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Program

Monday, June 21, 2021

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14:00	**Welcome**	**Paolo Giubellino (FAIR / GSI, Darmstadt)**	
	News from Gas-Filled Recoil-Separator Laboratories (Part 1)	**Chair person:** Araceli Lopez-Martens (IJCLab)	
14:10	Recent development of GARIS facility for study on superheavy elements (20+5 min)	Daiya Kaji (RIKEN)	4
14:35	JYFL-ACCLAB, in-flight separators MARA and RITU, status and prospects (20+5 min)	Jan Sarén & Juha Uusitalo (Univ. of Jyväskylä)	5
15:00	Spectroscopy of Fl decay chains and plans for Lundium (20+5 min)	Daniel Cox (Lund Univ.)	6
15:25	New uranium isotope discovered at SHANS and CAFE2 project in Lanzhou (20+5 min)	Zhiyuan Zhang (IMP, Chinese Academy of Sciences)	5
15:50	**Workshop Photo**		
15:55	**Coffee Break**		
	News from Gas-Filled Recoil-Separator Laboratories (Part 2)	**Chair person:** Michael Block (GSI / HIM / JGU)	
16:10	Recent Results from the BGS/FIONA at LBNL (20+5 min)	Jennifer Pore (LBNL)	7
16:35	Spectroscopy of Trans-fermium Nuclei with the Argonne Gas-Filled Analyzer (20+5 min)	Dariusz Seweryniak (ANL)	7
17:00	Recent results of GARIS-II + MRTOF experiment (15+5 min)	Toshitaka Niwase (RIKEN/Kyushu Univ.)	8
17:20	Recent spectroscopic studies in the actinide region using MARA and RITU separators (15+5 min)	Kalle Auranen (JYFL)	8
17:40	**End of day 1**		

Tuesday, June 22, 2021

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14:00	**Welcome**		
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14:05	Fission experiment using ^{254}Es target material at JAEA tandem accelerator facility (20+5 min)	Kentaro Hirose (JAEA)	9
14:30	Velocity filter SHELS at the U400 FLNR cyclotron: performance and experimental results (20+5 min)	Alexander Svirikhin** (Flerov Lab. of Nuclear Reactions, JINR)	10
14:55	High-precision mass spectrometry of ground states and low-lying isomers in heavy and superheavy nuclei with SHIPTRAP (15+5 min)	Francesca Giacoppo (GSI, Darmstadt)	21
15:15	Laser Spectroscopic Investigation of the heaviest actinides at GSI (15+5 min)	Premaditya Chhetri (GSI, Darmstadt)	10
15:35	**Coffee Break**		
	Recent News from Physics; Instrumentation (Part 2)¶	**Chair person:** Dariusz Seweryniak (Argonne National Laboratory)	
15:55	Survivability of compound nuclei at extreme conditions (20+5 min)	Jadambaa Khuyagbaatar (GSI, Darmstadt)	11
16:20	Decay studies of neutron deficient mendelevium isotopes (15+5 min)	Fritz-Peter Heßberger (GSI, Darmstadt)	12
16:40	Status of the cw-Linac project (15+5 min)	Winfried Barth (GSI, Darmstadt)	19
17:00	MARGE – New Modular Robotic Gas-Jet Target System for the chemistry of SHE homologues studies (15+5 min)	Pavel Bartl (Czech Technical University Prague)	13
17:20	**End of day 2**		

* presented by Karl Hauschild (IJCLab)

Wednesday, June 23, 2021

TIME*	TOPIC	Speaker	See page
14:00	**Welcome**		
	Recent News from Chemistry; Targets (Part 1)	**Chair person:** Charles M. Folden III (Texas A&M University)	
14:05	Reactions in the Gas-Phase and Adsorption Properties of Elements Cn and Heavier (20+5 min)	Miroslav Iliaš (Matej Bel University / HIM)	14
14:30	Status and plans of chemical research with heaviest elements at PSI and FLNR (20+5 min)	Patrick Steinegger (PSI)	14
14:55	Direct coupling of liquid-phase chemical setups for heaviest element studies to a recoil separator (15+5 min)	Dominik Krupp (HS Mannheim)	15
15.15	Off-line single-atom gas chromatographic adsorption studies of lead and bismuth (15+5 min)	Dominik Dietzel (Johannes Gutenberg Univ. Mainz)	16
15:35	**Workshop Photo**		
15:40	**Coffee Break**		
	Recent News from Chemistry; Targets (Part 2)	**Chair person:** Hiromitsu Haba (RIKEN)	
15:55	Chemical studies of Nh (Z=113) and Mc (Z=115) at TASCA (20+5 min)	Alexander Yakushev (GSI, Darmstadt)	16
16:20	Functionalized surfaces and oxidation states of on-line produced thallium (15+5 min)	Evgeny Tereshatov (Texas A&M Univ.)	17
16:40	The isotope program at ORNL for target for superheavy element research (15+5 min)	Julie Ezold (Oak Ridge National Lab.)	18
17:00	Key aspects for the production of the ideal actinide target for the production of superheavy elements (15+5 min)	Christoph Düllmann (Univ. Mainz / GSI, Darmstadt / HIM)	19
17:20	Ion-Beam Induced Structural and Chemical Changes in Targets Used for Superheavy Element Production (15+5 min)	Carl-Christian Meyer (JGU Mainz / HIM)	20
17:40	**End of TASCA 21 workshop**		

** Time corresponds to Central European Summer Time (CEST / UTC+02:00)*

Recent developments of the GARIS facility for studies of superheavy elements

Daiya Kaji

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From 2001 to 2017, a lot of studies on nuclear physics and chemistry of superheavy elements (SHEs) had been successfully performed by using gas-filled recoil ion separators GARIS [1] and GARIS-II [2] installed at RIKEN Heavy-Ion Linac (RILAC) facility. Since 2017, rearrangement of the GARIS-II and new development of accelerator and recoil separator in Radioactive Isotope Beam Factory (RIBF) has been done for further investigation of SHEs. Figure 1 shows general drawing of present GARIS facility for studies of SHEs.

The GARIS-II was moved from RILAC facility to RIKEN Ring Cyclotron (RRC) facility. High intensity heavy-ion beam provided by the 28 GHz superconducting ECR ion-source, heavy ion Linac RILAC-II, and the RRC is available. In addition to study on production and decay properties of SHEs, precise mass measurement of heavy elements by using a multi-reflection time-of-flight mass spectrograph (MRTOF-MS) [3] coupled with GARIS-II is also progressed. Recently, the direct mass measurement of ^{257}Db produced via the ^{51}V(^{208}Pb,2n) reaction was succeeded [4]. The details of the experiment and result are separately given in this workshop [5].

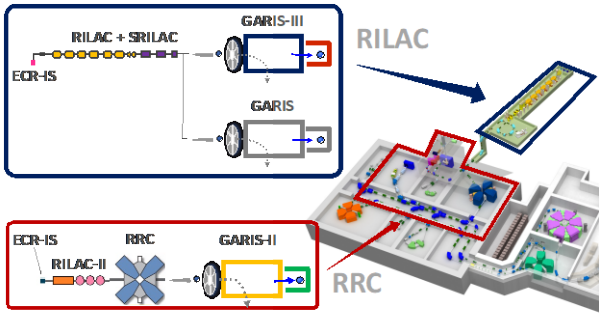

Fig.1 General drawing of the GARIS facility in RIBF.

The RILAC in RIBF upgraded to superconducting RIKEN linear accelerator (SRILAC) toward further investigation on SHEs. In addition to the GARIS, a new gas-filled recoil ion separator GARIS-III was also installed downstream of the SRILAC. The GARIS-III is same design, which consists of Q1-D1-Q2-Q3-D2, as the GARIS-II. Expanded chemistry room was also re-constructed next to irradiation room in the RILAC facility. In June 2020, the GARIS-III was operated and evaluated by using ^{40}Ar-induced fusion reactions. The details of the experiment and result are given in this workshop.

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JYFL-ACCLAB, in-flight separators MARA and RITU, status and prospects

Jan Sarén & Juha Uusitalo

Nuclear Spectroscopy Group, University of Jyväskylä

The Nuclear Spectroscopy Group (NSG) at JYFL-ACCLAB is employing two complementary in-flight separators in their spectroscopic studies. Recoil Ion Transport Unit (RITU) [1] is a gas-filled recoil separator and has been in operation for almost 30 years. Mass Analyzing Recoil Apparatus (MARA) [2], is a vacuum-mode double focusing mass separator, has been in use for about four years. As said separators are complementary and allow us to perform spectroscopic studies at and beyond the proton-drip line and in the Very Heavy Element (VHE) region starting from mass A= 40 onward. RITU is ongoing a major upgrade where the focal plane system is updated. In this presentation a status report of the separators will be given. In addition, prospects related to the future experimental program, relevant for the SHE-community, will be outlined.

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New uranium isotope discovered at SHANS and CAFE2 project in Lanzhou

Zhiyuan Zhang

Institute of Modern Physics, Chinese Academy of Sciences, China

Finding new isotopes and extending the landscape of the chart of nuclei are always exciting in nuclear physics. In my talk, I will give a report on the discovery of the most neutron-deficient uranium isotope ^{214}U and the more precise α-decay measurement of the even-even nuclei ^{216,218}U. The experiments were performed at the gas-filled recoil separator, SHANS, in Lanzhou. Based on these measurements, we found that the strong proton-neutron interaction may affect the formation of α particle in this region of nuclei and enhance the α-particle clustering in lightest uranium isotopes.

In order to study superheavy elements with improved experimental condition, we are carrying out a new project, CAFE2 (China Accelerator Facility for superheavy Elements), which contains an ECR ion source, an upgraded super-conducting linear accelerator and a new gas-filled recoil separator, SHANS2. I will briefly show the present status, progress, and plans for this project.

Spectroscopy of Fl decay chains and plans for Lundium

Daniel Cox

Department of Physics, Lund University

In the wake of the discovery of superheavy elements, nuclear spectroscopy experiments aim at providing anchor points at the uppermost end of the nuclear chart for nuclear structure theory, which otherwise had to solely rely on extrapolations. In two runs in 2019 and 2020, such a nuclear spectroscopy experiment was conducted to study α-decay chains stemming from isotopes of flerovium (element Z = 114) [1,2]. One incentive to study flerovium isotopes is that many, but not all, nuclear structure models or model parametrizations favour Z = 114 as the next magic proton number beyond lead, Z = 82.

The U310 experiment employed an upgraded TASISpec decay station, which is shown in Fig.1. It was placed behind the gas-filled separator TASCA. The fusion-evaporation reactions ^{48}Ca+^{242}Pu and ^{48}Ca+^{244}Pu provided a total of 32 flerovium-candidate decay chains in effectively 18 days of beam time. Two and eleven decay chains were firmly assigned to even-even ^{286}Fl and ^{288}Fl isotopes, respectively. The – admittedly unexpected – observations include (*i*) an excited 0^+ state at 0.62(4) MeV excitation energy in ^{282}Cn, and (*ii*) a Q_α = 9.46(1) MeV decay branch (1 out of 51) from ^{284}Cn into ^{280}Ds [2]. Both observations indicate that there is hardly any shell gap at proton number Z = 114 - at least not at neutron numbers $N \approx$ 172-174. This statement is supported by demanding beyond-mean-field model calculations, which include the necessary triaxial shapes [3,4]. The existence of the excited 0^+ state in ^{282}Cn requires "an understanding of both shape coexistence and shape transitions for the heaviest elements" [1]. Second, using the known Q_α = 10.79(4) MeV for the ^{292}Lv → ^{288}Fl α decay as well as the now precisely measured Q_α = 10.06(1) MeV for ^{288}Fl → ^{284}Ds, a smooth Q_α sequence *across* Z = 114 could be established.

An update on the new Lundium decay station and a future proposed experiment into neutron-deficient plutonium isotopes will also be presented..

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Recent Results from the BGS/FIONA at LBNL

Jennifer Pore

Lawrence Berkeley National Laboratory

FIONA was designed to directly measure the mass-numbers of heavy (Z>92) and superheavy isotopes (Z>103). These isotopes are created in fusion-evaporation reactions, where it is not uncommon for neighboring isotopes to be created simultaneously. Mass-number measurements allow for the direct identification of individual isotopes from these reactions. FIONA has now been coupled to the Berkeley Gas-filled Separator at Lawrence Berkeley National Laboratory. FIONA has been successful in having performed the first-ever super heavy element mass-number measurements for isotopes of elements 113 and 115. More recently, FIONA has been used to study the properties of neutron-deficient mendelevium isotopes, including the direct-identification of the new isotope ^{244}Md. A similar campaign of measurements is now underway aiming to identify the new isotope ^{239}Es. FIONA has also proven to be a useful tool in studying the chemistry of heavy elements. An update on the status of these different measurements will be presented along with future experimental plans for FIONA.

Spectroscopy of Trans-fermium Nuclei with the Argonne Gas-Filled Analyzer

Dariusz Seweryniak
on behalf of the AGFA collaboration

Physics Division, Argonne National Laboratory, Argonne, IL 60439, USA

Spectroscopy of trans-fermium nuclei around the Z=100 and N=152 deformed shell gaps has been an active area of research at the ATLAS facility at Argonne National Laboratory for many years since the pioneering experiments using the Gammasphere γ-ray detector array and the Fragment Mass Analyzer (FMA), which led to the observation of a rotational band and K-isomers in ^{254}No. Rotational bands, K-isomers, γ -decay and spontaneous fission decay properties of trans-fermium nuclei provide stringent tests of nuclear models which are also used to describe the heaviest known nuclei. To extend these studies to more proton-rich nuclei, odd-A and odd-odd nuclei, and heavier nuclei, the Argonne Gas-filled Fragment Analyzer (AGFA) was constructed. During the talk selected results of the first in-beam spectroscopy AGFA campaign with Gammasphere and first decay spectroscopy AGFA campaign in stand-alone mode will be reviewed. Among others the following experiments will be discussed: high statistics prompt and delayed γ-ray spectroscopy of the benchmark nucleus ^{254}No, observation of a rotational band in the fissile nucleus ^{254}Rf, characterization of a new K-isomer in ^{251}Md, and discovery of a new isotope ^{251}Lr. Plans for experimental program with AGFA will be also presented.

This material is based upon work supported by the U.S Department of Energy, Office of Science, Office of Nuclear Physics, under contract number DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

Recent results of GARIS-II + MRTOF experiment

Toshitaka Niwase

RIKEN Nishina Center

We have constructed the SHE-Mass facility, which is a combined system of a RIKEN gas-filled recoil ion separator GARIS-II and a multi-reflection time-of-flight mass spectrograph MRTOF-MS, to perform the precision mass measurement of heavy nuclides. The novel detector called "α-TOF" was recently developed, which allows us to correlation measurement of the time-of-flight of nuclides and their subsequent α-decay.

The α-TOF detector enables highly accurate mass measurement by using the α-decay signals as a footprint of the nuclide, even for rare events of a few events per day. The α-TOF detector also allows for nuclear spectroscopy studies using MRTOF-MS. As a demonstration experiments, we have directly determined the masses of ^{206,207}Ra isotopes and the excitation energy of the isomeric state of ^{207}Ra from time-of-flight and correlated α-decay measurements. We have also successfully the direct measured the mass of Db isotope.

In this presentation, I would like to talk about the results of these recent measurements.

Recent spectroscopic studies in the actinide region using MARA and RITU separators

K. Auranen[1,a], H. Badran[1,b], T. Grahn[1], P.T. Greenlees[1], A. Herzán[1,2], U. Jakobsson[1], R. Julin[1], S. Juutinen[1], J. Konki[1], M. Leino[1], A.-P. Leppänen[3], G. O'Neill[1,4,c], J. Pakarinen[1], P. Papadakis[1,d], J. Partanen[1,e], P. Peura[1], P. Rahkila[1], P. Ruotsalainen[1], M. Sandzelius[1], J. Sarén[1], C. Scholey[1,f], L. Sinclair[1,5], J. Sorri[1,b], S. Stolze[1,g], J. Uusitalo[1], and A. Voss[1]

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In this talk I will present the results, together with a brief physics discussion, obtained in a multitude of experiments focused on the study of nuclei near the light actinide region. These results include the observation of the isomeric $^{13}/_{2}^{+}$ ($\pi(i_{13/2})$) state in ^{201}Fr [1], as well as the first rigorous identification of the new α-decaying isotope ^{211}Pa [2]. In addition, an isomeric $^{13}/_{2}^{+}$ state arising from a $\nu i_{13/2}^{-1}$ configuration has been observed in ^{211}Th [3]. These three results were obtained using the GREAT spectrometer at the focal plane of the RITU gas-filled recoil separator. In our recent experiment employing the MARA separator we studied the structure of ^{213}Ac and ^{211}Ac nuclei via in-beam and delayed spectroscopy. Some preliminary results of these experiments will be discussed.

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Fission experiment using ^{254}Es target material at JAEA tandem accelerator facility

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From the measurements of fission-fragment mass distributions for nuclides around A=258 for spontaneous fission, a unique sharp change from asymmetric fission to symmetric fission mode was found by moving from ^{256}Fm to ^{258}Fm [1]. To understand such specific phenomenon will give a unique opportunity to study the fission mechanism.

We have developed a measurement system for multinucleon transfer fission and performed experiments using actinide targets and ^{18}O beams at the Tokai tandem accelerator facility of Japan Atomic Energy Agency [2,3,4]. The multinucleon transfer reaction is a powerful tool to populate a variety of nuclides with a wide range of exciting energies. For example, 23 nuclides from U to Bk with excitation energies up to 70MeV were produced in the reaction ^{18}O+^{237}Np [5]. The availability of ^{254}Es material from Oak Ridge National Laboratory allowed us to initiate an extended campaign to study fission of nuclides in this region. This presentation will review the results from several experiments which we performed in fusion-fission of ^{4}He+^{254}Es reaction, spontaneous fission in ^{18}O+^{254}Es and multinucleon transfer fission in ^{18}O+^{254}Es.

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Velocity filter SHELS at the U400 FLNR cyclotron: performance and experimental results.

Alexander Svirikhin

FLNR JINR, Dubna, Russia

The opportunity to have high intensity (> 1 pμA) accelerated beams of ions with A ≤ 60 together with the use of exotic targets provide the possibility to study many aspects of heavy ion induced reactions exploiting new generation of high efficiency, high resolution experimental setups. In recent years, decay properties of heavy nuclei at the focal plane of recoil separators ("decay spectroscopy") has been very intensively developed. The mixing of α decay with γ and β decay spectroscopy allows to investigate single particle states of heaviest nuclei as well as the spontaneous fission properties of isotopes in the Z = 98-105 and N = 152-162 region.

The scheme of a velocity filter was chosen for a detailed spectroscopic study of heavy isotopes. New experimental set up named SHELS (**S**eparator for **H**eavy **EL**ement **S**pectroscopy) was developed, manufactured and installed at the beam of the U400 cyclotron. The ion optical scheme of the new separator can be described as Q-Q-Q-E-D-D-E-Q-Q-Q-D, where Q denotes Quadrupole lenses, E - Electrostatic deflectors, D – Dipole magnets.

The modernized multi-parameter detector GABRIELA (**G**amma **A**lpha **B**eta **R**ecoil **I**nvestigations with the **EL**ectromagnetic **A**nalyser) consisting of 5 Ge detectors (1 Clover and 4 single crystal) and double sided silicon detector (DSSD, 128x128 strips) was installed at the focal plane of SHELS. In addition, the separator uses a combined detection system for studying the properties of SF nuclei, consisting of a focal DSSSD-box y surrounded by 3-He neutron counters (54 pcs.).

Our report presents the data of experiments made in recent years. A brief overview of the planned experiments and approaches to improving the experimental methodology is given.

Laser Spectroscopic Investigation of the heaviest actinides at GSI

Premaditya Chhetri

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Precision measurements of optical transitions of the heaviest elements is a versatile tool to probe the electronic shell structure which is strongly influenced by electron-electron correlations, relativistic and QED effects. Optical studies of transfermium elements with Z>100 are hampered by low production rates and the fact that any atomic information is initially available only from theoretical predictions. Using the sensitive **RA**diation **D**etected **R**esonance **I**onization **S**pectroscopy (RADRIS) technique coupled to the SHIP separator at GSI, a strong optical $^1S_0 \rightarrow {}^1P_1$ ground-state transition in the element nobelium (Z=102) was identified and characterized [1]. Furthermore, the isotopes $^{252-255}$No was measured, revealing the isotope shift and a hyperfine splitting for the odd mass nucleus ^{253,255}No [2]. From these measurements, nuclear information on the shapes and sizes were inferred. In addition, several high-lying Rydberg levels were observed, which enabled the extraction of the first ionization potential with high precision [3]. Recently, several isotopes of fermium (Fm, Z=100) was also measured.

These results will be discussed as well as the prospects for future investigations involving the study of additional nobelium and fermium isotopes and the exploration of the atomic structure of the next heavier element, lawrencium (Z=103).

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Survivability of compound nuclei at extreme conditions

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One of the main techniques for the production of exotic nuclei is via heavy-ion induced reactions. Usually, nuclei produced in such a way initially have extra energies in both external and internal degrees of freedom, which are released via various de-excitation channels like fission and evaporation of light particles. The latter one defines the survivability of excited heavy nuclei against fission and is one of the most interesting and important aspects for the production of the heaviest nuclei.

The nuclei of heaviest elements have mostly been produced in fusion-evaporation reactions. These are referred to as cold (hot), depending on the low (high) excitation energies of their compound nuclei (CN), which have large (small) angular momenta [1,2].

In the last two decades, fusion–evaporation reactions with ^{48}Ca projectiles and actinide targets, in which the formed CN have relatively low excitation energy but relatively high angular momenta have successfully been used for syntheses of the elements Cn-Og (Z=112-118) [3]. However, elements beyond Og can be produced only by using heavier projectiles, e.g., ^{50}Ti, which should result in shorter interaction times between the reactant nuclei [4]. Accordingly, it is still unknown how much the change from ^{48}Ca to ^{50}Ti will reduce the cross sections of fusion-evaporation reactions leading to the formation of the heaviest elements [5,6]. In fact, it is obvious that their nuclear structures will strongly effect on the fusion probability [7,8].

At the same time, during the collision of two very heavy nuclei, many reaction channels are open [9]. Among them, the multi-nucleon transfer channels are believed to provide an access to more neutron-rich SHN [10]. Those nuclei are believed to be produced at extreme conditions (e.g., with a large angular momentum), thus, their survival probability is one of the still unexplored issues.

I will discuss these aspects within the context of some recent experimental results obtained at the gas-filled recoil separator TASCA of the SHE-Chemistry department (GSI), where we carry out an intensive program on the studies of nuclear reactions.

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Decay studies of neutron deficient mendelevium isotopes

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In recent experiments performed at the velocity filter SHIP at GSI enhanced decay data of ^{247}Md and ^{250}Md were obtained.

^{247}Md was produced in several experiments at SHIP in the reaction ^{209}Bi(^{40}Ar,2n)^{247}Md. In a recent study a tentative decay scheme was presented [1]. Main features of a new study was to identify the decay of ^{247g}Md into the ground-state of the daughter nucleus ^{243}Es, to obtain more detailed information about the decay of the isomeric state ^{247m}Md, and to identify a spontaneous fission branch of ^{247g}Md [2]. The results will be discussed, and an improved decay scheme will be presented.

^{250}Md was produced as third member of the alpha – decay chain starting from ^{258}Db. A thorough analysis of the decay data revealed the existence of two long-lived low-lying levels partly decaying by alpha-emission [3]. The results will be compared with a theoretically predicted level scheme [4].

Discovery of ^{244}Md was recently reported from experiments performed at the BGS, LNBL, Berkeley [5] and TASCA, GSI, Darmstadt [6]. The results were conflicting. A critical comparison of the data, including results obtained for ^{245}Md at SHIP about 25 years ago [7], showed that the BGS data rather have to be attributed to ^{245}Md [8]. This feature will be discussed.

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MARGE – New Modular Robotic Gas-Jet Target System for the chemistry of SHE homologues studies

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Recently, the gas-jet transport system and target chamber developed at the University of Oslo was installed at the U-120M cyclotron beamline at the Nuclear Physics Institute (NPI) in Řež near Prague (Czech Republic). The front-end of the system is a target holder for thin metal foils from which reaction products recoil into a gas-filled chamber. The gas, seeded with KCl aerosol particles, stops the recoiling nuclides and transports them to a joint CTU-UiO-NPI laboratory that was built around the system[1]. The lab's main focus is on the chemistry of SHE homologues and on building an on-line versatile microfluidic aqueous chemistry apparatus. As a part of such developments, a new **M**odul**A**r **R**obotic **G**as-Jet Targ**E**t system (abbreviated as MARGE) was designed, constructed and successfully tested in April 2021.

The device has a modular design and consists of the following modules: carbon four-pole collimator, willemite beam monitor, and the target and gas-jet transfer chamber (GJT). The most innovative parts of MARGE are the robotic remote target-switching system (controlled by a software written in LabView) and the four-pole collimator that allows more precise beam focusing and on-line diagnostics. The remotely operated robotic two-axis arm fetches targets from a six-slot storage box. This brings significant advantage that targets can be switched without personnel having to enter the cyclotron vault, which greatly reduces personal radiation doses and wait time due to the necessary cool-down time. The inner geometry design of the gas-jet transfer chamber was based on computational fluid dynamics modeling to ensure even distribution of the gas flow across the target surface. In addition, the GJT target chamber module is designed as an individual building block. Such flexible and innovative design enables the module to be duplicated and stacked in series allowing simultaneous collection and transport of recoiling atoms from more than one target foil.

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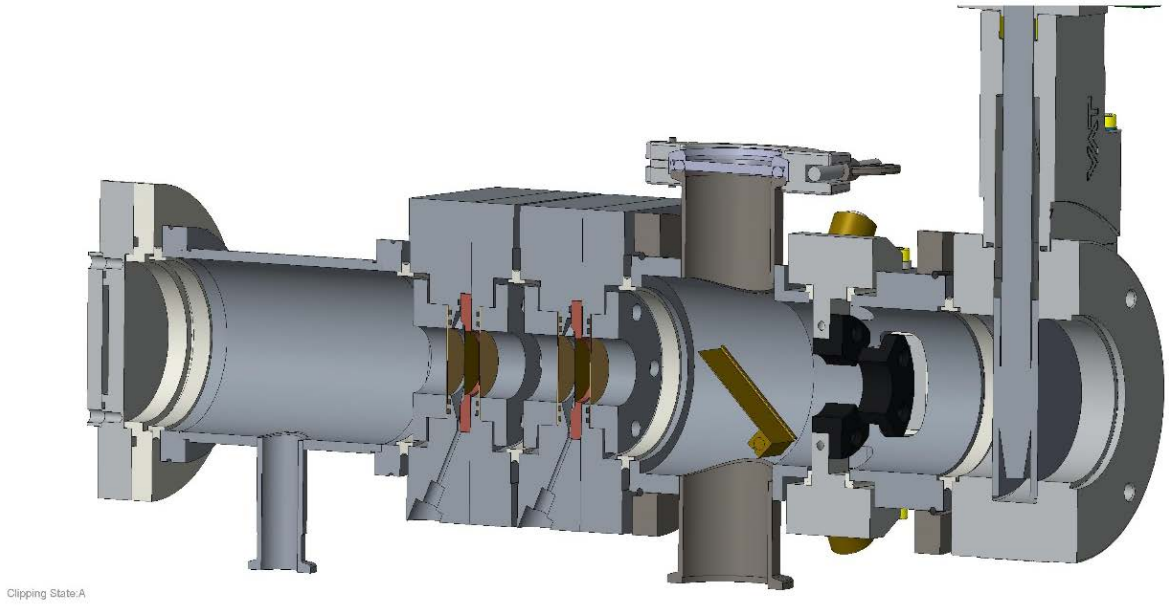

Reactions in the Gas-Phase and Adsorption Properties of Elements Cn and Heavier

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The heaviest elements whose properties have been characterized experimentally are Cn and Fl. Their volatility, as an adsorption enthalpy, on the surfaces of gold and quartz has been determined using gas-phase chromatography techniques [1-4]. The first attempt of chemical characterization of Nh has also been announced using a similar approach [5]. To render assistance to those experiments, formation energies of gaseous compounds of these SHEs and their homologs have been considered using modern relativistic quantum-chemical codes such as DIRAC and ADF. Moreover, interaction of those elements and their compounds with gold and quartz surfaces have been predicted using relativistic periodic codes such as ADF BAND [6,7]. In the presentation, analysis of those results with respect to the experimental outcome is discussed.

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Status and plans of chemical research with heaviest elements at PSI and FLNR

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In this contribution, we discuss the status of chemical research with heaviest elements at the Paul Scherrer Institute (PSI) in Switzerland and the Flerov Laboratory of Nuclear Reactions (FLNR), Russian Federation. Besides providing an overview over our current initiatives at PSI, we will present the status of preparation of the very first chemistry experiment at the Superheavy Element Factory of FLNR, targeting elements flerovium and copernicium in a 50-days-long campaign. The talk will conclude with our plans regarding future chemical investigations of superheavy elements, namely a reliable chemical characterization of nihonium as well as shorter-lived radioisotopes of elements beyond flerovium.

Direct coupling of liquid-phase chemical setups for heaviest element studies to a recoil separator

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Liquid-phase chemical studies of transactinide elements ($Z \geq 104$), often referred to as "superheavy elements" (SHE), could so far be performed only for the first three SHEs rutherfordium, dubnium and seaborgium [1]. Such chemical experiments with accelerator-produced fusion-evaporation residues (EVR) are multi-step processes involving

1) Thermalization of a EVR in a pressurized gas atmosphere
2) Transport of the EVR to a chemistry setup via a gas-jet, seeded with aerosol particles
3) Dissolution of the aerosol particle (with the attached SHE)
4) Chemical separation and sample preparation
5) Detection of the nuclear decay

with each step having its own time budget and yield losses.

In order to reduce the background from by-products of the fusion reaction as much as possible, chemical experiments with SHE have recently often been carried out behind physical preseparators. However, due to decreasing production rates with increasing atomic number Z and the yield losses of the individual steps, it has not been possible to investigate elements beyond seaborgium directly in the liquid phase until now.

We have developed a new system suitable for enabling fast liquid-phase chemistry experiments, which provides access to study shorter-lived SHE isotopes than what is accessible with current techniques. By connecting this new "*vacuum to liquid transfer chamber (VLTC)"* [2] behind a physical preseparator such as TASCA, the SHEs to be investigated are guided from the low-pressure side of the separator directly into the liquid phase of a chemical experiment. This eliminates the first three steps of the above listing. Feasibility of this VLTC concept was demonstrated in offline residence time experiments and by experiments with $^{250/252}$Cf fission fragments. In combination with established systems such as AIDA, ARCA II or SISAK new experiments characterizing the chemical properties of SHEs can be envisaged. This holds even more for recently developed technologies, e.g., chemically selective alpha detectors [3]. With VLTC new and more efficient ways for liquid phase chemistry experiments of the heaviest elements can be explored in the future.

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Off-line single-atom gas chromatographic adsorption studies of lead and bismuth

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Complementing the experiments with the superheavy elements Fl and Mc, off-line gas chromatographic studies with their lighter homologs Pb and Bi using ^{211}Pb ($t_{1/2}$ = 36.1 min) and ^{211}Bi ($t_{1/2}$ = 2.14 min) were carried out. These radioisotopes were available as decay products of a ^{227}Ac source, which emanated the short-lived volatile ^{219}Rn. This, along with its progenies were flushed through a gas-filled volume, which served for thermalizing Fl and Mc evaporation residues in the corresponding on-line experiments. The "miniCOMPACT" gas chromatograph comprising a column of 16 pairs of silicon-dioxide-coated PIN diode detectors forming a narrow channel was used. Single Pb and Bi atoms entering the miniCOMPACT undergo diffusion and adsorption/desorption steps, depending on their volatility and reactivity towards the detector surface material. Finally, the alpha decays of ^{211}Bi mark the final positions of these atoms in the column. By employing the spatial resolution along the column, internal chromatograms were obtained and were recorded as a function of experimental parameters like carrier gas type (He, Ar, SF_6, O_2), gas flow rate (1 - 3 L/min) and pressure (500 - 1000 mbar), thus characterizing the novel miniCOMPACT detector array and aiding to optimize the conditions for experiments with superheavy elements. The obtained chromatograms were compared to Monte-Carlo-Simulations to extract the interaction strength expressed in the form of the adsorption enthalpy. Pb and Bi showed the expected high reactivity towards the silicon dioxide surface of the miniCOMPACT; correspondingly, lower limits were extracted for the absolute values of the adsorption enthalpies. Furthermore, experiments with oxygen as a reactive gas were carried out. No measurable differences in the distribution were found. Due to the strong interaction, lower limits for these values were obtained.

Chemical studies of Nh (Z=113) and Mc (Z=115) at TASCA

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for the TASCA collaboration

Chemical studies of the odd-Z elements nihonium (Nh) and moscovium (Mc) are the hottest current topic in superheavy element (SHE) chemistry research. These elements are predicted to be more reactive compared to their neighbors Cn and Fl, which are stabilized due to relativistic closed-shell effects. The unpaired electron in Nh and Mc renders these more reactive, which leads to several challenges in gas-phase experiments. They are not as easy to transport to a chemistry and detection setup, where their adsorption properties on heterosurfaces are studied.

In the past years, Nh and Mc were in the focus of experiments at TASCA, which was used as a physical preseparator to ensure the unambiguous identification of rare decay chains. We report here on results of the two last SHE chemistry runs at TASCA, carried out in 2020 and 2021. These aimed at studying the adsorption of Nh and Mc on silicon oxide and gold surfaces. During two 3-week irradiations of ^{243}Am targets with a ^{48}Ca ion beam, several decay chains were detected that we attribute to originate from ^{288}Mc and ^{284}Nh. The experimental details and preliminary results of these experiments will be presented.

Functionalized surfaces and oxidation states of on-line produced thallium

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Chemical characterization of discovered and IUPAC recognized elements is one of the important tasks of superheavy element community. Nowadays, 118 known elements are named but not all of them have been chemically studied or limited number of experiments hasn't provided conclusive results. There are of course some technical limitations, for example in terms of very short half-lives ($T_{1/2} \leq 0.2$ s) for elements with $Z \geq 115$. However, elements 109 – 111 haven't been chemically studied at all and a few chemical experiments aimed at element 113 behavior still have unanswered questions. The goal of our group is to demonstrate proof-of-principle results that connect liquid phase off-line experiments with on-line gas phase chemistry. For example, usually gas phase chemical setups utilize gold coated detectors. Other coating materials also have been considered, but generally all of them lead to physisorption of desired analytes. Chemical modification or functionalization of surfaces (including a detector surface) is possible via silanization of silicon substrates [1] or self-assembled monolayer formation on gold [2]. In both cases the terminating group of a molecule attached to the surface determines the surface chemical selectivity. Imidazolium-based ionic liquids have been successfully implemented by our group for metal separation in off-line regime [3] and as a result a similar termination group has been considered for functionalization. Also, the same type of ionic liquids was used to study oxidation states of cyclotron-produced thallium and it was shown that such a chemical system is quite sensitive to reveal a non-monovalent thallium behavior [4]. Thallium in this particular case was chosen because it is the heaviest homolog of element 113 and it's believed that the cyclotron production results in the only monovalent state. Detailed results of these experiments will be discussed.

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The isotope program at ORNL for target for superheavy element research

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For more than 50 years, Oak Ridge National Laboratory's (ORNL) unique research facilities and staff have provided the research community with heavy actinides through fermium (^{257}Fm). These actinides have been used in the fabrication of targets for the discovery of nine superheavy elements, as identified in Table 1. The Radiochemical Engineering Development Center and the High Flux Isotope Reactor are truly one-of-a-kind facilities for the production and recovery of heavy actinides. All aspects of the reactor-produced heavy actinides will be addressed from fabrication of curium targets to the radiochemical separations and purification processing as depicted in Figure 1. Research activities for new production and separations techniques are being pursued at ORNL and will include novel irradiation schemes and radiochemical processing for berkelium and einsteinium production.

Table 1. Superheavy element discoveries enabled by ORNL-produced radioisotopes

Element	Year Produced	Target
104-Rutherfordium	1964	^{242}Pu, ^{249}Cf
105-Dubnium	1970	^{249}Bk, ^{249,250}Cf
106-Seaborgium	1974	^{249}Cf
113-Nihonium	2004	^{243}Am (decay from 115)
114-Flerovium	2000	^{244}Pu
115-Moscovium	2004	^{243}Am
116-Livermorium	2005	^{245,248}Cm
117-Tennessine	2010	^{249}Bk
118 - Oganesson	2006	^{249}Cf

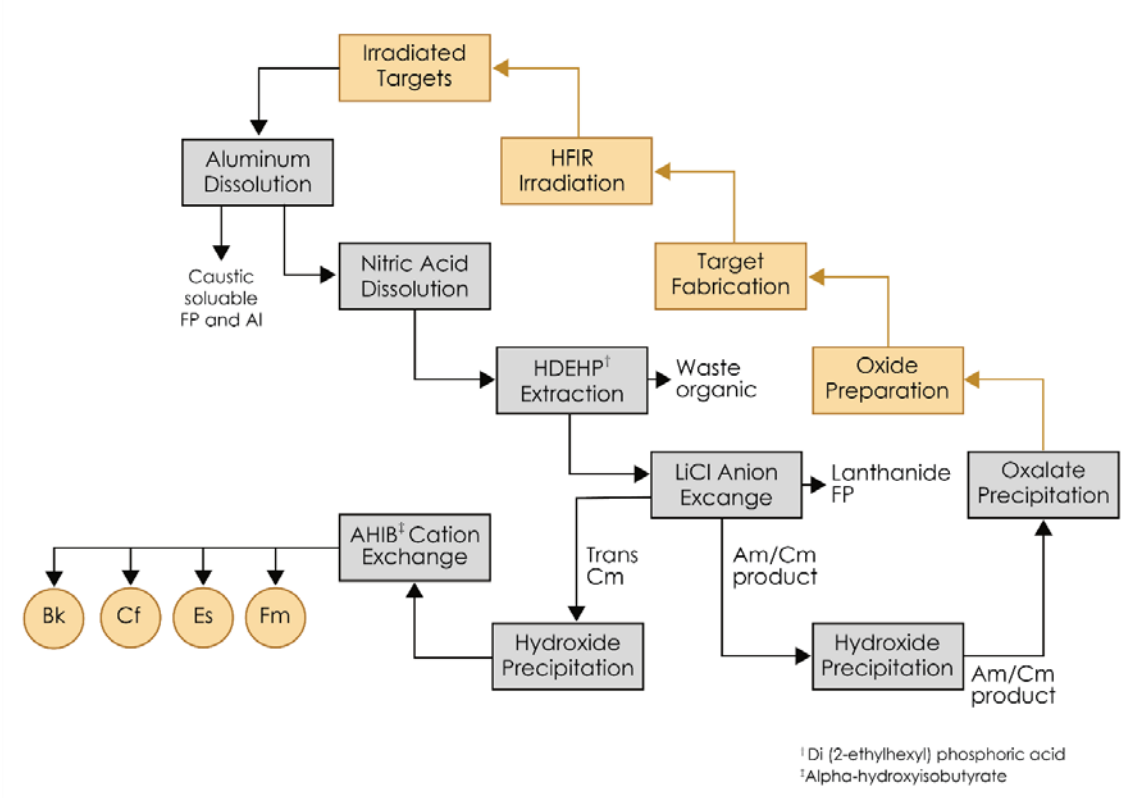

Figure 1. Radiochemical separations and purification of heavy actinides at ORNL.

Key aspects for the production of the ideal actinide target for the production of superheavy elements

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All isotopes of the elements with atomic numbers Z ≥ 114 as well as many of the longer-lived isotopes also of lighter superheavy elements (SHE) are only accessible in fusion reactions with actinide targets. Accordingly, the production of actinide targets is an important topic in the field of SHE research. Relevant aspects that affect the production of the "ideal target" include:

- Availability of sufficient amounts of the isotope of interest, ideally in highly-enriched form
- In the absence of capabilities to produce self-supporting targets: the choice of the backing material and thickness
- Efficient production methods for the target layer, applicable to rare isotopes
- Production of the target layer in adequate areal density and elemental purity
- Beam-resistance of the backing/target combination
- Possibility to recycle the actinide material

I will discuss the actinide target production at the Department of Chemistry in Mainz and highlight topics that should be addressed by the community on the way to the "ideal" target for next-generation heavy-ion accelerator facilities serving a SHE program.

Status of the cw-linac project

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GSI and the Helmholtz Institute Mainz have great expertise in the development of advanced superconducting linac accelerating cavities. Compared to normal conducting cavities, the advantage of such superconducting accelerator cavities is their high power efficiency, coupled with high field gradients, which allows the construction of more compact, energy-saving and thus more cost-effective accelerators. With the medium-term goal of designing the superconducting continuous wave (cw) linac **HELIAC** (**HE**lmholtz **LI**near **AC**celerator) based on this innovative technology for the low-energy program at UNILAC at GSI, so-called 217 MHz crossbar H-mode (CH) accelerating cavities were developed, prototyped and successfully tested. In the next future, these successful developments will be continued with the development, construction and testing of a complete linac accelerator module (cryomodule) for heavy ion energies of up to 4.5 MeV/u. The accelerator comprises three superconducting CH cavities, two solenoid lenses, and a superconducting rebuncher to fully focus the ion beam into short bunches. In order to cool and operate the superconducting components to the low temperatures of 4 degrees Kelvin required to reach the superconducting phase, they will be integrated into a specially designed cryostat. Results of the recent R&D-activities and a brief status of the entire HELIAC project will be presented.

Ion-Beam Induced Structural and Chemical Changes in Targets Used for Superheavy Element Production

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Superheavy elements are produced via heavy-ion fusion reactions, using high-energy ion beams. Target production, especially of actinides as they are used to generate the heaviest elements in hot fusion reactions, relies mainly on the Molecular Plating (MP) method [1,2], an electrochemical deposition from alcoholic solution. [2] The lanthanides and actinides are very electropositive elements, reacting with water to form hydrogen and metal hydroxides or oxides. Therefore, the pure metals cannot be deposited electrochemically from an aqueous solution. [1,2,7] Nonetheless, in MP [2], the lanthanides and actinides are added to the alcoholic solution (typically isobutanol and/or isopropanol) in aqueous inorganic acids. [1] Details of layers produced by MP are still under study. Long-term stability of MP pro-duced targets is typically achieved in a so-called “baking-in” procedure, in which the fresh target is exposed to suc-cessively increasing beam intensities. This leads to non-trivial structural and chemical transformations, which have hitherto mostly been described by studies using microscopic methods [2,3] like atomic force microscopy (AFM) and scanning electron microscopy (SEM).

MP targets of the same thickness of different lanthanides were prepared and characterised by Raman spectroscopy, which provided new insights into the systematics of the MP process. To improve our understanding of the baking-in processes, comparative tests were carried out using Coulomb barrier heavy-ion beams provided from the UNILAC accelerator at GSI Helmholtz Centre for Heavy Ion Research Darmstadt, Germany. Thulium MP targets, serving as analogues to targets of heavy actinides, were irradiated at the UNILAC with Au ions at 8.6 MeV/n, and fluences, ranging from 10^{10}- 10^{13} ions·cm^{-2} to systematically characterize their phase behaviour under these conditions. To prevent heating of the samples, the ion flux was kept below 2×10^{9} ions·cm^{-2}·s^{-1} for the Au beam [4]. This fluence series was analysed by SEM, and confocal Raman spectroscopy.

As a next step to support the Raman data Ion Beam Analysis [5,6] (IBA) was conducted at the Helmholtz-Zentrum Dresden-Rossendorf, Germany, to obtain depth-resolved changes in the thulium-oxygen-carbon-ratios in the MP thin films. At the workshop preliminary new insights into MP thin films and their behaviour under irradiation will be presented.

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High-precision mass spectrometry of ground states and low-lying isomers in heavy and superheavy nuclei with SHIPTRAP

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A comprehensive understanding of the heaviest elements requires detailed studies of the quantum mechanical nuclear shell effects which determine regions of enhanced shell stabilization and allow the very own existence of such heavy nuclides as bound systems. Investigations of the nuclear structure evolution for different proton to neutron ratios around the deformed neutron shell gap at N=152 are ongoing by applying Penning-Trap Mass Spectrometry (PTMS) with the SHIPTRAP setup. Such investigations at the upper limit of the nuclear chart will provide information for a better understanding of the nature of the underlying strong interaction and will help to constrain predictions attempting to pinpoint the position of the island of stability.

During the last experimental campaigns (2018, 2020 and 2021) the masses of ^{251}No and ^{254}Lr have been directly measured for the first time with the mass spectrometer SHIPTRAP at GSI. In addition, the excitation energies of the long-lived, low-lying isomeric states ^{251m}No and ^{254m,255m}Lr have been determined with high accuracy applying the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) technique. With its supreme mass resolving power, the PI-ICR technique is established as a complementary tool to decay spectroscopy in the region of the heaviest elements. Furthermore, the high sensitivity of the PI-ICR technique allowed a first direct mass measurement of the ground state and the 11/2- metastable state of ^{257}Rf at a rate of few detected ions per day. These results have been accomplished thanks to careful investigations and improvements of the efficiency of the SHIPTRAP setup: in an online run in February 2020, the rate of ^{257}Rf extracted from the cryogenic gas cell was increased by about an order of magnitude. Such efficiency boost opened the door to a fist investigation in May 2021 of the more exotic superheavy nuclide ^{258}Db (Z=105) available at even lower yields.

In this contribution an overview of the recent experimental campaigns will be given.