$)
$E_{\alpha1}$=9.12 MeV - assigned to ^{269}Hs
$E_{\alpha2}$=8.65 MeV t2=24.886 s - assigned to ^{265}Sg
$E_{\alpha3}$=escape - assigned to ^{261}Rf
$E_{\alpha4}$=8.20 MeV t4=8.029 s - assigned to ^{257}No

TVEvent #1: ^{269,270}Hs. October 29, 2002
$E_{\alpha1}$=9.284 MeV - assigned to ^{269,270}Hs
$E_{\alpha2}$=escape - assigned to ^{265,266}Sg
E_{SF}=31 MeV t3=10.484 s - assigned to ^{261,262}Rf
TVEvent #2: ^{269,270}Hs. November 8, 2002; 8:00 a.m.
$E_{\alpha1}$=9.124 MeV - assigned to ^{269,270}Hs
$E_{\alpha2}$=escape - assigned to ^{265,266}Sg
E_{SF}=31 MeV t3=17.721 s - assigned to ^{261,262}Rf
TVEvent #3: ^{269,270}Hs. November 10, 2002
$E_{\alpha2}$=8.695 MeV - assigned to ^{265,266}Sg
E_{SF}=51 MeV t3=13.599 s - assigned to ^{261,262}Rf
TVEvent #4: ^{269,270}Hs. November 8, 2002; 9:12 a.m.
$E_{\alpha2}$=8.902 MeV - assigned to ^{265,266}Sg
E_{SF}=85 MeV t3=14.561 s - assigned to ^{261,262}Rf
TVEvent #5: Not assigned; possible random event.
$E_{\alpha2}$=8.379 MeV
E_{SF}=92 MeV t3=12.273 s

TVCorrelated chains observed:

E_{beam} (MeV)	E_1 (MeV)	E_2 (MeV)	Δt_2 (s)	E_3 (MeV)	Δt_3 (s)	E_4 (MeV)	Δt_4 (s)	Assignment
145	8.93	8.69	32.5	8.29	32.1	8.29	2.50	^{269}Hs
145	9.06	8.68	85.6	93	4.44			^{269}Hs
145	9.11	8.68	2.48	67/13	7.09			^{269}Hs
145	8.91	8.65	6.75	29	6.69			^{269}Hs
145	9.03	8.60	7.70	111/26	6.42			^{269}Hs
145	8.92	8.72	6.82	90/101	1.29			^{269}Hs
145	8.35	38	0.116					None

145	8.85	100/74	1.62					^{270}Hs		
136	9.08	8.71	8.70	100/74	0.580			^{269}Hs		
136	9.10	80/90	96.0							^{269}Hs[a]
136	8.90	89/55	0.0496					^{270}Hs		
136	8.92	106/82	0.449					^{270}Hs		
136	8.88	96/110	0.444					^{270}Hs		
136	9.30	8.20	149	89/95	12.0				^{271}Hs[a]	
136	8.67	117/102	306					None		

[a] TVTentative assignment

TVCorrelated chains observed:

E_{beam} (MeV)	E_1 (MeV)	E_2 (MeV)	Δt_2 (s)	E_3 (MeV)	Δt_3 (s)			E_4 (MeV)	Δt_4 (s)	Assigment	
150	9.18	8.62	10.9	8.51	4.89	8.24	20.8	^{269}Hs			
150	9.13	8.68	7.61	79/88	2.25			^{269}Hs			
140	8.61	83/84	3.35								^{265}Sg[a]
140	9.11	8.63	52.0	75/-	3.04					^{269}Hs[b]	
140	9.22	8.47	12.3	84/120	0.128			^{269}Hs			

[a] TVIncomplete (α)-α-SF chain from ^{269}Hs

[b] TVFirst particle not position correlated

^{261}Rf Levels

Current data do not allow a conclusive assignment of any level to the g.s.

2012Au07 assign the longer lived state to the isomer.

The labeling of states is in accordance with 2008Du09.

Based on the re-examination of earlier data, 2008Du09 note that both states in ^{261}Rf are fed with similar intensity when parent ^{265}Sg is produced as an EVR.

In the case of the direct production of grand-parent ^{269}Hs, the decays proceed preferentially through 'b' states (2008Du09, 2012Ha05).

Cross-feeding of both states does occur. Relative intensities are from 2012Ha05.

Cross Reference (XREF) Flags

A	^{265}Sg α decay (14.4 s)
B	^{265}Sg α decay (8.5 s)

E(level)	$T_{1/2}$	XREF	Comments
x	68 s *+3−3*	AB	%α=100 (2012Ha05) This level was labelled ^{261}Rf[a] by 2008Du09 as possible g.s. $T_{1/2}$: from 2008Du09. Others: 65 s *10* (1999Ar21,1970Gh01); 65 s (1994Lo27, 1994La22); 78 s *+11−6* (1996Ka66,2002Ho11); 74 s *+7−6*; 75 s ± 7 recommended as weighted average including 1996Ka66 (2000Sy01); 81 s *9* (2012Au07 for isomer); 20 s *+110−10* (2008Dv02); 71 s *+342−33* (2008Ga08); $74 s *+74−25* (evaluated value) using the approximations of 1984Sc13 for events 8, 11, 33 and 49 in 2008Du09. $T_{1/2}$(SF)≥11 min (2000Ho27); >709 s (1996Ka66). $T_{1/2}$(calc)=61 s for Q(α)=8.409 MeV (2013Mu08) using Viola-Seaborg systematics for g.s. %α>80, %SF<10, %ε+%β^+<15 (1999Ar21,1970Gh01); %α=?; %β^+<15; %SF <10 (2012Au07 for isomer); %SF <11 (2002Ho11). %SF<0.11 (2008Du09) from a re-evaluation of data; %SF<0.13 (68% c.i. from 2011Ha13). E(level): Average EA=8280 keV 40 (QA=8409 keV 40) from 25 correlated α decay events (2013Mu08); Average EA=8280 keV 50 (QA=8409 keV 50) from 113 events (2011Ha13). This may be the possible g.s., based on systematics (evaluators) and consistent with the findings of 2008Du09. J^π: 2012Au07 suggest $9/2^+$ and denote this as an isomeric state in agreement with 2002Ho11. 2003Au02 had suggested $9/2^+$ or $3/2^+$ based on systematics. $9/2^+$ is recommended by evaluators for the g.s. J^π: Ω(n)=$7/2^+$ from 1997Mo25. β_2(theory): 0.228 from 1995Mo29; 0.251 from 2003Mu26.

234+x *57*	1.9 s *4*	AB	%SF=73 *6*; %α=27 *6* (2011Ha13) This level was labelled $^{261}Rf^{b}$ by 2008Du09 as possible isomer.

Continued on next page (footnotes at end of table)

Adopted Levels (continued)

^{261}Rf Levels (continued)

E(level)	$T_{1/2}$	XREF	Comments
			%2011Ha13 values at 68% c.i. Others: %SF=91 (2008Du09,2008Dv02); %SF=82 *9*, %α=18 *9* (2012Ha05). %SF=40, as g.s. (2002Ho11,2003Tu05); %SF=88 *5* %α=12 *5* (2013Mu08); %SF≈82 (2012Ha05); %SF=73 *6* %α=27 *6* (2012Au07 as g.s.). E(level): Calculated from Eα difference. $T_{1/2}$: from 9 α-decays and 86 SF events (2011Ha13). Other: 3.26 s as g.s. (1996Ho13); 4.2 s *+34−13* as g.s. (2001Ho11). 1.8 s ±4 from 86 SF events; 1.9 s ±4 for 9 α events and 88 SF events (2011Ha13); 2.2 ± 3 s (2012Au07 as g.s.). $T_{1/2}$(SF): >709 s (1996Ka66); 2.6 s *+7−5* from 22 fission events (2012Ha05); 7 s *+31−3* (2008Ga08)from one observation pending confirmation and computed by evaluators using the method of 1984Sc13. $T_{1/2}$(calc)=10 s for Q(α)=8.653 MeV (2011Ha13) using Viola-Seaborg systematics for g.s. EA=8510 keV 60 (QA=8642 keV 60) from 7 α events (2012Ha05); 8520 keV 50 (QA=8653 keV 50) from 9 α events (2011Ha13). QA=8646.42 keV 50.00 from 2012Wa38 for ground state. J^{π}: $1/2^+$ is recommended based on systematics (evaluators). 2012Au07 suggest $3/2^+$ for this level as g.s.