SPECTROSCOPY OF TRANSFERMIUM NUCLEI USING THE GABRIELA SETUP*

T.W. Hagen[a], A. Lopez-Martens[b,c], K. Hauschild[b,c]
A.V. Belozerov[d], M.L. Chelnokov[d], V.I. Chepigin[d], D. Curien[e]
O. Dorvaux[e], G. Drafta[f], B. Gall[e], A. Görgen[a,g]
M. Guttormsen[a], A.V. Isaev[d], I.N. Izosimov[d], A.P. Kabachenko[d†]
D.E. Katrasev[d], T. Kutsarova[h], A.N. Kuznetsov[d], A.C. Larsen[a]
O.N. Malyshev[d], A. Minkova[h], S. Mullins[i], H.T. Nyhus[a]
D. Pantelica[f], J. Piot[e], A.G. Popeko[d], S. Saro[j], N. Scintee[f]
S. Siem[a], E.A. Sokol[d], A.I. Svirikhin[d], A.V. Yeremin[d]

[a]Department of Physics, Oslo University, 0316 Oslo, Norway
[b]CSNSM, IN2P3-CNRS, 91405 Orsay Campus, France
[c]Department of Physics, University of Jyväskylä, 40351, Finland
[d]FLNR, JINR, Dubna, 141980, Russia
[e]IPHC, IN2P3-CNRS, 67037 Strasbourg, France
[f]Institute for Physics and Nuclear Engineering
Bucharest Magurele, P.O. Box MG6, Romania
[g]DAPNIA/SPhN, CEA-Saclay, 91191 Gif-sur-Yvette, France
[h]Department of Atomic Physics, University of Sofia, 1164 Sofia, Bulgaria
[i]iThemba Labs, P.O. Box 722, 7129 Somerset West, South Africa
[j]Department of Physics, Comenius University, 84215, Bratislava, Slovakia

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Heavy elements above Fm ($Z = 100$) are nuclei with vanishing liquid-drop fission barriers and are therefore entirely stabilized by quantum shell effects. Due to the large density of single-particle levels and strong polarized Coulomb fields, theoretical predictions of magic numbers are extremely model dependent. Furthermore, shell closures for one nucleon species depend strongly on the number of the other species. Reliable experimental data is needed in order to test and constrain theory. As there is a lack of such data in the region, new data is needed along with the confirmation of previous data. A detection system dedicated to the spectroscopy of transfermium nuclei was constructed in 2004 and installed at the focal plane of the VASSILISSA separator at the FLNR, Dubna, by a Franco–Russian collaboration. The results from the 2009 campaign will be presented.

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† Deceased.

1. Introduction

The heaviest elements provide a unique laboratory to study nuclear structure and nuclear dynamics under the influence of large Coulomb forces and large mass. The spectroscopy of transfermium elements has made great progress in recent years thanks to the use of efficient detector arrays around the target position and at the focal plane of recoil separators. The data, although scarce, has shed light on some theoretical weaknesses. For example there exists now a rather clear disagreement between the predictions of shell positioning obtained from all existing effective interactions/energy density functionals (predicting $N = 150$ and $Z = 98, 104$ as sub-shell closures) and experimental data (which seems to indicate $N = 152$ and $Z = 100$ as sub-shell closures). This is why the systematic study of the structure and decay properties of deformed transfermium elements is essential and will probably be for many years, the only available way to reach an understanding of the structure at the upper end of the nuclear chart.

2. Experimental setup

The experiment was preformed at the Flerov Laboratory of Nuclear Reactions in Dubna, using the multi-detector GABRIELA (Gamma Alpha Beta Recoil Investigation with the kinematic Electromagnetic Analyzer VASSILISSA) placed at the focal plane of the separator VASSILISSA [1]. GABRIELA was designed to detect the radiation emitted in the decay of evaporation residues (ERs). The original system is described in detail in Ref. [2]. In the later years improvements and updates have been made to GABRIELA: including new focal plane and tunnel detectors. The detector array used consists of a Time-of-Flight (TOF) detector, a 48×48 strip Double Sided Silicon-strip Detector (DSSD) to measure the energy of the implanted ER and subsequent decay products and four 32-strip Si detectors forming a box upstream of the DSSD making up the tunnel detector for the detection of α particles, fission and internal conversion electrons (ICE). An array of seven germanium detectors from the French–UK loan-pool, six encased in BGO shields for Compton suppression, that surround the DSSD and a seventh unsuppressed germanium detector, placed in a collinear geometry with respect to the beam line, completes the detector array. This seventh detector has had the length of the aluminum end cap reduced to get the germanium crystal closer to the DSSD, resulting in an increased γ-ray efficiency by a factor 2.

The reaction $^{207}\mathrm{Pb}(^{48}\mathrm{Ca}, 2-3n)^{253;252}\mathrm{No}$ was used. The run time of the experiment was about 19 days with a mid target energy of 220 MeV. The total beam dose was 3.4×10^{18} particles. The targets were mounted on a rotating wheel and had 2 different thicknesses (350 and 680 $\mu\mathrm{g/cm}^2$) and

1.5 μm Ti backing. Their isotopic composition was 96.2% ^{207}Pb, 2.6% ^{208}Pb, 1.1% ^{206}Pb and 0.1% ^{204}Pb. During the run about 90.000 $^{253-254}$No αs were detected at the focal plane of VASSILISSA, close to an order of magnitude more than during the first GABRIELA campaign in 2004.

3. Results

The decay of ^{253}No populates excited states in ^{249}Fm, which then decay to the ground state by photon or ICE emission [3,4,5,6]. Figure 1 shows the γ-rays coincident with α particles emitted in the decay of ^{253}No. There are three previously known strong transitions of energy 279, 221, and 150 keV. The 209 keV transition, predicted in reference [3] from X-ray intensities and simulations, can now be firmly established and the 58 keV interstate transition is also clearly seen. In addition, there is one other transition of energy 670 keV assigned to ^{249}Fm on the basis of Q-value calculations.

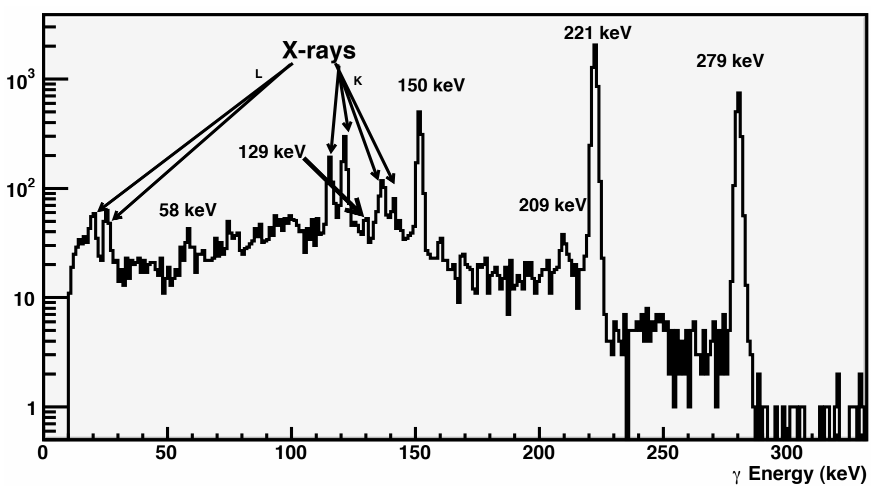

Fig. 1. Energy spectrum of γ-rays detected in coincidence with the α decay of ^{253}No.

Conversion coefficients could be extracted for the 279, 221, 209 and 150 keV LM transitions and the 279 keV K transition. The multipolarity characters of the transitions can be determined by comparing the experimentally obtained results to theory [7]. The 221 and 150 keV transitions are clearly E1s. The conversion coefficients of the 279 keV transition is large compared to the theoretical E1 coefficient. However, by looking at the ratio of L *versus* K conversion the 279 keV transition is determined to be an E1 transition with anomalous conversion coefficients. The 209 keV is of M1 character. The results are supported by the agreement between observed and expected X-ray intensities for the given character assignments.

To conclude, the low-energy level scheme of ^{249}Fm has been revisited with 10 times more statistics than the previous experiment [3]. The alpha decay of ^{253}No mainly populates the $9/2-$ [734] state, which decays by 3 $E1$ transitions to the ground state band. Looking at the measured $(BM1/B(E2+M1))$ ratio within the ground state band supports the $7/2+$ [624] assignment of the ground state of ^{249}Fm. About 10% of the α decay feeds a $5/2+$ [622] single particle state, which decays to the ground state by an $M1$ 209 keV transition. Evidence for a higher-lying state at 670 keV was also observed. This confirms the data obtained at SHIP [6]. Looking at the systematic of similar nuclei [4, 8], as shown in Fig. 2, the results are found to follow the trend of the $N = 149$ isotones.

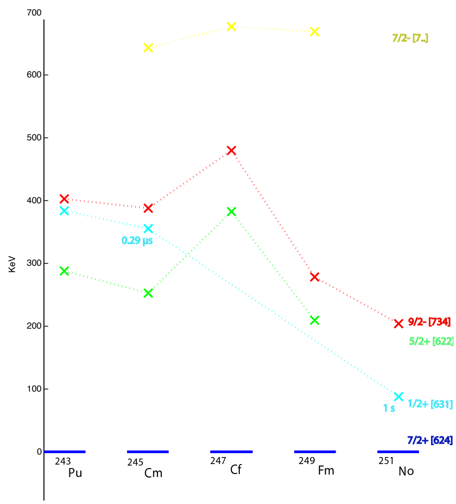

Fig. 2. Systematics of the low-energy levels of $N = 149$ isotones obtained from this work and Refs. [4, 8].

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