

GSI Annual Report 2014 (extracts)

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Chemical study of Fl, Cn, their lighter homologs, and Rn at TASCA*

A. Yakushev^{1#}, L. Lens², Ch.E. Düllmann^{1,2,3}, D. Ackermann¹, M. Asai⁴, J. Ballof², M. Block^{1,3}, H. Brand¹, D.M. Cox⁵, J. Despotopulos⁶, A. Di Nitto², K. Eberhardt^{2,3}, J. Even³, F. Fan⁷, P. Golubev⁸, H. Haba⁹, W. Hartmann¹, R.-D. Herzberg⁵, F.P. Heßberger^{1,3}, J. Hoffmann¹, A. Hübner¹, E. Jäger¹, J. Khuyagbaatar^{1,3}, B. Kindler¹, J.V. Kratz², J. Krier¹, N. Kurz¹, S. Lahiri¹⁰; B. Lommel¹, M. Maiti¹¹, A. Mistry⁵, Ch. Mokry², K. Moody⁶, Y. Nagame⁴, J.P. Omtvedt¹², Ph. Papadakis¹³, Z. Qin⁷, D. Rudolph⁸, J. Runke¹, I. Rusanov¹, L.G. Sarmiento⁸, T. Sato⁴, M. Schädel⁴, P. Scharrer³, B. Schausten¹, D. Shaughnessy⁶, J. Steiner¹, P. Thörle-Pospiech^{2,3}, N. Trautmann², J. Uusitalo¹³, D. Ward⁵, M. Wegrzecki¹⁴, N. Wiehl^{2,3}, V. Yakusheva³

¹GSI, Darmstadt, Germany; ²University of Mainz, Germany; ³Helmholtz Institute Mainz, Germany; ⁴JAEA Tokai, Japan; ⁵University of Liverpool, UK; ⁶LLNL Livermore, USA; ⁷IMP, Lanzhou, P.R. China; ⁸Lund University, Sweden; ⁹RIKEN, Wako-shi, Japan; ¹⁰SINP Kolkata, India; ¹¹IIT Roorkee, India; ¹²University of Oslo, Norway; ¹³University of Jyväskylä, Finland; ¹⁴ITE, Warsaw, Poland

Chemical studies on superheavy elements (SHE) with closed electron shell configurations, Cn and Fl, address the question of how strong relativistic effects influence chemical properties. This is a challenging task from both physical and chemical points of view due to low production rates and a high background from volatile byproducts disturbing the safe identification of Cn and Fl decay chains. Up to now only a limited number of experiments has been performed, resulting in the identification of only a few decay chains assigned to Cn and Fl isotopes [1-4]. Several attempts on investigation of Fl were performed by a PSI-FLNR collaboration, resulting in the detection of three decay chains from Fl, two chains from ²⁸⁸Fl and one from ²⁸⁷Fl [2,4]. Two Fl atoms, one with the atomic mass number 288 and one with the atomic mass number 289, were observed in an experiment at TASCA [3]. Hence, the determined values of the adsorption enthalpy of Fl on Au are still fairly uncertain due to low statistics.

A new chemistry experiment with Fl was carried out at TASCA in 2014. For the production of ^{288,289}Fl a ⁴⁸Ca⁺¹⁰ beam ($E_{\text{lab}} = 260$ MeV) with an intensity of about $5 \cdot 10^{12}$ particles/s impinging on ²⁴⁴PuO₂ targets. They were electrodeposited on 2.5 μm thick Ti backing foils and had thicknesses of about 800 μg/cm² ²⁴⁴Pu. A beam dose of about $2.6 \cdot 10^{18}$ was accumulated during 10 days of bombardment. TASCA was operated in the High Transmission Mode and its magnetic settings were adjusted to collect the ions with $B \cdot \rho = 2.27$ T·m at the exit of TASCA, where a Recoil Transfer Chamber (RTC; 60x40x20 mm³) was attached. The RTC inner surface was coated with a Teflon™ layer. Three COMPACT detector arrays (COMPACT³) were connected to the RTC exit in series. The first array was covered with a SiO₂ layer, and the two following ones with Au layers. All layers were 30-50 nm thick. The first two detector arrays were kept at room temperature (+22 °C). A negative temperature gradient from +22 °C to -162°C was applied along the last detector array. A He/Ar gas mixture (He:Ar = 70:30) was circulated in a gas loop and purified with Hydrosorb™ and

Oxysorb™ cartridges and a hot titanium getter. The COMPACT arrays were connected to the RTC and to each other with about 20-cm long PTFE capillaries (2 mm inner diameter). In a preparatory experiment, short-lived Pb and Hg isotopes were produced with ¹⁴⁴Sm and ¹⁴²Nd targets, respectively, and ²¹⁹Rn was produced as a member of the ²²⁷Ac decay chain. Prior to measuring their yields and distributions in COMPACT³, the rates at which Pb and Hg entered the RTC were measured in a 60x40 mm² DSSSD mounted in the RTC position. Transport times and yields to COMPACT³ were optimized with ^{182,183}Hg, due to much higher production rates compared to Pb isotopes. The use of three detector arrays in series allowed separating species with volatility and reactivity ranging from the non-volatile Pb, over the volatile metal Hg, to the noble gas Rn (Figure 1). Pb was adsorbed under diffusion-controlled deposition in the first COMPACT array. Mercury passed the SiO₂ array and deposited in the second array, on the gold surface, under diffusion controlled deposition. Radon adsorption started on the last detector array at very low temperature. The data on Cn and Fl are currently under evaluation.

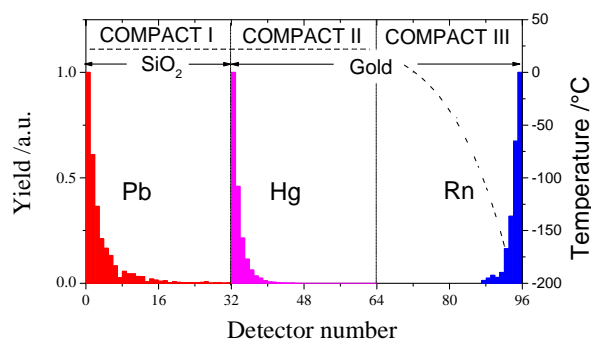


Figure 1: Measured Pb, Hg and Rn distributions.

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#a.yakushev@gsi.de



Recoil- α -fission and recoil- α - α -fission chains stemming from element 115

D. Rudolph¹, U. Forsberg¹, Ch.E. Düllmann^{2,3,4}, P. Golubev¹, F.P. Heßberger^{2,3}, J. Khuyagbaatar^{2,3}, J.V. Kratz⁴, L.G. Sarmiento¹, A. Yakushev², D. Ackermann², L.-L. Andersson³, M. Block², H. Brand², D. Cox⁵, X. Derks^{3,4}, A. Di Nitto⁴, K. Eberhardt^{3,4}, J. Even³, C. Fahlander¹, J.M. Gates⁶, J. Gerl², K.E. Gregorich⁶, C.J. Gross⁷, R.-D. Herzberg⁵, E. Jäger², B. Kindler², J. Krier², I. Kojouharov², N. Kurz², B. Lommel², A. Mistry⁵, C. Mokry^{3,4}, H. Nitsche⁶, J.P. Omtvedt⁸, P. Papadakis⁵, J. Runke², K. Rykaczewski⁷, M. Schädel^{2,9}, H. Schaffner², B. Schausten², P. Thörle-Pospiech^{3,4}, T. Torres², T. Traut⁴, N. Trautmann⁴, A. Türler¹⁰, A. Ward⁵, and N. Wiehl^{3,4}

¹Lund University, Lund, Sweden; ²GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany; ³Helmholtz Institute Mainz, Mainz, Germany; ⁴Johannes Gutenberg-Universität Mainz, Mainz, Germany; ⁵University of Liverpool, Liverpool, United Kingdom; ⁶Lawrence Berkeley National Laboratory, Berkeley, USA; ⁷Oak Ridge National Laboratory, Oak Ridge, USA; ⁸University of Oslo, Oslo, Norway; ⁹Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Japan; ¹⁰Paul Scherrer Institute and University of Bern, Villigen, Switzerland

Products of the $^{48}\text{Ca}+^{243}\text{Am}$ fusion-evaporation reaction were studied with the TASI Spec set-up [1, 2] behind TASCA [3-5]. Thirty correlated α -decay chains originating from different isotopes of E115 were observed [6, 7], produced with an overall production cross section of ≈ 10 pb. There are $1+22=23$ five- α -long chains linked to the production of $^{287,288}\text{115}$ [6], in agreement with $2+31=33$ chains reported earlier [8]. The combined $22+31=53$ chains associated with $^{288}\text{115}$ yield a statistically solid reference.

Besides these 'long chains', two recoil- α -fission and five recoil- α - α -fission chains are present in the TASI Spec data [7]. Interestingly, the interpretation and thus the assignment of these 'short chains' to a certain isotope of E115 turns out to be non-trivial. The issue is discussed with the help of Fig. 1: Panel (a) shows the relevant beginning of the long $^{288}\text{115}$ reference chain. The average values of the $2+5=7$ new short chains in panel (b) are consistent with the numbers in panel (a). This indicates at first sight ~ 5 -15% fission or electron-capture branches of $^{284}\text{113}$ and ^{280}Rg . However, this view is at variance with the interpretation of $3+1=4$ short chains previously observed at Dubna [8] [panel (c)]. There, one chain, denoted 'D3', is significantly different from all the other E115 chains. However, only including this particular chain in the $3+1=4$ averaging procedure generated a seemingly consistent link between E115 and E117 [8, 9] [panel (d)]. Panel (e) provides a refined interpretation of all published E117 data [9, 10]. The rightmost sequence averaged

over twelve E117 chains opens for a connection to E115 via 'D3', while the other ten E117 chains would be consistent with (a subset of) other E115 chains [11].

More high-quality spectroscopic data is obviously required. This is necessary to provide the foundation for a relevant nuclear-structure based interpretation of links between decay chains of these two odd- Z elements [7, 11].

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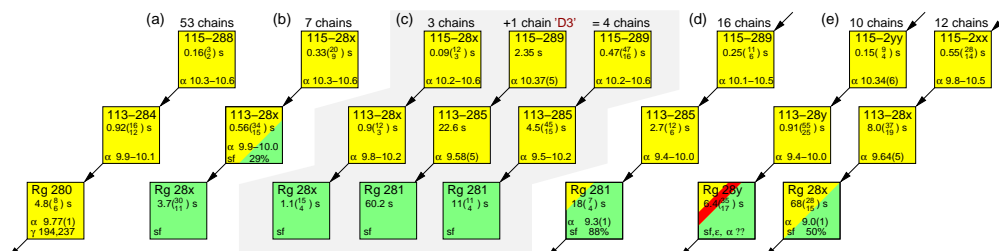


Figure 1: Average values from selections of decay chains of isotopes of E115 to E113 into Rg ($Z = 111$). (a) 53 $^{288}\text{115}$ reference chains [6, 8]. (b) Seven recoil- α - α -fission chains observed with TASI Spec [7]. (c) Data from all four recoil- α - α -fission 'Dubna chains' listed in Table III of Ref. [8]. (d) Sixteen chains associated with the decay of $^{293}\text{117}$, i.e. interpreted to populate the isotope $^{289}\text{115}$ [9]. (e) Possible re-interpretation [11] of all existing E117 decay data [9, 10].



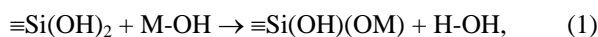
First periodic relativistic calculations of adsorption of the superheavy elements on a quartz surface

V. Pershina

GSI Helmholtzzentrum, Darmstadt, Germany

Gas-phase chromatography experiments provide information about volatility of superheavy elements (SHE) and their homologs as adsorption enthalpies, ΔH_{ads} , on a surface of a chromatography column. Two main types of surfaces are used: gold and quartz. Straightforward theoretical predictions of ΔH_{ads} were made in the past on the basis of cluster calculations for adsorption on metals (e.g., gold [1]), or physisorption models for adsorption on inert surfaces [2]. Periodic codes were until recently not suited for solid state, or adsorption calculations on the SHEs. With further developments of the relativistic quantum theory and computational algorithms, as well as creation of proper basis sets, treatment of those phenomena for $Z \leq 120$ became now possible using the ADF BAND code [3]. Accordingly, we started the 2c-DFT calculations of ΔH_{ads} of Hg, Cn, and Fl on a gold and of Tl and element 113 on a quartz surfaces using this program package. Here, preliminary results for the latter case are presented.

In the presence of oxygen in the chromatography column, element 113 should form 113OH by analogy with TlOH. A quartz surface is very probably fully hydroxylated forming *geminal silanols*, $\equiv\text{Si}(\text{OH})_2$, the most stable modification. The M atoms ($M = \text{Tl}$ and element 113) may then react with such a surface in the following way



so that replacement of H of a surface OH group by M can take place. Accordingly, we have optimized a quartz (001) slab cut out of the α -quartz bulk, where the surface O-bonds are saturated with H, i.e., $\equiv\text{Si}(\text{OH})_2$. The scalar relativistic (SR) geometry optimization with fully relaxed upper 3 layers of the Si and surrounding O atoms have given the formation energy, E_f , of such a slab as -138.97 kJ/mol. The SR geometry optimization of a slab with Tl or element 113 atoms substituting one H (Fig. 1) have then given E_f of $\equiv\text{Si}(\text{OH})(\text{OTl})$ of -137.06 eV and E_f of $\equiv\text{Si}(\text{OH})(\text{O113})$ of -137.02 eV. Earlier, we have obtained 4c-DFT $D_e(\text{Tl-OH}) = 3.68$ eV and $D_e(113\text{-OH}) = 2.42$ eV [4]. Taking into account $D_e(\text{H-OH})$ of 4.77 eV, as well as the differences in D_e between H-OH and Tl-OH and between H-OH and 113-OH, the energy balance of reaction (1) was predicted as 1.91 eV for Tl and -0.4 eV kJ/mol for element 113 using the obtained E_f of $\equiv\text{Si}(\text{OH})(\text{OM})$ and $\equiv\text{Si}(\text{OH})_2$. The single-point SO calculations (i.e., with the SO interaction on top of the SR optimized geometry) have

given the reaction (1) energy as 2.32 eV for Tl and -0.47 eV for element 113. These values mean that the reaction will proceed to the right with the formation of the $\equiv\text{Si}(\text{OH})(\text{OM})$ complex only for element 113. The Tl-OH bond is obviously too strong in the molecule to be replaced by the $\equiv\text{Si}(\text{OH})(\text{O-Tl})$ one, while the 113-OH one is weak enough, so that the reaction can proceed to the right. Further calculations with the geometry optimization at the SO level and a supercell model treating single adsorbed atoms should be performed to confirm these preliminary conclusions.

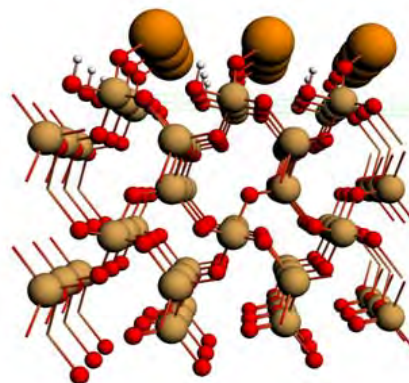


Fig. 1. Atom M ($M = \text{Tl}$ and element 113), the largest circles, chemisorbed on the fully hydroxylated quartz surface (side view).

The obtained results are, however, in some contradiction with the measured $-\Delta H_{\text{ads}}(\text{TlOH})$ of 134 ± 5 kJ/mol on quartz similar to $-\Delta H_{\text{ads}}(\text{TlOH})$ of 146 ± 3 kJ/mol on gold [5]. Those like values are an indication that the mechanism of adsorption on quartz and gold is obviously the same, caused by long-range interactions. This scenario could be considered in the next study using BAND.

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Synthesis and chemical investigation of Sg(CO)₆*

J. Even^{†1}, A. Yakushev², Ch.E. Düllmann^{1,2,3}, H. Haba⁴, M. Asai⁵, T.K. Sato⁵, H. Brand², A. Di Nitto³, R. Eichler^{6,7}, F.L. Fan⁸, W. Hartmann², M. Huang⁴, E. Jäger², D. Kaji⁴, J. Kanaya⁴, Y. Kaneya⁵, J. Khuyagbaatar¹, B. Kindler², J.V. Kratz³, J. Krier², Y. Kudou⁴, N. Kurz², B. Lommel², S. Miyashita^{5,9}, K. Morimoto⁴, K. Morita^{4,10}, M. Murakami^{4,11}, Y. Nagame⁵, H. Nitsche^{12,13}, K. Ooe¹¹, Z. Qin⁸, M. Schädel⁵, J. Steiner², T. Sumita⁴, M. Takeyama⁴, K. Tanaka⁴, A. Toyoshima⁵, K. Tsukada⁵, A. Türler^{6,7}, I. Usoltsev^{6,7}, Y. Wakabayashi⁴, Y. Wang⁸, N. Wiehl^{1,3}, and S. Yamaki^{4,14}

¹Helmholtz-Institut Mainz, Mainz, Germany; ²GSI, Darmstadt, Germany; ³Johannes Gutenberg-Universität, Mainz, Germany; ⁴Nishina Center for Accelerator-Based Science, RIKEN, Wako, Japan; ⁵Advanced Science Research Center, JAEA, Tokai, Japan; ⁶University of Berne, Switzerland.; ⁷PSI, Villigen, Switzerland; ⁸Institute of Modern Physics, Lanzhou, Chinese Academy of Sciences, China; ⁹Hiroshima University, Japan; ¹⁰Kyushu University, Japan; ¹¹Niigata University, Japan; ¹²University of California, Berkeley, CA, U.S.A.; ¹³Lawrence Berkeley National Laboratory, Berkeley, CA, U.S.A; ¹⁴Saitama University, Japan

Gas phase chemical studies of the superheavy elements have been limited to simple inorganic compounds so far [1]. Due to challenging experimental conditions, access to other compound classes was limited. With the combination of physical preseparation and gas-phase chemistry, many limitations could be overcome [2,3]. We succeeded in the synthesis of a carbonyl complex of a superheavy element - seaborgium hexacarbonyl (Sg(CO)₆), at the GAs-filled Recoil Ion Separator GARIS [4]. Sg(CO)₆ has been predicted to be stable [5] and its adsorption behavior on a SiO₂ surface is expected to be very similar to that of W(CO)₆ [6]. Thus, we investigated Sg(CO)₆ along with W(CO)₆. 6-s ¹⁶⁴W, and ≈ 10-s ²⁶⁵Sg were synthesized in the reactions ¹⁴⁴Sm(²⁴Mg,4n)¹⁶⁴W and ²⁴⁸Cm(²²Ne,5n)²⁶⁵Sg. Evaporation residues (EVRs) were separated from the primary beam and lighter transfer products within GARIS. At the focal plane of GARIS, a recoil transfer chamber (RTC) was installed. The EVRs passed the entrance window of the RTC and were thermalized in a He / CO atmosphere (≈ 600 mbar) in the RTC. The free single ions of W and Sg reacted with CO, forming volatile complexes [7]. The RTC was flushed continuously, transporting volatile compounds through a 10-m long capillary to the Cryo Online Multidetector for Physics and Chemistry of the Transactinides COMPACT [8], a thermochromatography detector array. The chromatography channel is formed by 32 pairs of silicon PIN diodes covered with a SiO₂ surface, kept at temperatures between 22°C and -140°C. Volatile compounds adsorb at a certain temperature on the detector surface. The deposition pattern was compared with Monte Carlo Simulations MCS, which allowed determining the adsorption enthalpy -ΔH_{ads}. W and Sg were transported

to COMPACT, hence formed volatile compounds with the CO [7]. In total, 15 decay chains assigned to the decay of ²⁶⁵Sg plus three uncorrelated fission event assigned to the decay of ²⁶¹Rf as a daughter of ²⁶⁵Sg were observed under background-free conditions. The total beam integral was 1.52 · 10¹⁹. Both, the W and the Sg complexes deposited mainly in the last third of the detector (see Fig. 1). The Sg species show the same adsorption behavior as W(CO)₆, which supports the assignment to Sg(CO)₆ [7]. The experimental distributions and the MCS are shown in Fig. 1.

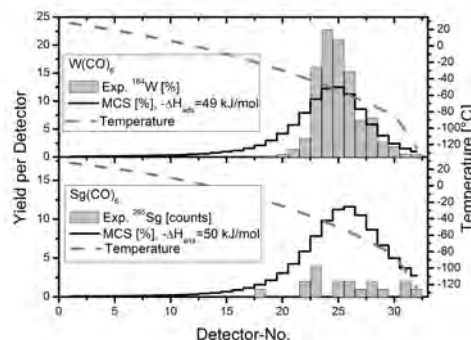


Figure 1: Distribution of ¹⁶⁴W and ²⁶⁵Sg in the COMPACT detector array. The bars show the experimental distributions, the solid lines show the results from MCS. (after [7]).

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† jeven@triumf.ca, present adress: TRIUMF, Vancouver, Canada

Online chemical study of Pb, Hg and Tl on SiO₂ and Au surfaces at TASCA

L. Lens¹, J. Ballof¹, A. Yakushev², Ch.E. Düllmann^{1,2,3}, H. Brand², X. Derkx¹, A. Di Nitto¹, J. Even³, W. Hartmann², F.P. Heßberger^{2,3}, A. Hübner², E. Jäger², J. Khuyagbaatar^{2,3}, B. Kindler², J.V. Kratz¹, J. Krier², N. Kurz², B. Lommel², C. Mokry¹, J. Runke², P. Scharrer³, B. Schausten², J. Steiner², P. Thörle-Pospiech^{1,3}, M. Wegrzecki⁴, N. Wiehl^{1,3}, V. Yakusheva³

¹Univ. Mainz, Germany; ²GSI, Darmstadt, Germany; ³Helmholtz Institut Mainz, Germany; ⁴ITE, Warsaw, Poland

Experiments on the interaction of lead (Pb), mercury (Hg), and thallium (Tl) with SiO₂ and Au surfaces were conducted at the gas-filled separator TASCA as preparatory experiments for future studies of the chemistry of element 113 and Fl (flerovium, Z=114).

A first experiment, with Hg focused on the minimization of the transport time for short-lived radionuclides to the gas chromatography setup COMPACT [1]. This is crucial for successful experiments with superheavy elements, due to their low production rates and short half-lives. The complete fusion reaction (188 MeV) ⁴⁰Ar+¹⁴⁴Sm (415 μg/cm², ¹⁴⁴Sm as SmF₃) was applied to produce Hg, using short (1 s) beam pulses, repeated every 60 s. Hg was separated from unwanted reaction products by the magnetic recoil separator TASCA. In the TASCA focal plane, Hg penetrated a thin Mylar^R window and entered the Recoil Transfer Chamber (RTC) [2], which was connected to the gas transport system and constantly flushed by a He/Ar (70/30) mixture with a flow rate between 0.7-0.85 l/min. A 4 m Teflon capillary (1 mm inner diameter) connected the RTC (volume: 140x40x20 mm³) to COMPACT, which was kept at room temperature. The thin capillary led to a reduced pressure in COMPACT, beneficial for getting good energy resolution. The surface of the detector array was covered with a thin gold layer. The carrier gas, purified by HydrosorbTM and OxisorbTM cartridges, was circulated in a loop. A mean transport time of 3.6 ± 0.3 s was determined. To reduce this, a Teflon insert inside the RTC (RTC dimensions: 70x40x20 mm³) was installed and the capillary between RTC and COMPACT was changed to a 20 cm capillary (inner diameter: 1 mm), so the gas flow rate could be increased to 1.7 l/min. Due to these changes, the mean transport time was reduced to 1.5 ± 0.5 s. To avoid losses of reaction products in the RTC, denser carrier gas (e.g., Ar instead of He/Ar) could now be used.

In a second experiment, the adsorption behavior on SiO₂ and Au surfaces of the rather reactive metal Pb was directly compared to that of the less reactive metal Hg, as well as to that of Tl, which is a chemical homolog of element 113. For this, two COMPACT arrays, both kept at room temperature, were connected in series (COMPACT²). The detectors of the first one were covered with a SiO₂ layer and those of the second one by Au. Previous work showed that Pb should be retained on SiO₂ at temperatures below 600 °C, while Hg can be adsorbed at room temperature on Au, but not on SiO₂ [3-6]. The reactions of 300.8 MeV ⁵⁰Ti with ¹⁴⁰Ce, ¹⁴¹Pr, and ¹⁴²Nd (400 μg/cm², present as trifluorides) were used to produce ¹⁸²⁻¹⁸⁴Hg, ^{184,185}Tl, and ^{185,186}Pb. Mercury was detected in

COMPACT by irradiations of all three targets, produced as a fusion product from different de-excitation channels, or as decay product after α or EC/β⁺-decays from Pb or Tl, respectively. Pure Ar was used as carrier gas, which allowed reduction of the RTC depth, but negatively affected the energy resolution. Additionally to HydrosorbTM and OxisorbTM cartridges, a hot Ti getter was installed for further reduction of the O₂, H₂O content. As shown in Fig. 1 (upper panel), the separation of Pb and Hg based on their different reactivity towards SiO₂ was achieved.

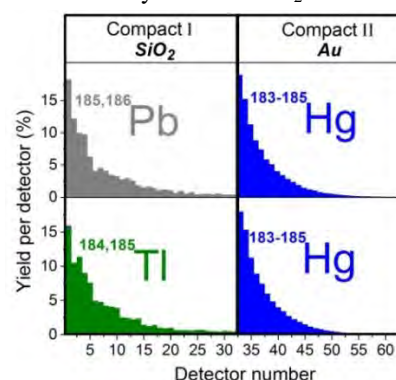


Figure 1: Pb, Tl and Hg distributions in COMPACT²

Pb was retained under diffusion-controlled deposition in the first COMPACT array, whereas Hg passed this and deposited on the Au surface. The obtained results agree with theoretical predictions [3,7] and helped optimizing the experimental setup for an upcoming Fl experiment. This improved setup allows to directly compare the chemical behavior of Fl, Pb, Hg, Cn and Rn.

For the first time, Tl was investigated in the online regime. Short-lived Tl radioisotopes were pre-separated with TASCA, thermalized in the RTC and carried by Ar gas further to COMPACT, cf. Fig. 1 (lower panel). They adsorbed on the SiO₂ coated detector array, which agrees with offline studies on SiO₂ and Au surfaces [8]. Produced Hg isotopes were detected on the Au surface of the second COMPACT array.

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ALBEGA: A decay spectroscopy setup for chemically separated samples *

A. Di Nitto^{†1}, A. Yakushev², Ch.E. Düllmann^{1,2,3}, J. Khuyagbaatar^{2,3}, J. Krier², J. Ballof⁴, J. Bar⁷, T. Budzyński⁷, D.M. Cox⁴, X. Derckx^{1,3}, J. Dormand⁴, J.D. Despotopoulos⁵, K. Eberhardt^{1,3}, J. Even³, P. Grabiec⁷, L. Harkness-Brennan⁴, R.D. Herzberg⁴, A. Huebner², E. Jäger², D. Judson⁴, B. Kindler², H. Kłos⁷, J.V. Kratz¹, J. Kulawik⁷, N. Kurz², L. Lens¹, B. Lommel², K. Moody⁵, Ch. Mokry¹, A. Panas⁷, P. Prokaryn⁷, D. Rudolph⁶, J. Runke², I. Rusanov², P. Scharrer¹, B. Schausten², D. Shaughnessy⁵, D. Szmigiel⁷, A.J. Ward⁵, and M. Wegrzecki⁷

¹Mainz University, Germany; ²GSI Darmstadt, Germany; ³HIM Mainz, Germany; ⁴Liverpool University, UK; ⁵LLNL, Livermore, USA; ⁶Lund University, Sweden; ⁷ITE Warsaw, Poland

There are many on-going programmes dedicated to elucidate the nuclear structure of SuperHeavy Elements (SHE atomic number $Z \geq 104$) based on different methods [1]. The SHE are accessed in heavy-ion induced fusion-evaporation reactions, with the nuclear spectroscopy experiments typically performed at in-flight recoil separators.

An alternative approach exploits a chemical isolation system either directly or after separator [2], this was adopted in different experiments [3-5]. A significant improvement of the background conditions was observed applying this method.

A next generation setup for measurements of ALpha-BETA-Gamma decays (ALBEGA) after chemical isolation was recently built. ALBEGA is dedicated to simultaneous measurements of α particles, electrons, photons and fission fragments. Volatile chemical species adsorb on a cooled segmented Si detector. Radiation emitted in the decay is measured with surrounding detectors, cf. Fig.1. The

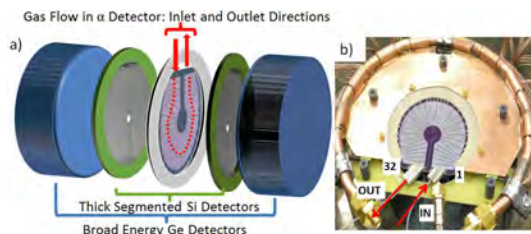


Figure 1: A schematic of ALBEGA, where the arrows indicate the gas flow inside the tight channel (a). A picture of the α detector mounted on the cooling support and connected to the capillaries for gas flushing.

core is a “sandwich” of two segmented Si detectors with a gas channel inside, sensitive to charged particles (“ α detector”). A round channel is etched in both wafers, glued together to form a tight channel. At both sides and parallel to the α detector two thicker, segmented Si detectors are mounted (cf. Ref. [6]). The Si detectors are backed by two 3-cm-thick broad energy Ge detectors for X and γ rays. All

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[†] a.dinitto@gsi.de

the detectors were assembled in a packed configuration to maximize the geometrical efficiency.

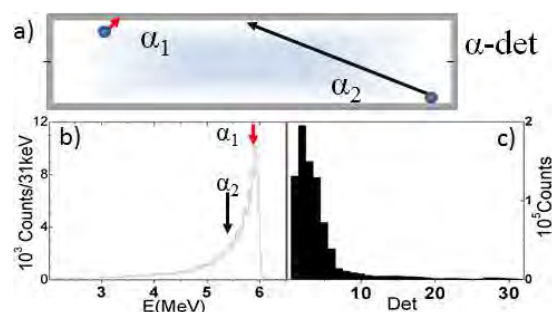


Figure 2: The α particles are emitted isotropically at various angles in the narrow channel (a). Depending on their incident angle, they pass through different effective thicknesses of detector dead layer and gas, thus undergoing energy loss to a different degree, before entering the active detector area. Accordingly, α peaks show characteristic low-energy tailing, e.g. the $^{140}\text{Ce}(^{50}\text{Ti}, 6-7n)$ reaction energy spectrum (b). The measured energies corresponding to the two particles α_1 and α_2 are indicated, they have the same initial energy but different path. The distribution pattern observed in the experiment (c) is due to the Hg retention on the inner channel Au coating, and the maximum is observed on the segments at the channel entrance.

The setup was first tested and calibrated with α particles and γ rays produced by decay chains of ^{219}Rn emanated from an ^{227}Ac source. Then the $^{140}\text{Ce}(^{50}\text{Ti}, 6-7n)$ reaction was used to produce $^{184,183}\text{Hg}$, which was pre-separated in TASCA [3] and then transported to ALBEGA with rapidly flowing of Ar gas. The energy spectrum and the distribution pattern measured are shown in Fig. 2.

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Performance of a modified 1.4 MeV/u gas stripper for $^{238}\text{U}^{4+}$

Paul Scharrer¹, Egon Jäger², Winfried Barth^{1,2}, Mario Bevcic², Christoph E. Düllmann^{1,2,3}, Lars Groening², Klaus-Peter Horn², Khuyagbaatar Jadambaa¹, Jörg Krier², Alexander Yakushev²
¹HIM, Mainz, Germany; ²GSI, Darmstadt, Germany; ³Johannes Gutenberg-Universität, Mainz, Germany

The GSI UNILAC will serve as an injector system for the FAIR facility. Therefore it has to meet high demands in terms of beam brilliance. A key projectile for FAIR will be ^{238}U [1]. In current routine operation U^{4+} -ions from a MEVVA ion source are accelerated to 1.4 MeV/u by the High Current Injector (HSI). Inside the adjacent gas stripper, the charge state of the ions is increased to raise the efficiency of further acceleration. Behind the stripper, a system of dipole magnets allows the selection of ions with the desired charge state (U^{28+}) [2].

To increase the beam intensity after the gas stripper, an upgrade program has started to increase the stripping efficiency into the desired charge state. The current gas stripper is based on a supersonic N_2 -jet, created through a laval nozzle at 0.4 MPa back-pressure. The continuous gas flow limits the usable gas pressure due to the high gas load for the differential pumping system. This also prevents the optimal use of other promising stripper gases, as a saturated charge distribution cannot be reached [3].

To overcome this limit, a modified gas stripper setup was developed [4]. The flange with the laval nozzle on top of the main stripper chamber was replaced by a new flange, featuring a pulsed gas valve designed for a back-pressure of up to 12 MPa and an opening time down to a few microseconds. The new flange is shown in Fig. 1. To prevent the gas from instantaneous removal, an extension was added to the flange with a T-fitting at the end to match the beam line. This creates a high-pressure interaction zone for the stripping process. The valve is located in the extension, facing down towards the beam line. The pulsed gas injection is triggered by a timing signal of the central accelerator control unit. The valve is opened only when a beam pulse passes the stripper and closed immediately afterwards, decreasing the gas load for the pumping system and lowering the gas consumption by a factor of up to 200.

During two measurement campaigns in 2014 the new stripper setup was tested with a U^{4+} -beam (1 Hz, 100 μs pulse length). An opening time of 0.5 ms was used for the pulsed gas valve. The opening time was chosen based on pressure measurements near the gas inlet as well as beam current measurements behind the stripper. Besides N_2 , which allowed comparing the setup to the current gas-jet stripper, the charge spectra were measured for various other gases (H_2 , He, O_2 , Ne, Ar and CO_2).

For all used gases except H_2 , a saturation of the charge state distribution was observed with an increase of the back-pressure. The beam emittance and the energy loss were measured using the determined settings for a saturated charge state distribution. Additionally, the stripping

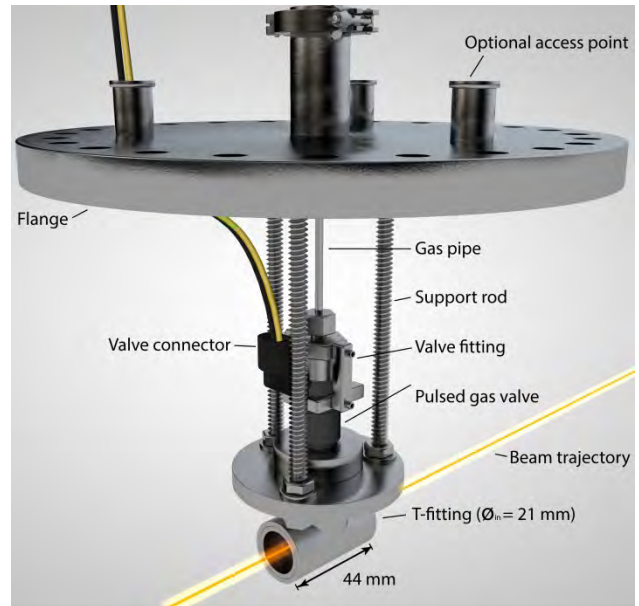


Figure 1: Model of the new stripper flange

efficiency was measured for every populated charge state. A saturation of the charge state distribution with H_2 could not be observed due to the pressure limitations of the pulsed gas valve. Therefore, one can assume that the average charge state will rise, if the pressure is increased further.

Using H_2 with the pulsed gas cell, it was possible to set a new record for the U^{28+} beam intensity behind the gas stripper at the GSI UNILAC [5].

The pulsed gas injection enables various possibilities for the use at the GSI UNILAC, including the simultaneous use of different stripper gases for particular ion beams. Preparing for routine operation, the pulsed gas cell has to be tested and optimized for all to be used types of ion beams.

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Pulsed beams at TRIGA-LASER and Ca^+ isotope shifts*

C. Gorges¹, S. Kaufmann¹, T. Beyer², K. Blaum², Ch. E. Düllmann^{3,4,5}, Ch. Geppert³, J. Grund⁴, M. Hammen⁴, J. Krämer¹, Sz. Nagy², D. Renisch³, R. Sanchez⁵, and W. Nörtershäuser^{1,3}

¹IKP, TU Darmstadt, Germany; ²MPIK, Universität Heidelberg, Germany; ³Institut für Kernchemie, Universität Mainz, Germany; ⁴HIM, Mainz, Germany; ⁵GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Germany

The prototypes of the MATS and LASPEC experiments [1] for FAIR have been established as TRIGA-TRAP and TRIGA-LASER, respectively, at the Institute for Nuclear Chemistry at Mainz University. Together they form the TRIGA-SPEC setup [2] since they have a common beamline that will deliver short-lived isotopes produced inside the research reactor for high-precision Penning-trap mass spectrometry at TRIGA-TRAP and collinear laser spectroscopy at TRIGA-LASER. Here, we report on the progress at the collinear beamline in 2014.

A python based control system called 'TRITON' has been developed for slow control of the experiment. It is a common frame in which voltages of the ion optics along the beamline, the readings of Faraday cups, pressure gauges, multi-meters, the status of valves along the beamline as well as the laser frequency are monitored and continuously recorded during operation. It allows for beam tuning by changing the ion optical settings and controlling the beam shape analyzing sections equipped with fluorescence screens and faraday cups. Additional devices can be easily added into a database structure, providing a very flexible system for future extensions.

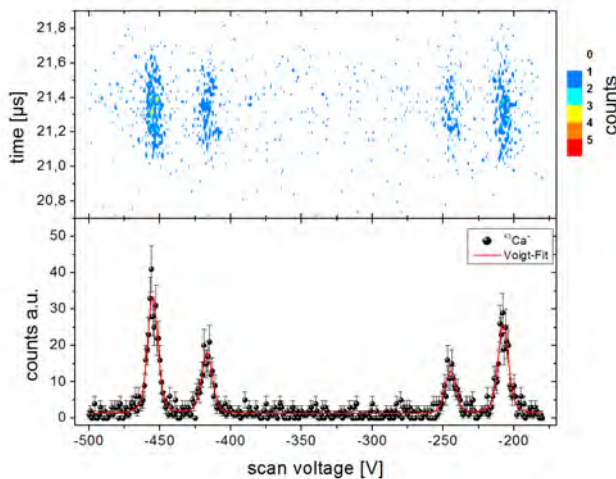


Figure 1: Time resolved spectrum of ^{43}Ca . The upper graph shows the time of flight of individual photons plotted against the scanning voltage. The countrate is color-coded. The lower trace shows the projection of the counts inside the relevant time window and the result of a hyperfine structure fit using Voigt profiles.

Real time data acquisition (DAQ) and time-resolved

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photon detection was realized as a prototype on a field programmable gate array (FPGA). It has been tested using bunched beams produced by the RFQ cooler and buncher in the TRIGA-SPEC beamline. Figure 1 shows a time-resolved spectrum of $^{43}\text{Ca}^+$. A low-intensity beam of this isotope was created from metallic calcium, which was inserted into the online ion source. After mass separation and cooling and bunching in the RFQ, short bunches were released towards the TRIGA-LASER beamline. From the upper chart, representing the photon detection times after release of the bunch from the RFQ, a bunch length of about 600 ns can be extracted. The counts detected between 21.0 and 21.6 μs are projected onto the Doppler-tuning axis in the lower graph and provide the hyperfine spectrum of this isotope. A second FPGA is now implemented into the system to establish all timing signals for the RFQ operation and Doppler tuning as well as the voltage control during a laser scan on the real-time system. This will then be completely embedded in a new python-based DAQ system running on a PXI system in which both FPGA's are implemented.

Additionally, we were able to measure the isotope shifts of $^{42,44,48}\text{Ca}$ with respect to ^{40}Ca in the D2-line of Ca^+ and to reduce their uncertainty by about a factor of four. The results can be found in table 1.

Table 1: Isotope shift measurements in the D2-line (1st row) compared with literature [3] (2nd row). The brackets show statistical and systematical errors.

$\delta\nu_{\text{IS}}^{40-42}$ [MHz]	$\delta\nu_{\text{IS}}^{40-44}$ [MHz]	$\delta\nu_{\text{IS}}^{40-48}$ [MHz]
426.4(15)(10)	850.1(10)(20)	1710.6(35)(42)
430.0(180)(40)	842.0(130)(80)	1699.0(190)(160)

The next steps that are taken at TRIGA-LASER are the establishment of the full DAQ system, further specifications of the longitudinal beam emittance of the bunches released from the RFQ, and to establish collinear-anticollinear laser spectroscopy to further improve the accuracy of isotope shift measurements.

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Uranium high current development at UNILAC

Winfried Barth^{1,2}, Aleksey Adonin², Christoph E. Düllmann^{1,2,3}, Peter Gerhard², Manuel Heilmann², Ralph Hollinger², Egon Jäger², Jadambaa Khuyagbaatar^{1,2}, Joerg Krier², Paul Scharrer¹, H. Vormann², Alexander Yakushev², Stepan Yaramyshev²

¹ Helmholtz Institute Mainz, Germany

² GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

³ Johannes Gutenberg-Universität Mainz, Mainz, Germany

Previously a peak record had been achieved in 2007 (Fig.1), while 30% of the FAIR- U^{28+} beam current was accomplished at the end of the transfer line. Caused by a strong High Current Injector (HSI) performance degradation, up to October 2014 the available beam current dropped down to 13% of the design value only. After re-optimization of the complete front end system the HSI is again able to deliver a high uranium beam current. In a short run applying the new fast pulsed high density H_2 -gas cell more than a factor of three higher U^{28+} beam current is now available at 1.4 MeV/u. The stripper performance could be optimized applying significantly higher target densities. The new U^{28+} intensity record exceeds the latest peak record by 56% (Fig. 1).

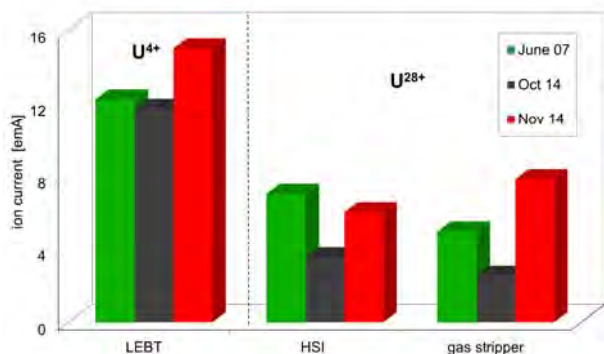


Fig. 1: Achievement of a new uranium beam ($28+$) intensity record at GSI-HSI and gas stripper section. The former U^{28+} -peak value (2007) was exceeded by 56%.

A new fast pulsed high density gas cell [1] was successfully commissioned with uranium beam from the GSI HSI. Besides, the entire Injector system was optimized for high beam intensity operation. A 25% higher U^{4+} beam current extracted by a newly developed multi aperture beam extraction system (VARIS ion source [2,3]) were used to optimize the Low Energy Beam Transport system and matching line to the RFQ. A beam current of 15.3 emA (Fig. 2) was available for injection into the RFQ. In particular the most sensitive Medium Energy Beam Transport section was optimized for high current high transmission beam transport applying a slightly different set of rf-parameters. With this the HSI was allowed for stable and reliable high current uranium operation. A careful matching of the high power (0.5 MW pulse power) U^{4+} beam to the gas stripper cell was accomplished resulting in a U^{28+} beam current of 7.7 emA (Fig. 2) after stripping and charge separation at 1.4 MeV/u.



Fig. 2: Beam transformer measurement after careful optimization of a VARIS-uranium beam.

The world intensity record for U^{28+} pulse operation could be reached after less than three days of beam time, including 15 hours beam time spent for commissioning of the H_2 -gas cell-stripper. More than 50% of U^{28+} - FAIR intensity requirements (and 65% of beam brilliance) was achieved at 1.4 MeV/u. Increased beam currents for all heavy ions are expected - stripper tests are envisaged using Pb-, Au-, Ta-, Xe-, Kr-, CH_3 -beams. An upgrade of the HSI [4-6] is potentially sufficient to meet the FAIR performance at the GSI-UNILAC. Further optimization of stripper performance should be started in an advanced machine experiment program. Beam acceleration up to 11.4 MeV/u and transport to SIS18 is the next step to confirm high intensity operation in the SIS18.

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