TASCA 25

April 23 - 24, 2025

21st Workshop on Recoil Separator for Superheavy Element Chemistry & Physics

Program & Abstracts

(22 April 2025)

Wednesday, April 23, 2025

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15:00	Reactivity of polonium towards quartz surfaces	Katharina Hermainski (JGU)	9
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	News from Recoil-Separator Laboratories (Part 3)	**Chair:** Christelle Stodel (GANIL)	
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16:10	Recent studies of heavy nuclei with Argonne Gas-Filled Analyzer	Amel Korichi (IJCLab, Orsay)	10
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Time corresponds to Central European Summer Time (CEST / UTC+02:00h)

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9:35	Fission modes in neutron-rich Fm region by 6-dimensional Langevin equation using Cassini ovals shape parametrization	Kazuki Okada (JAEA)*	13
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13:35	Single-atom thallium studies on quartz surfaces**	Felix Sprunk (JGU)	16
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	News from Recoil-Separator Laboratories (Part 4)	**Chair:** P. Steinegger (PSI/ETH Zürich)	
15:50	SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S3) at GANIL	Armand Bahini (GANIL)	20
16:15	Update on the AGGIE Gas-Filled Separator at Texas A&M University	Charles M. Folden III (Texas A&M Univ.)*	21
16:40	Functionalized Detectors for Superheavy Element Homolog Chemistry Experiments**	Amelia S. Kirkland (Texas A&M Uni)*	21
17:00	A New Era of Experimental SHE Chemistry at LBNL	Jennifer Pore (LBNL)*	22
17:25	**Closing remarks** Ch. E. Düllmann (JGU / GSI / HIM), A. Yakushev (GSI), J. Khuyagbaatar (GSI), J.Ballof (GSI)		
17:30	**End**		

* Contributions are expected to be presented via ZOOM

** The contributions marked this way comprise 15 minutes presentation + 5 minutes discussion time, the unmarked contributions 20 minutes + 5 minutes discussion time

Upper limit for the $^{248}Cm(^{50}Ti,xn)^{298-x}Og$ reaction cross section

B. JP Gall[1, 2], K. Morita[2, 3], K. Morimoto[2], D. Kaji[2], S. Ishizawa[2, 4], T. Niwase[2, 3], S. Yamaki[2, 5], H. Haba[2], Y. Komori[2], T. Yokokita[2], K. P. Rykaczewski[6], K. Kessaci[1, 2], Z. Asfari[1, 2], M. W. Bordeau[1, 2], T. Tanaka[1, 2, 3], P. Brionnet[2], H. Arakawa[5], M. Asai[2, 7], O. Dorvaux[1, 2], M. Filliger[1], T. Fujii[5], K. Fujita[2, 7], S. Goto[2, 8], E. Ideguchi[2, 9], K. Inomata[5], Y. Ito[2, 7], H. Kikunaga[2, 10], H. Kudo[2, 8], S. Mitsuoka[3], B. C. Rasco[6], H. Sakai[2], F. Tokanai[2, 4], A. Toyoshima[2, 7] and T. Yamaguchi[2, 5]

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After the synthesis of element 113, nihonium (Nh) via the $^{209}Bi(^{70}Zn, n)^{278}Nh$ cold fusion reaction [1-3] using the RIKEN heavy-ion Linear ACcelerator (RILAC) and the GAs-filled Recoil Ion Separator (GARIS), the search for the heaviest isotopes of oganesson was initiated with GARIS-II [4] by means of the $^{248}Cm(^{50}Ti, xn)^{298-x}Og$ fusion evaporation reaction. The optimal bombarding energy for the $^{248}Cm+ {}^{50}Ti$ reaction was determined from the quasielastic barrier distribution extracted from the excitation function of quasielastic backscattering [5]. This method optimizes the compound nucleus formation.
The search for Og was conducted for 39 days on the basis of the experimentally derived ^{50}Ti beam energy of 227.9 MeV at the middle of ^{248}Cm target. A precise analysis of the dataset based on multiple event search strategies revealed no decay chains with a total dose on ^{248}Cm target of 4.93×10^{18} ^{50}Ti projectiles, reaching a sensitivity of 0.27 pb and a 84% upper cross section limit of 0.50 pb.
After a presentation of the experimental setup and the details of the experiment, the upper limit derived for the Og production cross section determined will be discussed and compared to the latest theoretical predictions [6-8]. The presentation will finish by a discussion of high intensity ^{50}Ti beam production and the possible role of this isotopic beam in synthesis of next superheavy elements.

References

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Measurement of ground-state and isomeric-state ratio in nuclei produced in multinucleon transfer reactions using JAEA Recoil Mass Separator

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Multinucleon transfer (MNT) reaction is attracting interest in the field of astrophysics and superheavy-element research as the reaction can produce neutron-rich actinide and superheavy nuclei. In contrast to fusion evaporation residue, however, reaction mechanism such as excitation energy and spin distributions of the primary excited compound nucleus is not understood, which will significantly impact the cross sections of produced evaporation residues (ERs), as it will determine survival probability to produce ERs in competition to fission. We have started to measure cross sections of evaporation residues (ERs) produced in MNT reactions using the recoil mass separator, JAEA-RMS[1]. Taking advantage of a feature that JAEA-RMS can easily rotate (0~40 degrees) around the target chamber, we can separate ERs at finite recoil angles. We established the on-line alpha-decay measurement at the focal plane Si detector to identify produced nuclides, and their cross sections were measured as a function of recoil angle. This result is the first to realize the on-line decay measurement ERs produced by the MNT reactions at a finite angle. The transported ERs changed largely with respect to electro- and magnetic-rigidity given to RMS. In the studied reaction $^{30}Si+^{209}Bi$, we observed remarkable differences in the cross sections between high-spins isomeric state and low-spin ground state ($^{212}At^{iso}(9^-)/^{212}At^{g.s.}(1^-)$, $^{214}Fr^{iso}(8^-)/^{214}Fr^{g.s.}(1^-)$, $(^{212}At^{iso}(9^-)/^{212}At^{g.s.}(1^-)$, $^{214}Fr^{iso}(8^-)/^{214}Fr^{g.s.}(1^-)$, $^{211}Po^{iso}(25/2^+)/^{211}Po^{g.s.}(9/2^+)$), which have a memory of spin distribution of compound nucleus.

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The result of $^{48}Ca + ^{243}Am$ reaction on SHANS2

Zaiguo Gan[1,2,3], Zhiyuan Zhang[1,3], Minghui Huang[1,2,3], Chunli Yang[1], Jianguo Wang[1,2], Long Ma[1,2], Huabin Yang[1], Xiaolei Wu[1,2], Mingming Zhang[1], Yulin Tian[1,2], Yongsheng Wang[1], Junyin Wang[1]

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Using the ^{48}Ca beam provided by the CAFE2 at IMP, the experiment of $^{48}Ca+^{243}Am$ was performed at SHANS2. The α-decay chains of the ^{288}Mc and ^{287}Mc were successfully observed in the experiment, and for the first time measured the last two chain members ^{268}Db and ^{264}Lr, during the beam-stopped period. Systematic measurements were performed on the production cross-section of ^{288}Mc. Notably, the magnetic rigidity parameters used in the experiment differed from values reported in literature. This parameter is crucial for superheavy element synthesis and required special attention during the experiment.

References

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First results of SHE Factory with beams of ^{54}Cr and ^{50}Ti

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The ^{238}U(^{54}Cr,4*n*)^{288}Lv and ^{242}Pu(^{50}Ti,3-4*n*)^{288,289}Lv reactions have been studied at the gas-filled separator DGFRS-2 at the SHE Factory at Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research. Three new isotopes were discovered: two α-decaying nuclei ^{288}Lv, ^{289}Lv and granddaughter of ^{288}Lv, spontaneously fissioning ^{280}Cn, which was observed after the first registration of α decay of ^{284}Fl. Besides, for the first time we reliably registered the *pxn* channel of the ^{242}Pu + ^{50}Ti reaction which was not evidently observed in the ^{48}Ca-induced reactions in previous studies. The cross sections of the 3*n* and 4*n* channels of the ^{242}Pu + ^{50}Ti reaction were measured at excitation energy of the ^{292}Lv compound nucleus E^* = 41 MeV. The cross section of the 4*n*-evaporation channel of the ^{238}U + ^{54}Cr reaction, leading to the same compound nucleus, at E^* = 42 MeV turned out to be approximately 15 times lower than the total cross section of the ^{242}Pu + ^{50}Ti reaction at close excitation energy. Thus, for the first time it was convincingly proved in experiment that the reactions of isotopes of actinide elements with ^{50}Ti are an order of magnitude preferable to reactions with ^{54}Cr for the synthesis of new elements 119 and 120.

Studies on Heavy Nuclei ^{261,262}Bh and ^{247}Md at SHANS2

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The gas-filled recoil separator, SHANS2, a state-of-the-art instrument at the China Accelerator Facility for Superheavy Elements (CAFE2), has been successfully commissioned for studies of heavy and superheavy nuclei since its full operational deployment in early 2022. During its initial commissioning phase, SHANS2 demonstrated breakthrough capabilities with high transmission efficiency and background suppression through a series of test reactions. The system facilitated the synthesis and unambiguous identification of a few new neutron-deficient isotopes, such as ^{203,204}Ac.

In this contribution, we will present the recent status and the performance of SHANS2. Through the reactions ^{54}Cr+^{209}Bi and ^{40}Ar+^{209}Bi, the heavy nuclei ^{261,262}Bh and ^{247}Md were unambiguously observed at the focal-plane detectors of SHANS2. Their decay properties are re-investigated using the α-γ spectroscopy, which demonstrates an excellent capability of SHANS2 for the study of superheavy nuclei.

References

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The past, present, and future of multinucleon transfer research using in-flight separator RITU

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In multinucleon transfer (MNT) reactions two nuclei undergo an exchange of protons and neutrons, without forming a compound nucleus characteristic of fusion reactions. There has been significant interest recently regarding the use of multinucleon transfer reactions for the production of exotic heavy and super-heavy nuclei. Theoretical studies have highlighted the importance of shell effects in the formation of exotic heavy nuclei [1,2], and experiments have been performed at GSI [3], LNL [4], and HIAF [5].
Several experiments have been performed at the Accelerator Laboratory at the University of Jyväskylä to investigate whether the structure of exotic neutron-rich isotopes can be probed with MNT reactions, and whether the reaction mechanism can be studied. Target-like recoiling nuclei produced in MNT reactions are transported by in-flight separator RITU to a double-sided silicon strip detector (DSSD) at the focal plane. JUROGAM, an array of germanium detectors, is located around the target position to detect prompt γ rays. In the past an experiment was performed which showed promising results regarding the identification of MNT-products of both target-like and beam-like nuclides; in the reaction ^{65}Cu on ^{209}Bi thirty-one isotopes were identified, suggesting up to twelve nucleons have been transferred. Recently, a CD detector was added upstream of the target to enhance the quality of the measurements for the beam-like nuclides. Using a beam of ^{76}Ge on a variety of targets around the doubly magic ^{208}Pb the MNT production mechanism and structure of beam-like products are being investigated. Plans for future experiments are being developed, including further improvements to the experimental setup. A historical overview of MNT research performed in the Jyväskylä accelerator laboratory, its results, and the future plans will be presented.

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Status and Prospect of the SHE Chemistry at IMP

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Due to the extremely low production yield and short half-lives, experiments to explore the chemical properties of SHEs (superheavy elements, Z > 103) always rely on state-of-the-art equipment. IMP (Institute of Modern Physics, Chinese Academy of Sciences) has successfully commissioned the China Accelerator Facility for Superheavy elements (CAFE2) and the gas-filled recoil separator SHANS2 [1], which offer us the opportunity to perform experiments on the chemistry of SHEs in China.
Recently, a thermochromatography detection system named LEGEND (on-Line Experiment in Gas-phasE for Nihonium Detector) has been developed in IMP for the chemical study of SHEs [2]. On-line test experiments with short-lived Fr and Tl isotopes have been performed. Rotating ^{243}Am targets with a diameter of 20 cm were successfully prepared. First exploration with a ^{48}Ca beam and ^{243}Am targets at CAFE2 and SHANS2 was performed using the LEGEND with high performance 4H-SiC detectors [3], and one ^{288}Mc (Z=115) event was observed at the high temperature zone (65℃) on a Si_3N_4 surface. ^{266}Bh (Z=107) is also available in the ^{243}Am(^{26}Mg,3n) reaction at CAFE2 and SHANS2. Based on the above achievements, experimental study on the chemistry of Nh (Z=113) and Mc, as well as the Bh carbonyls will be carried out at IMP in the near future.

References

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Fission and K-isomer studies @TASCA

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Superheavy nuclei (SHN) with enormous amounts of nucleons (e.g., protons up to Z = 126) are still one of the main subjects in nuclear physics [1]. The main purpose of this research is to examine the ground-state fission stability of SHN at around Z = 114 − 126 and N = 184, where occurrences of next closed shells are theoretically expected [1]. The fission half-lives of these SHN have been predicted to be much longer than those of neighboring ones.
To date, SHN with Z up to 118 (Og, Oganneson) and with neutron numbers up to N = 177 are known [2,3]. The experimental data, e.g., partial spontaneous fission half-lives of the known SHN, confirm the concept of the island of stability. However, fission properties (fission-barrier height and shape, fragment mass distribution, etc.), which are necessary for constructing a more complete picture of the fission landscape of SHN, are still poorly studied. This situation stems mostly from a lack of comprehensive experimental data on fission.
In recent years, the fission stability of the high-K state in SHN became one of the main topics in the field [4,5]. Experimental data on such K-isomeric states show that the ground and high-K states' fission stability is inverted.
I will discuss the above-mentioned topics and present the related recent experimental findings at the gas-filled recoil separator TASCA, GSI (e.g., [6]).

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Status and plans of the Heavy Elements group at PSI / ETHZ

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Following the successful experiments with Cn and Fl, the gas-phase chemical characterization of late transactinide elements (or Superheavy Elements, SHEs) using dedicated thermochromatography detectors has become more challenging. These challenges are largely associated with the identification of suitable chemical systems, which provide access to well-defined chemical species of these exotic elements under carefully controlled experimental conditions. Furthermore, the half-lives of all isotopes of elements beyond Fl demands for the development of new experimental approaches.
The Heavy Elements group at PSI and ETH Zürich is dedicated to addressing these challenges, while also starting to look at chemically less characterized SHEs. Our group is currently conducting research on (1) high-temperature α-spectroscopy detectors to be implemented in our Cryo-OnLine Detector (COLD) combined with offline/online homolog experiments of Tl toward studying the gas-adsorption behavior of Nh, (2) advancing our Isothermal Vacuum Chromatography (IVAC) approach with the help of a buffer gas cell (i.e., chemistry experiments with millisecond-short-lived radionuclides), and (3) the initiation of new liquid-phase chemistry experiments with SHEs.
In this presentation, we will provide a comprehensive overview of the status of our research and our strategy for the years to come. It is the declared objective of our group to conduct these challenging experiments not by ourselves, but in the framework of international collaborations.

Towards the carbonyl chemistry of Bh – studies of carbonyl complexes with ^{259}Sg

Alexander Yakushev[1] for the TASCA collaboration[2]

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[2]*https://superheavies.uni-mainz.de/tasca/*

Studies on seaborgium carbonyl complex formation and its reactivity, volatility, and the chemical stability were performed at TASCA in 2024. These studies build up on our work, when a JGU Mainz – GSI-led collaboration established a new class of superheavy element (SHE) compounds by the first synthesis of the Sg carbonyl complex in experiments performed at RIKEN [1].
This experiment was conducted with ^{265}Sg ($T_{1/2} \approx 10$ s) produced in the hot fusion reaction ^{248}Cm(^{22}Ne,5n)^{265}Sg. This work represented a milestone in chemical studies of SHEs and triggered investigations towards the synthesis of carbonyl complexes of the heavier SHEs Bh, Hs, and Mt, see e.g. [2].
Chemical studies of the SHE with atomic number Z = 113 – 115 have been successfully performed at the separator TASCA [3,4]. The detection systems developed for these studies open the perspective for such studies also with shorter-lived SHE isotopes, which can be produced in cold fusion reactions with higher cross sections, e.g. ^{208}Pb(^{54}Cr,1n)^{261}Sg, ^{208}Pb(^{52}Cr,1n)^{259}Sg or ^{208}Pb(^{55}Mn,1n)^{262}Bh.
In a first step, performed in 2024, the key properties of $Sg(CO)_6$, including kinetic aspects of the carbonyl complex formation, were successfully studied. The isotope ^{259}Sg ($T_{1/2} = 0.3$ s) was produced via the nuclear reaction ^{208}Pb(^{52}Cr,1n)^{259}Sg and preseparated with TASCA. The ^{259}Sg recoils were thermalized in a gas mixture of helium and carbon monoxide (CO). More than 80 decay chains originating from ^{259}Sg were registered in the combined detection setup within 14 days of beamtime. The Sg hexacarbonyl complex is formed in the reaction of Sg ions/atoms with CO ligands via a multi-step process. The intermediate reaction products $Sg(CO)_x$ (x = 0 – 5) are more reactive and non-volatile, and thus, were detected in the first miniCOMPACT detector.
The final product $Sg(CO)_6$ showed a low interaction strength with a detector surface and adsorbed by physisorption at a low temperature in the second COMPACT detector.
The chemical yield of $Sg(CO)_6$ was found to be similar to that found in the first Sg carbonyl study [1], despite a much shorter half-life of ^{259}Sg compared to ^{265}Sg. Thus, the rather low chemical yield of $^{265}Sg(CO)_6$ observed in [1] was not caused by slow kinetics.
This study opens the perspective for the first study of carbonyl complexes of Bh, which are unknown yet.

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Reactivity of polonium towards quartz surfaces

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The study of superheavy elements contributes to a better understanding of the influence of relativistic effects on chemical properties. To prepare studies of livermorium (element 116) which is so far chemically uncharacterized, we have investigated the volatility of single-atom quantities of polonium by applying gas-solid thermochromatography. ^{204}Po was produced by irradiating ^{206}Pb targets with a ^{3}He beam. Experiments were performed in helium and oxygen atmospheres, and on quartz surfaces with different degrees of hydroxylation. On quartz glass with low OH-concentrations in helium, the most volatile species was found and assigned to elemental polonium. On a more highly hydroxylated quartz glass, an additional deposition zone of a less volatile species was observed and attributed to a polonium species formed by chemical reaction with the surface. Experiments in oxygen atmosphere revealed a complex interaction between PoO_2 formed in the gas phase and the quartz surface. During this interaction, PoO_2 probably decomposes to PoO and elemental polonium. The experiments indicate that chemical reactions of the analyzed species with the solid phase are just as important to consider as gas phase reactions.

Exploring the isotopic border of seaborgium @TASCA

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The fission of heavy atomic nuclei is the main constraint on the existence of chemical elements with large atomic numbers. Nuclei with $Z > 103$ are stabilized against fission due to effects resulting from the nuclear shell structure and can thus exist for a time longer than 10^{-14} s. This is the time needed for an atomic shell to be established [1]. The so-called isotopic borders for particular superheavy elements can be studied in the neutron-deficient nuclei [2,3]. However, the present experimental technique (i.e., in-flight separation) is limited to study nuclei with half-lives of about 10^{-6} s.

Another approach suitable for studying sub-µs nuclei is via long-lived *K*-isomeric states [4,5]. Recently, at TASCA, the 60-ns isotope ^{252}Rf was discovered via its *K*-isomeric state, which has a halflife long enough to survive the flight through the separator [3]. This result shows that the isotopic border of Rf isotopes is yet to be reached.

The next step is to explore the isotopic border of Sg isotopes. Recently, at TASCA, we studied the neutron-deficient isotopes $^{257-259}$Sg, aiming to investigate their fission properties and to probe the location of the isotopic border.

In the talk, results from the experiment will be discused in detail.

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Recent studies of heavy nuclei with Argonne Gas-Filled Analyzer

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Studies of heavy nuclei with Argonne Gas-Filled Analyzer (AGFA) have continued over past two years. In the fall of 2023, a series of in-beam experiments with Gammasphere were conducted, followed by a campaign of decay experiments with AGFA in stand-alone in the spring of 2024. The emphasis was on the structure of trans-fermium nuclei near the deformed magic numbers Z=100 and N=152.

Among the results, a ground-state rotational band was observed for the first time in one of most the fissile nuclei known, ^{250}No (see Figure). The extracted moment of inertia for ^{250}No is smaller compared to neighboring trans-fermium nuclei, likely due to increasing pairing correlations with the departure from the Z=100 and N=152 deformed closed shells. In another experiment, prompt γ-ray transitions and the decay of the 3-quasiparticle K-isomer in ^{249}Md were successfully studied.

Additionally, results from previous AGFA campaigns were recently published. The high-statistics study of K-isomers in ^{254}No aimed at resolving long-standing ambiguities in spin-parity and configuration assignments for the 2- and 4-quasiparticle intrinsic excitations identified in this nucleus, resulted in the observation a newly measured half-life in the nanosecond range, establishing a second 2-quasiparticle isomer in ^{254}No. Furthermore, a detailed decay scheme of the K-isomer in ^{251}Md was just submitted for publication [2]. From its decay pattern, the isomer's spin-parity is suggested to be $23/2^+$, formed from the 3-quasiparticle configuration $\pi 7/2[514]\otimes\nu 2(7/2[624]\otimes 9/2[734])K^{\pi}=8^-$.

In the talk, first results from recent experimental campaigns and recently published results will be discussed.

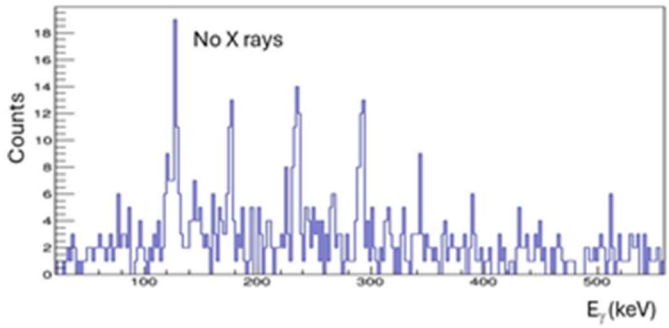

Fig. The ground-state rotational band in ^{250}No observed in using Gammasphere coupled to AGFA.

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Laser spectroscopy of fermium isotopes across the N=152 shell gap

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Obtaining a comprehensive picture of nuclear phenomena in heavy nuclei requires precise measure-ments of nuclear ground-state properties, e.g., spins, electromagnetic moments, and charge radii. These provide important data on the shell structure and serve as benchmarks for theory. These properties can be extracted from laser spectroscopy data with high precision. However, due to the low sample availabilities and production rates of heavy actinides, not only nuclear data is sparse but also information on the atomic level structure mostly relies on theory predictions, so that laser spectroscopy experiments need to start with a search for spectral lines.

In fermium, which is the heaviest element that can be produced in nuclear reactors, an off-line atomic level search was enabled with a Fm-255 sample provided from ORNL in the early 2000s [Sewtz et al, PRL 90, 163002 (2003)]. This work laid the foundation of our recent measurement campaigns, targeting Fm-255,257 in off-line laser spectroscopy in Mainz, and Fm-245,246,248-250,254 on-line at SHIP using the radiation detected resonance ionization spectroscopy (RADRIS) technique, involving various direct and indirect production schemes. The extracted isotope shifts in an atomic ground-state transitions allowed the determination of changes in mean-square charge radii across the N=152 shell gap and were recently published [Warbinek et al, Nature 634, 1075 (2024)]. In addition, the off-line data, together with input from atomic theory, allows the extraction of nuclear electromagnetic moments in Fm-255 and the determination of the ionization energy of Fm from Rydberg convergences.

FRIB Decay Station - a quest for complete spectroscopy of nuclear decays

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The FRIB Decay Station was designed and built to take advantage of the opportunities to study the exotic isotopes available at FRIB. The FDS Initiator (FDSi) is the first phase of this development. It is a community effort to realize the concept of complete spectroscopy in the initial phase of FRIB operations [1]. FDSi is designed to achieve simultaneous measurements of radiations emitted in nuclear decays. This is achieved by a combination of charged particles, gamma rays, and neutron detectors assembled in tandem arrays capable of accepting the same beam of fragments. A series of FDSi experiments performed in 2022-2025 resulted in measurements for isotopes with $Z<47$ [2, 3, 4, 5]. The experiments demonstrated the validity of the FDS original concept.

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Investigation of non-fusion reaction products in the $^{51}V + ^{248}Cm \rightarrow ^{299}119^*$ fusion-evaporation reaction

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The ongoing search for element $Z = 119$ is conducted at the RIKEN Nishina Center using the $^{51}V + ^{248}Cm \rightarrow ^{299}119^*$ fusion-evaporation reaction at the SRILAC/GARIS-III facility [1,2]. During this search, many parasitic reaction products were also transported into GARIS-III's decay station. These products generate a wide range of decay times and energies, some of which overlap with the expected region of interest for the $Z = 119$ decay chain.

These reaction products predominantly arise from quasi-fission and fusion-fission processes during the fusion-evaporation reaction. They exhibit an isotropic distribution northeast of ^{208}Pb, with an average mass $A = 219-220$. Those events were identified using both electronic systems currently implemented in the GARIS-III setup: the Mesytec-based Analog DAQ and the Pixie-16 digital electronics [3]. This study presents the methodologies and efficiencies of these data acquisition systems in identifying fast-decay events. In addition, thanks to the waveform analysis performed on the digital data [3], a strong reduction of the signal in the region of interest for the search of new element $Z = 119$ was observed.

The measured isotropic distribution has similar characteristics to previous studies of hot fusion reaction with actinide targets [4]. However, thanks to the addition of the fast and efficient digital, direct identification of isotopes at $N = 128$ was made possible. Additionally, the implantation profiles measured in this study show significantly different characteristics than the previous studies [4], both in terms of the energy spectrum and profile/transportation.

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Fission modes in neutron-rich Fm region by 6-dimensional Langevin equation using Cassini ovals shape parametrization

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The dynamical approach to nuclear fission using multi-dimensional Langevin equations has been widely employed in calculations of the fission process. This approach provides physical quantities that can be directly compared with experimental data, such as fission fragment mass and total kinetic energy distributions. In spontaneous fission within the actinide region, it is known that the shape of the fission fragment mass distribution changes dramatically with mass number [1]. For Fm, double-humped distributions indicating asymmetric fission dominance are observed at $A \leq 257$, while a single-humped distribution appears at $A = 258$. To understand this phenomenon, dynamical calculations using the high-dimensional Langevin equation play an important role.
In this research, the fission modes of neutron-rich Fm isotopes are investigated by solving the six-dimensional Langevin equation employing six deformation parameters α, α_1, α_2, α_3, α_4 and α_5 in the Cassini shape parameterization [2], which can flexibly describe various shapes of fissioning nuclei.

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Evaluation of synthesis of new superheavy elements and the possibility of reaching the Island of Stability from neutron-rich regions in nuclear chart

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At present, the research into the synthesis of superheavy elements is being pursued under two main goals. One goal is to synthesize elements with larger atomic numbers, and the other is to reach Island of Stability predicted as the next double magic nucleus. The periodic table is currently marked up to element 118, Oganesson (Og) [1], and experiments are being conducted with the aim of synthesizing element 119 as the next new element. Recently, a successful synthesis experiment ($^{54}Cr + {}^{238}U \rightarrow {}^{292-x}Lv$) has been carried out using a Cr beam [2]. On the other hand, the method of reaching Island of Stability is still under discussion based on theoretical calculations and the search for specific methods. Recently, a method based on multi-nucleon transfer reactions has been proposed and discussed. In this study, a method using secondary beams due to unstable nuclei is proposed as a method to reach Island of Stability and its potential is shown based on theoretical calculations. The dynamical and statistical models are used to calculate the production of compound nuclei in the neutron-rich region, their decay processes and to evaluate the evaporation residue cross-sections. To produce neutron-rich compound nuclei, as well as future experimental plans, including the advantage of survival probabilities, are discussed [3]. The possibility of synthesizing new elemental syntheses, exploiting "the dynamic effects of the shell structure", will be discussed.

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GASSOL: A new solenoidal pre-separator for studies of chemical properties of superheavy elements

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A new gas-filled separator based on a superconducting solenoid is under construction in FLNR. The main purpose of the setup is to increase the efficiency and event count in gas-phase SHE chemistry experiments. The simulation results of the SHE's image size on the focal plane of GASSOL will be discussed and the benefit of using solenoidal magnet will be demonstrated. Current status of the magnet production, expected technical and experimental challenges and preliminary plan of test experiments will be presented and discussed.

The status of development of the S^3 Super-Separator-Spectrometer and the commissioning of its target station

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GANIL facility was upgraded with a superconducting linear accelerator, which delivers highly intense stable beams ranging from protons to uranium ions. Light ions are used at the Neutron for Science (NFS) experimental hall [1] and heavier ions are essential to produce exotic nuclei, like heavy neutron-deficient isotopes and super heavy nuclei, in the Super Separator Spectrometer (S^3) [2, 3].

By combining the intense heavy ion beams with the fully instrumented target station, the various electromagnetic components, the fixed and movable beam dumps, S^3 is a powerful tool to purify the elements of interest produced in the target from the primary intense ion beam, and retrieving them up to the focal plane with a high transmission. The detection set-ups, SIRIUS implantation-decay spectroscopy station [4] or S^3-LEB (Low Energy Branch) are unique to study in detail the rare nuclei produced by fusion-evaporation and to provide very pure exotic beams for low energy experiments [5].

After introducing the S^3 spectrometer with its scientific programs and technical achievements, we will detail the first commissioning of S^3 conducted in November 2024. In addition, we propose to report on current targets' development at GANIL and to present advancements on rotating targets' stations including their instrumentation to control the integrity of targets.

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Commissioning with beam of Advanced Demonstrator, the first cryogenic module of HELIAC

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The superconducting heavy ion HELmholtz LInear Accelerator (HELIAC) is designed to meet the needs of the Super Heavy Element (SHE) research and material science user programs at GSI in Darmstadt. The beam energy can be varied smoothly between 3.5and 7.3 MeV/u, with an average current of up to 1 mA and a duty cycle of 100 %. Recently the first cryomodule CM1 was commissioned with beam. CM1 comprises three Crossbar H-mode (CH)-type accelerating cavities, a CH-rebuncher, and two superconducting solenoid lenses. Following the commissioning of the cryogenic supply- and RF-systems, a beam test was conducted at the end of 2023. A Helium ion beam was accelerated to the design energy of 2.7 MeV/u. The beam energy could be varied continuously between 1.3 MeV/u and 3.1 MeV/u. In June 2024 a Argon ion beam was accelerated to the design energy of 2.7 MeV/u.

Towards Element 116 (Lv) Chemistry Experiments: The Status of the new Universal High-Density Gas Stopping Cell (UniCell)

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Experimental investigations targeting chemical properties of superheavy elements (SHE) have reached element 115 (Mc) [1]. Chemistry experiments of the most heavy elements are carried out by thermalizing their energetic recoils obtained in fusion-evaporation reactions within a gas-filled volume and transporting these solely by gas-flow to a detection setup. The transport process typically requires at least several hundred milliseconds. The even heavier elements 116 (Lv) to 118 (Og) were synthesized and production cross sections were reported. However, only isotopes with half-lives shorter than 100 ms are known to date. To extend chemical studies to these elements, a stopping cell with superimposed electrical fields to significantly reduce the transport time and retain high efficiency is required. First exploratory experiments with a stopping cell coupled to a chemistry-detection setup have been successfully conducted and demonstrated the feasibility of the approach [2,3]. In recent stopping cells, the extraction efficiency is typically in the order of 30 – 75% and the extraction time in the order of tens of ms [4]. To enable studies of the next-heavier chemically unexplored element 116 (Lv), high efficiency for fast-extraction times is highly desirable. Following a concept by Varentsov and Yakushev, the atmospheric-pressure stopping cell UniCell, exploiting a ceramic ion funnel, has been designed and is currently under construction. In this contribution, we report on results of simulations studying the stopping cell in detail and present the status of its construction and its future prospects.

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Theoretical studies of adsorption properties of group 15, 16 and 17 elements, Bi/Mc, Po/Lv and At/Ts, on surfaces of gold and quartz

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Results of recent calculations of adsorption properties of the group 15, 16 and 17 superheavy elements Mc, Lv and Ts, and their lighter homologs Bi, Po and At, respectively, on surfaces of gold and quartz are presented (with those for At/Ts published in [1]). The calculations were performed using a relativistic periodic DFT approach implemented in the AMS BAND software [2]. The aim of the work was to interpret the outcome of gas-phase chromatography experiments on the lighter homologs of the SHEs [3-7] and provide adsorption energies and other data for future experiments on adsorption of Mc, Lv and Ts on these surfaces.

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Single-atom thallium studies on quartz surfaces

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To gain a better understanding of the chemistry of the superheavy element nihonium, several single-atom experiments with its lighter homolog thallium were performed in the past [1-3]. Because these studies provided partly contradictory results for the obtained species and their adsorption enthalpies, we have carried out additional thermochromatography experiments. ^{195}Tl and ^{196}Tl were produced by irradiation of a gold foil at the cyclotron of ÚJV in Řež. The experiments were conducted offline, and the deposited species were analyzed using gamma spectroscopy. Measurements were performed with oxygen, helium and moist mobile phases on quartz glass columns.
Thallium was found to be highly reactive, reacting with trace amounts of water or oxygen impurities in the mobile phase and on the surface. We observed the deposition of a species with an adsorption enthalpy of -123^{+4}_{-3} kJ/mol. In line with the literature, we assign it to TlOH [3]. Additionally, we observed a low-volatile species showing a broad deposition pattern, characteristic of a transport reaction. Experiments in moist helium revealed the influence of water on the column surface. Our experiments suggest that surface properties are of high importance for the behavior of the species during transport. The adsorption enthalpy of metallic thallium could not be extracted from our studies because of its high reactivity even under the most inert conditions that were achieved in our studies.

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Liquid-Phase Chemistry of SHE Homologues at the CTU in Prague

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Since 2016, research oriented towards aqueous phase chemistry of the homologues of the superheavy elements (SHEs) has been carried in the Czech Republic as a part of joint experimental effort of the Czech Technical University in Prague (CTU), the University of Oslo (UiO), and the Nuclear Physics Institute of the Czech Academy of Sciences (NPI CAS). This cooperation rendered possible establishing a laboratory dedicated to the chemistry of homologues of SHEs directly in the building that houses the isochronous cyclotron U-120M operated by the NPI CAS in Rez near Prague, which can provide a ^{3}He beam of energies up to 50 MeV and intensities of up to 500 nA.

The cooperation focuses on three main subareas: a) finding and testing suitable liquid-liquid extraction systems for fast and efficient extraction of various elements belonging to the same chemical group, thus far groups 5, 6, 7, and 13 have been targeted, b) building an on-line aqueous chemistry apparatus covering all the route starting from the production and collection of nuclear reaction products (NRPs) to the phase separation process following the liquid-liquid extraction, c) and the detection process in the respective phases after the phase separation process.

A substantial progress has been made in the subject of building the on-line aqueous chemistry apparatus. A modular target system was commissioned in 2021 [1] that provides robotic target exchange and the possibility of stacking multiple recoil-transfer chambers (RTCs) in series so that independent gas-jet transport (GJT) systems can be operated simultaneously. This feature was already put into operation – there are currently two independent branches running two independent RTCs and GJTs, specifically an aerosol RTC-GJT system supplying aqueous phase experiments run mainly by the CTU and UiO groups and a non-aerosol RTC-GJT system hosting gas phase experiments (run by the GSI group).

The aqueous chemistry branch is also currently equipped with a subsystem for continuous dissolution of the aerosol particulates [2]. Further, a microfluidic extraction system is utilized, and it proves very promising for the extraction part of the on-line aqueous chemistry apparatus. For this application, several liquid-liquid extraction systems are investigated at the CTU, including, but not limited to, the extraction of group 6 elements by various extraction agents. Additionally, the extraction of group 13 elements was also studied in the past [3] and revealed an instability in oxidation states of Tl aqueous species that has been further investigated. The coupling of the microfluidic subsystem with the other subsystems is under development. Recently a significant effort has been invested into the development of a flow-through electrochemical cell for adjusting oxidation states prior to the extraction, and a suitable technique for on-line detection of mainly alpha (self-assembled monolayers as prospective reactive surfaces of silicon detectors) emitters.

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Fission modes towards the island of stability

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The systematics of Mass-TKE distributions in fission of heavy and superheavy nuclei reveals several complex features of the collective nuclear degree of freedom and structural effects that are matter of intense interest. Understanding of such features is particularly important in the mass range $256 \leq A \leq 276$ and charge range from Z=100(Fm) to Z= 110(Ds) because this region of the nuclear chart constitutes the transitional region that connects the heavy actinides with the superheavy region [1].
In this framework mass and TKE distribution of two compound nuclei of ^{263}Bh, ^{269}Bh have been recently measured in ^{54}Cr + ^{209}Bi and ^{37}Cl + ^{232}Th reactions at JYFL accelerator laboratory using the two-arms time-of-flight spectrometer TOSCA. With the aim to provide a detailed data interpretation a new code named SAF (Static Approach to Fission) has been developed and validated.
The successfully validation of SAF calculations, which reproduced for the first time the mass and TKE distributions of the ^{123}Ce* fission fragments [3], as well as the results of the experimental and simulated mass and TKE distributions of ^{263}Bh and ^{269}Bh nuclei will be presented.

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Analysis of kinetic energy dissipation by collision angle in multi-nucleon transfer reactions

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Synthesis of neutron-rich nuclei is important for the study of Islands of Stability and r-process. However, to produce the neutron-rich nuclei in heavy mass regions will be limited by conventional fusion reactions. Therefore, in recent years, multi-nucleon transfer (MNT) reactions have attracted attention as a method of producing neutron-rich nuclei [1]. However, the reaction mechanism is not yet well understood due to its novelty and complexity. In the future, it will be necessary to estimate the physical quantity of evaporation residue (ER) in the production of neutron-rich nuclei of heavy and superheavy nuclei. In this study, we construct a dynamical model that describes the dynamics of the MNT reaction and verify the model by comparing it with experimental data to clarify the reaction mechanism.
This study aims of deal with the production of neutron-rich nuclei in heavy and superheavy elemental regions. We have been studying the angular momentum of compound nuclei produced in the MNT reaction. The results show that the angular momentum brought into the compound nucleus is affected by the contact time between the projectile and the target. It is also known that the contact time varies with the collision angle between the projectile and target. In this study, we investigate the kinetic energy dissipation at different collision angles. We attempt to analyze the MNT reaction from a new perspective by showing the relationship between collision angle and energy dissipation and various physical quantities.
The theoretical model we use is based on the two-center shell model to describe the configuration of nuclei [2]. The time evolution of the configuration is described by the multidimensional Langevin equation [3]. In this presentation, the effect of using deformed target nucleus and the effect of collision angle with deformed target nucleus are discussed from the viewpoint of kinetic energy dissipation, based on the results of dynamical model calculations.

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Verification of the mechanism for synthesizing a doubly magic superheavy nucleus

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The existence of a doubly magic superheavy nucleus ^{298}Fl is predicted. To synthesize this nucleus, it is necessary to produce more neutron-rich compound nucleus than ^{298}Fl. This is because the excited compound nucleus will be cooled down with neutron emissions.

According to this paper [1], the compound nucleus ^{304}Fl has some interesting mechanisms. One of them is the effect of neutron emissions. Due to neutron emissions, the neutron number in this nucleus approaches the doubly closed shell, and the fission barrier height will increase. This makes the survival probability of ^{304}Fl quite slowly decrease even at high excitation energy. However, the combination of projectile and target nuclei that synthesize this nucleus has not yet been found. Therefore, it was thought difficult to confirm this effect in experiments.

Recently, experiments were conducted on ^{40}Ar+^{238}U and ^{48}Ca+^{232}Th reactions in JINR [2]. We realized that the compound nuclei of these reactions have the same mechanism as ^{304}Fl in terms of the effect of neutron emissions. According to the mass table [3], the shell correction energy, which can be approximated as the fission barrier height, of $^{278,\ 280}$Ds increases with neutron emissions. Therefore, we expect the survival probability of $^{278,\ 280}$Ds to decrease quite slowly even at high excitation energy. In fact, the experimental values of the evaporation residue cross sections don't have the large differences between at the peak excitation energy (about 40MeV) and the high excitation energy (over 55MeV) [2].

The synthesis of superheavy nucleus includes the projectile-target contact process, the competition process between fusion and quasi-fission, and the decay process. We estimated the evaporation residue cross sections by combining three probabilities of these processes. We used the coupled-channel method [4], the dynamical model with multidimensional Langevin approach [4, 5] and the statistical model [6].

In this presentation, we mainly discuss the effect of neutron emissions and the associated increase in the fission barrier height in known fusion reactions. This effect is very important in the synthesis of a doubly magic superheavy nucleus.

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SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S^3) at GANIL

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The stability of nuclei beyond the spherical double shell closure of ^{208}Pb rapidly decreases because of the disappearance of the macroscopic fission barrier. This phenomenon is however compensated by quantum shell effects caused by alternating zones of high and low densities caused by deforma-tion. The island of superheavy stability is foreseen as a doubly spherical gap whose position varies depending on the model used [1, 2]. Spectroscopy in the region of high masses is very close to the limits of the existing detection systems. The extension of the investigation on nuclear structure to heavier nuclei is governed by an improvement in the efficiency of the transport and selection of the nuclei of interest as well as in the detection systems. The very high intensity beams provided by the NEW GAnil INjector (NEWGAIN) and the LINear ACcelerator (LINAC), combined with the high transmission and selection power of the Super Separator Spectrometer (S^3) [3–5], will offer unprecedented production rates of nuclei in the nanobarns region.

SIRIUS (Spectroscopy and Identification of Rare Isotopes Using S^3) [4, 5] will be the detection system dedicated to spectroscopy experiments for superheavy nuclei with S^3. SIRIUS consists of five segmented silicon detectors optimized for precision spectroscopy of alpha, beta and fission decay, surrounded by five EXOGAM high-purity germanium detectors for gamma-rays, and a Secondary Emission Detector (SED) placed upstream to track the ions and measure their time of flight. The conjunction of these detectors with the mass resolving power and the transmission of S^3 will make it a unique instrument for the study of superheavy nuclei.

In this contribution, after a brief review of the current status of S^3, we will report on the offline tests of SIRIUS and the performances of its detectors.

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Update on the AGGIE Gas-Filled Separator at Texas A&M University

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After several years of development, the AGGIE gas-filled separator at the Cyclotron Institute at Texas A&M University is now operating in production mode. Our Heavy Elements Group has been using it for a variety of experiments related to both nuclear reaction studies and online chemistry experiments. We recently measured excitation functions for the ^{156,157,158,160}Gd(^{48}Ti, *x*n) and ^{162,163,164}Dy(^{48}Ti, *x*n) reactions to produce Rn and Ra, respectively.
These products have a variation in compound nucleus deformation, and this has given us information on the corresponding change in survival. We have also worked to modify Si detector surfaces with organic monolayers to convert them into a chromatography column. We have conducted a first experiment using the ^{162}Dy(^{40}Ar, *x*n) reaction to produce Po, and a second experiment is planned in 2025. In collaboration with researchers from the Paul Scherrer Institute, we are developing techniques for fast chemistry experiments on nuclides with half-lives of less than 1 s. We have used the ^{147}Sm(^{36}Ar, 5n) reaction to produce ^{178}Hg ($t_{1/2}$ = 266.5 ms) and have transported it to an isothermal vacuum chromatography setup. Finally, an upgrade of AGGIE to increase its maximum magnetic rigidity is in progress. This talk will discuss these experiments, the most recent results, and future plans.

Functionalized Detectors for Superheavy Element Homolog Chemistry Experiments

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Several experiments aimed at chemical properties of superheavy elements (SHE) have studied the interactions of single atoms on the surface of Si-based solid-state α-detectors. Recent advancements include coating the detectors with thin Au layers, to measure the adsorption enthalpies of SHEs on different surfaces. Unfortunately, some SHEs such as nihonium (Nh) have a strong adsorption on Au surfaces, which only allows for the lower limit of its adsorption enthalpy to be measured.
A chemically selective technique to broaden the range of surfaces for adsorption enthalpy measurements is under development at Texas A&M University. Au-coated Si detectors are further coated with an alkanethiolate self-assembled monolayer (SAM), which has a terminal group selected for the element of interest. This has been demonstrated to work offline in solution for Ir and Rh (homologs of Mt), and in online gas-phase experiments for Ir, Er, and At. A detector array called the SAMs Polonium Isotope Detector ARray (SPIDAR) is in development to measure the efficacy of the SAM-coated detectors
One current project is to develop a system to study Lv by characterization of SPIDAR with its homolog Po. Offline, ^{216}Po (from the decay of ^{228}Th) is extracted into a recoil transfer chamber (RTC), which then can be used to test the detector array. Online, Po has been produced in the ^{160}Dy(^{40}Ar, *x*n) (*x* = 2-5) reactions. The radioisotopes were separated from the primary ion beam and reaction by-products using the gas-filled recoil separator AGGIE and are thermalized with a simple RTC (sRTC). Here, we present our latest results and future plans.

A New Era of Experimental SHE Chemistry at LBNL

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Superheavy Elements (SHE, Z > 103) are predicted to exhibit unique chemical properties that differ significantly from those observed in lighter elements due to the strong relativistic effects at play. Experimental studies have already revealed unexpected chemical behaviors in this region. However, conducting experiments in this area is extremely challenging, as they must be performed on an atom-by-atom basis. To date, no experiment has been able to directly identify molecular species produced, with assumptions often being made instead. To address this challenge, a new method has been developed at the 88-Inch Cyclotron facility at Lawrence Berkeley National Laboratory to perform atom-at-a-time gas phase chemistry. This technique utilizes the FIONA spectrometer to perform direct mass-to-charge measurements of produced chemical species. Preliminary measurements have detected the formation of actinide molecular species in elements such as Ac (Z = 89), No (Z = 102), and Lr (Z = 103). The results of these initial measurements will be discussed, along with an outlook for future SHE research.