

Adopted Levels

Type	Author	History Citation	Literature Cutoff Date
Full Evaluation	Balraj Singh	NDS 156, 70 (2019)	31-Jan-2019

Q(β^-)=-2940 SY; S(n)=5940 SY; S(p)=1440 SY; Q(α)=11200 50 [2017Wa10](#)
 Estimated uncertainties ([2017Wa10](#)): $\Delta Q(\beta^-)$ =940, $\Delta S(n)$ =1050, $\Delta S(p)$ =880.
 S(2n)=13200 940 (syst,[2017Wa10](#)). S(2p)=3490 ([1997Mo25](#),theory).
 Others: Q(α)=10960 100 from $E\alpha$ =10.81 MeV 10 ([2010Og01](#)).

Experiments at FLNR-JINR-Dubna:

2010Og01, 2011Og04 (also [2012OgZZ](#), [2011Ha63](#), [2011Og07](#)): Z=117 (Ts) element discovered through correlated α -decay chain of six successive α -decaying nuclides, all identified for the first time: ²⁹⁴Ts -> ²⁹⁰Mc -> ²⁸⁶Nh -> ²⁸²Rg -> ²⁷⁸Mt -> ²⁷⁴Bh -> ²⁷⁰Db; the last one decays by SF mode. Reaction: ²⁴⁹Bk(⁴⁸Ca,3n), E=247 MeV; rotating target. ²⁴⁹Bk radioactive target was produced in neutron irradiation of Cm and Am targets in high flux isotope reactor at ORNL. The chemically purified target contained 22.2 mg of ²⁴⁹Bk and only 1.7 ng of ²⁵²Cf, with no other detectable impurities. Targets of 0.31 mg/cm² thickness deposited onto Ti foils were prepared at RIAR, Russia; and mounted on a disk that was rotated at 1700 rpm perpendicular to the beam direction. Facility: U-400 cyclotron with the Dubna gas-filled recoil separator (DGFRS) of the Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research in Dubna (JINR). Evaporation residues passing through the separator registered by time-of-flight system, implanted in 4x12cm Si-detector array. Energy resolution (FWHM) for α particles implanted in focal plane 60-140 keV, side detectors 160-230 keV. Position resolution <1.2 mm. Measured $E\alpha$, half-lives, α - α correlations. Collaboration: JINR and RIAR in Russia; LLNL, ORNL, University of Nevada and Vanderbilt university in USA.

One correlated decay chain was assigned by [2011Og04](#) to the decay of ²⁹⁴Ts, with the following α -decay history:

Event #1: Excitation energy of the compound nucleus ²⁹⁷Ts=35 MeV, ([2011Og04](#),[2010Og01](#)).
 $E_{\alpha 1}$ =10.81 MeV 10, $\Delta t_{\alpha 1}$ =112 ms, assigned to ²⁹⁴Ts.
 $E_{\alpha 2}$ =9.95 MeV 40, $\Delta t_{\alpha 2}$ =0.023 s, assigned to ²⁹⁰Mc.
 $E_{\alpha 3}$ =9.63 MeV 10, $\Delta t_{\alpha 3}$ =28.3 s, assigned to ²⁸⁶Nh.
 $E_{\alpha 4}$ =9.00 MeV 10, $\Delta t_{\alpha 4}$ =0.74 s, assigned to ²⁸²Rg.
 $E_{\alpha 5}$ =9.55 MeV 19, $\Delta t_{\alpha 5}$ =11.0 s, assigned to ²⁷⁸Mt.
 $E_{\alpha 6}$ =8.80 MeV 10, $\Delta t_{\alpha 6}$ =1.3 min, assigned to ²⁷⁴Bh.
 E_{SF} =219 MeV 5, Δt_{SF} =33.4 h, assigned to ²⁷⁰Db; decays by SF.

2013Og04, 2012Og06, 2013Og01: ²⁴⁹Bk(⁴⁸Ca,3n),E=246.8, 251.7, 243.7, 255.7 and 259.8 MeV. Rotating ²⁴⁹Bk radioactive target was produced in neutron irradiation of Cm and Am targets in high flux isotope reactor at ORNL. The chemically purified 12.7 mg of ²⁴⁹Bk (about half of the total ²⁴⁹Bk material produced at ORNL) containing 0.51 mg of ²⁴⁹Cf with no other detectable impurities was shipped to JINR. Six targets were prepared at RIAR facility in Russia, each target with a thickness of 0.33 mg/cm² deposited on 0.72 mg/cm² thick Ti foils, and mounted on a disk that was rotated at 1700 rpm perpendicular to the beam direction. Facility: U-400 cyclotron with the Dubna gas-filled recoil separator (DGFRS) of the Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research in Dubna (JINR). Evaporation residues passing through the DGFRS separator registered by time-of-flight system. Focal plane detector system: two 6x6 cm² Si detectors, each of 16 strips with position sensitivity in the vertical direction. These detectors were surrounded by six similar 6x6 cm² Si side detectors without position sensitivity. Behind the focal plane detectors, two veto Si detectors, similar to the side detectors, were mounted for detecting or rejecting signals from high-energy long-range charged particles produced in direct reactions of ⁴⁸Ca with the DGFRS materials. Measured $E\alpha$, half-lives, α - α correlations. FWHM for α particles was 34-73 keV. Collaboration: JINR and RIAR in Russia; LLNL, ORNL, University of Tennessee and Vanderbilt university in USA.

Two events were assigned to the decay of ²⁹⁴Ts in [2012Og06](#), and one events in [2013Og04](#), with the following α -decay histories:

Event #1 ([2012Og06](#)):

Excitation energy of the compound nucleus ²⁹⁷Ts=12.64 MeV.
 $E_{\alpha 1}$ =10.960 MeV 70, $\Delta t_{\alpha 1}$ =100.72 ms, assigned to ²⁹⁴Ts.
 $E_{\alpha 2}$ =10.28 MeV 12, $\Delta t_{\alpha 2}$ =0.3010 s, assigned to ²⁹⁰Mc.
 $E_{\alpha 3}$ =9.61 MeV 11, $\Delta t_{\alpha 3}$ =5.7895 s, assigned to ²⁸⁶Nh.
 $E_{\alpha 4}$ =9.18 MeV 30, $\Delta t_{\alpha 4}$ =145.34 s, assigned to ²⁸²Rg.
 $E_{\alpha 5}$ =9.396 MeV 70, $\Delta t_{\alpha 5}$ =4.1713 s, assigned to ²⁷⁸Mt.
 $E_{\alpha 6}$ =8.791 MeV 70, $\Delta t_{\alpha 6}$ =102.58 s, assigned to ²⁷⁴Bh.

Adopted Levels (continued)

$E_{\text{SF}}=142.4$ MeV, $\Delta t_{\text{SF}}=37.49$ h, assigned to ^{270}Db : decays by SF.

Event #2 (2012Og06):

Excitation energy of the compound nucleus $^{297}\text{Ts}=13.11$ MeV.

$E_{\alpha 1}=10.967$ MeV 73, $\Delta t_{\alpha 1}=3.986$ ms, assigned to ^{294}Ts .

$E_{\alpha 2}=9.775$ MeV 73, $\Delta t_{\alpha 2}=0.6976$ s, assigned to ^{290}Mc .

$E_{\alpha 3}=9.750$ MeV 11, $\Delta t_{\alpha 3}=3.6525$ s, assigned to ^{286}Nh .

$E_{\alpha 4}=9.04$ MeV 11, $\Delta t_{\alpha 4}=29.202$ s, assigned to ^{282}Rg .

$E_{\alpha 5}=9.382$ MeV 73, $\Delta t_{\alpha 5}=7.2154$ s, assigned to ^{278}Mt .

$E_{\alpha 6}=8.69$ MeV 30, $\Delta t_{\alpha 6}=55.722$ s, assigned to ^{274}Bh .

$E_{\text{SF}}=195.9$ MeV, $\Delta t_{\text{SF}}=23.49$ h, assigned to ^{270}Db : decays by SF.

Event #3 (2013Og04):

Excitation energy of the compound nucleus $^{297}\text{Ts}=12.33$ MeV.

$E_{\alpha 1}$ missing α , no $\Delta t_{\alpha 1}$, expected to be ^{294}Ts .

$E_{\alpha 2}=10.231$ MeV 50, $\Delta t_{\alpha 2}=0.3887$ s, assigned to ^{290}Mc .

$E_{\alpha 3}=9.651$ MeV 50, $\Delta t_{\alpha 3}=36.4506$ s, assigned to ^{286}Nh .

$E_{\alpha 4}=9.001$ MeV 50, $\Delta t_{\alpha 4}=166.8553$ s, assigned to ^{282}Rg .

$E_{\alpha 5}$ missing α , no $\Delta t_{\alpha 5}$, expected to be ^{278}Mt .

$E_{\alpha 6}=8.732$ MeV 50, $\Delta t_{\alpha 6}=39.1454$ s, assigned to ^{274}Bh .

$E_{\text{SF}}=221.7$ MeV, $\Delta t_{\text{SF}}=1.1564$ h, assigned to ^{270}Db : decays by SF.

Experiments at GSI:

2014Kh04: ^{294}Ts produced and identified through correlated α -decay chain of seven successive α -decaying nuclides: $^{294}\text{Ts} \rightarrow ^{290}\text{Mc} \rightarrow ^{286}\text{Nh} \rightarrow ^{282}\text{Rg} \rightarrow ^{278}\text{Mt} \rightarrow ^{274}\text{Bh} \rightarrow ^{270}\text{Db} \rightarrow ^{266}\text{Lr}$; the last nuclide ^{266}Lr identified for the first time, decays by SF mode. Reaction: $^{249}\text{Bk}(^{48}\text{Ca},3n)$, $E=252.1, 254.0, 258.0$ MeV in the center of target. ^{249}Bk radioactive target was produced at ORNL. About 0.48 mg/cm² thick target in the form of $^{249}\text{Bk}_2\text{O}_3$ was electrodeposited on 2.20 μm thick Ti backing, and mounted on a rotating wheel at the accelerator complex at GSI using Gas-filled Trans-Actinide Separator and Chemistry Apparatus (TASCA). Measured position and time correlations between evaporation residues (EVR), α , and SF events, $E\alpha$, half-lives, EVR- α - α , and EVR- α -SF correlations.

Four correlated decay chains were observed, two long ones, and two shorter ones with different decay characteristics. Only the two long decay chains are discussed in this paper, with the following α -decay history, while the other two were relegated to a future detailed publication as per reference 36 in the paper, however no further publication seems to have appeared from these authors since their 2014Kh04 paper.

Chain #1 (2014Kh04):

$E_{\alpha 1}=11.07$ MeV 4, $\Delta t_{\alpha 1}=55.9$ ms, assigned to ^{294}Ts .

$E_{\alpha 2}=10.31$ MeV 4, $\Delta t_{\alpha 2}=2.98$ s, assigned to ^{290}Mc .

$E_{\alpha 3}=9.3$ MeV 3, $\Delta t_{\alpha 3}=5.96$ s, assigned to ^{286}Nh .

$E_{\alpha 4}=8.86$ MeV 3, $\Delta t_{\alpha 4}=172$ s, assigned to ^{282}Rg .

$E_{\alpha 5}=9.42$ MeV 3, $\Delta t_{\alpha 5}=6.79$ s, assigned to ^{278}Mt .

$E_{\alpha 6}=8.84$ MeV 3, $\Delta t_{\alpha 6}=45.1$ s, assigned to ^{274}Bh .

$E_{\alpha 7}=7.89$ MeV 3 partial, $\Delta t_{\alpha 7}=1.3$ h, assigned to ^{270}Db .

$E_{\text{SF}}=135$ MeV, $\Delta t_{\text{SF}}=3.8$ h, assigned to ^{266}Lr : decays by SF.

Chain #2 (2014Kh04):

$E_{\alpha 1}=11.02$ MeV 4, $\Delta t_{\alpha 1}=92.6$ ms, assigned to ^{294}Ts .

$E_{\alpha 2}=10.2$ MeV 2, $\Delta t_{\alpha 2}=0.66$ s, assigned to ^{290}Mc .

$E_{\alpha 3}=4.64$ MeV partial, $\Delta t_{\alpha 3}=2.35$ s, assigned to ^{286}Nh .

$E_{\alpha 4}=9.05$ MeV 3, $\Delta t_{\alpha 4}=373$ s, assigned to ^{282}Rg .

$E_{\alpha 5}=9.47$ MeV 3, $\Delta t_{\alpha 5}=3.53$ s, assigned to ^{278}Mt .

$E_{\alpha 6}=8.8$ MeV 2, $\Delta t_{\alpha 6}=41.3$ s, assigned to ^{274}Bh .

$E_{\alpha 7}=7.90$ MeV 3 partial, $t_{\alpha 7}=1.6$ h, assigned to ^{270}Db .

Adopted Levels (continued)

$E_{\text{SF}}=189$ MeV, $\Delta t_{\text{SF}}=29$ h, assigned to ^{266}Lr : decays by SF.

For theoretical studies, consult Nuclear Science References (NSR) database at NNDC, BNL for 64 primary references dealing with the half-lives and other aspects of nuclear structure in this mass region.

 ^{294}Ts Levels

<u>E(level)</u>	<u>$T_{1/2}$</u>	<u>Comments</u>
0	51 ms +38-16	<p>$\% \alpha \approx 100$ Only the α-decay mode has been observed. E(level): observed activity is assumed to correspond to the g.s. of ^{294}Ts. $Q(\alpha)$: 10960 keV 100 from $E\alpha=10.81$ keV 10. J^π: $1^-, 2^-$ from $\Omega(\text{proton})=3/2^-$; $\Omega(\text{neutron})=1/2^+$ (1997Mo25, theory). $T_{1/2}$: from 2017Og01 and 2015Og05 reviews. Measurements: 51 ms +94-20 (2014Kh04, from two correlated events, also 51 ms +41-16 by combining their data with the decay chains from 2013Og04); 50 ms +60-18 (2013Og04 from three events out of a total of four observed events reported in 2013Og04, 2012Og06 and 2011Og04); 78 ms +370-36 (2010Og01, 2011Og04, 2011Og07 from one correlated event). Measured $E\alpha=11.05$ MeV 4 (2014Kh04) from decay of ^{294}Ts; Average $E\alpha=10.81$-10.97 MeV (2013Og04), 10.81 MeV 10 (2011Og07 review), deduced from 3 events out of a total of 4 observed events. Production cross-sections: 0.5 pb +11-4 at $E^*=35$ MeV (2011Og04); 0.30 pb +70-26 at $E^*=35$ MeV (2012Og06); 1.1 pb +12-6 at $E^*=35$ MeV (2013Og04); 0.7 pb +16-6 at $E(^{48}\text{Ca})=252.0$-256.1 MeV and 0.9 pb +20-7 at $E(^{48}\text{Ca})=255.9$-260.0 MeV (2014Kh04).</p>