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1

Determining charge radii of exotic nuclei from charge-changing reactions

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Charge-changing cross sections (CCCS) at intermediate energies have been used to determine the rms point-proton radii (Rp) for exotic nuclei. However, one key question remains: Can one get consistent charge radius results on different targets? In this talk, I will present our recent CCCS measurements of more than 60 p-sd shell nuclei on various targets at 900 and 300 MeV/nucleon. Benefiting from the large and systematic data set, we show for the first time that charge-particle evaporation after neutron removals is crucial in charge-changing reactions. We then identified a new and robust relationship between the scaling factor of the Glauber model calculations on different targets and the separation energies of the nuclei with known radii. This allows us to deduce Rp from the cross sections on hydrogen for the first time. Nearly identical Rp values are deduced from both target data for the neutron-rich carbon isotopes; however, the Rp from the hydrogen target is systematically smaller in the neutron-rich nitrogen isotopes.

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Axially asymmetric nuclear shapes

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The rotation of deformed nuclei generates easily recognizable patterns of excited nuclear states, called rotational bands. If the nucleus has axial asymmetry, the rotational bands are more complex, for instance, in addition to the ground-state band of an even-even nucleus, excited γ bands occur. These sets of bands are formed because the nucleus rotates simultaneously around its three axes, a motion that looks like tilted precession (TiP) of the total angular momentum around the axis with largest moment of inertia (MoI) similar to the precession of a rotating top.
The most unambiguous way to establish the axial asymmetry of the nuclear shape are direct Kumar-Cline measurements carried out within multi-step Coulomb excitation experiments. While such an analysis is model-independent and in general is the most robust proof of stable axial asymmetry, the technique is experimentally challenging and have been carried out only for a small number of deformed nuclei. Thus, the axial asymmetry of the nuclear shape is often derived based on observed features of rotational bands and on theoretical expectations, for instance energy staggering in the γ band of even-even nuclei, tilted precession and wobbling in odd-mass nuclei, chiral bands, and others. In this presentation an alternative way of deducing axial asymmetry will be presented and discussed.
Chiral bands observed in the Tl isotopes with the Afrodite array at iThemba LABS will be summarized, [1], in particular new results on chiral structures in ^{195}Tl will be presented.
In addition, the terminology of "wobbling" [2] and "tilted precession" [3] will be discussed. Wobbling was introduced by Bohr and Mottelsson as a harmonic vibration coupled to a simple one-dimensional rotation, and the excited bands were labelled by the number of excited wobbling phonons. They used a harmonic approximation of the three-dimensional rotational Hamiltonian at high spins. However, lately, bands at low spins, where the harmonic approximation does not hold were also associated with wobbling [3]. The terminology issues will be discussed briefly, and a way forward will be proposed [5].
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Notes:

3

Atomic-scale materials characterisation with radioactive isotopes - highlights from emission Mössbauer spectroscopy

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Intentionally incorporating foreign atoms in semiconductors to realise new and/or novel functionalities gives rise to structural changes that profoundly affect their electronic, magnetic and optical properties. Consequently, information on material properties and dynamic processes such as dopant diffusion and relaxation processes are necessary and can be determined using various techniques. A particular class are techniques employing radioactive isotopes implanted in materials as probes. These combine a two-fold approach: (a) material modification and (b) material characterisation at the atomic level, the latter achieved through utilising the isotopes mainly as "spies" via the radiation/particles emitted during decay. This provides knowledge on lattice sites of desired daughter dopants, lattice location changes with thermal annealing, and the defects/complexes formed with host atoms.

Mössbauer Spectroscopy is a very sensitive technique capable of detecting minor shifts in energy levels that emanate from hyperfine interactions between the nuclear moments of the probe/dopant and any local electric and magnetic fields in their immediate environment. A novel extension is emission Mössbauer Spectroscopy (eMS) employing short-lived radioactive isotopes developed at ISOLDE, CERN. eMS studies have been undertaken mainly using ^{57}Mn* ($t_{1/2}$ = 1.5 min) produced via proton-induced fission in a UC_2 target followed by multistage laser ionisation [1], mass separation and acceleration to 40-60 keV. In addition, other precursor isotopes, such as ^{57}Co ($t_{1/2}$= 272 days) and ^{119}In ($t_{1/2}$= 2.4 min), have also been used.

Over the years, eMS has been applied in several different material systems at ISOLDE, with investigations initially on the role of Fe in silicon to recent studies on the nature and origin of magnetic effects observed in transition metal doped semiconductors[2-5] envisaged for spintronic applications. Special features of the technique will be presented and discussed, together with representative results in binary[4] and ternary III-nitrides[5]. The results will mainly focus on investigations of the lattice sites of the probes, their charge and spin states, and the magnetic interactions of dopants in ternary-nitrides (virgin and Mn pre-doped).

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Notes:

4

Nuclear level density for Uranium

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The energy level density for $^{234-240}$U at the minima and saddle point are calculated based on the framework of covariant density functional theory. The total level density is calculated by convoluting the intrinsic density with the corresponding collective level density. For even-even nuclei, the collective level density is obtained by the five-dimensional collective Hamiltonian while the parameters of the Hamiltonian like the inertia parameters are extracted from the covariant density functional theory. For even-odd nuclei, the collective level density is acquired by the core-quasiparticle coupling model together with collective wave functions of the neighboring even-even nuclei. The intrinsic level density is computed from the entropy and its determinant matrix in the finite-temperature covariant density functional theory.
The nuclear level density at the minimum is consistent with the available data while the trends and details at the high excitation energy for both the minima and the saddle points are close to the results obtained by Hilarie.

Notes:

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SOME FEATURES OF BETA DECAY OF EXOTIC NUCLEI AND K-ISOMERS

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The probability of the β-transition to the nuclear level with excitation energy E is proportional [1] to the product of the lepton part described by the Fermi function f(Qβ − E) and the nucleon part described by the β-decay strength function Sβ(E). At excitation energies E smaller than Qβ (total β-decay energy), Sβ(E) determines the characters of the β-decay. For higher excitation energies that cannot be reached with the β-decay, Sβ(E) determines the charge exchange nuclear reaction cross sections, which depend on the nuclear matrix elements of the β-decay type [1-3].It was shown [2-5] that the high-resolution nuclear spectroscopy methods give conclusive evidence of the resonance structure of Sβ(E) both for GT and first-forbidden (FF) β-transitions in spherical, deformed, and transition nuclei. The splitting of the peaks in the Sβ(E) for the GT β+/EC-decay of the deformed nuclei into two components was demonstrated [3-6]. Resonance structure of the Sβ(E) for β-decay of halo nuclei was analyzed in [7-9].
Fission and alpha-decay of the high-spin isomers are rather strongly forbidden, while the beta-decay of the high-spin isomers can populate high-spin levels near the yrast-band [10]. Than after a few gamma-decays the yrast-band levels may be populated. The prediction of the energies of the levels of the corresponding yrast-band can be done by using the model proposed in [11]. Such prediction is extremely useful in planning and carry out experiments, especially in the region of heavy and superheavy nuclei [12,13].
In this report the fine structure of Sβ(E) is analysed. Resonance structure of Sβ(E) for GT and FF β-decays, structure of Sβ(E) for halo nuclei, quenching [9] of the weak axial-vector constant gAeff, splitting of the peaks in Sβ(E) for deformed nuclei connected with the anisotropy of oscillations of proton holes against neutrons (peaks in Sβ(E) of GT β+/EC-decay) or of protons against neutron holes (peaks in Sβ(E) of GT β− − decay), and Sβ(E) for the high-spin isomers [10] β-decays in heavy and superheavy nuclei are discussed.

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Notes:

6

Breakup dynamics of a neutron-halo projectile on heavy target at deep sub-barrier energies

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By studying the total fusion and breakup cross-sections in the interaction of the neutron-halo 11Be projectile on the lead target 208Pb, it is shown that, even for the neutron-halo projectile, the breakup channel remains the most dominant reaction channel at sub-barrier energies, following a characteristic behavior that was also previously verified for the case of the proton-halo projectile 8B. This feature is found to emanate from the enhancement of the breakup cross-section, due to the continuum–continuum couplings (CCC) coming exclusively from its Coulomb component. We further speculate that the enhancement of the Coulomb breakup cross-section at sub-barrier incident energies by the CCC could be associated with the projectile breaking up on the outgoing trajectory, provided these couplings can be proven to delay the breakup process.

Notes:

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Low-Energy Electron scattering - proton and exotic nuclei -

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Electron scattering is the gold standard for probing nuclear structures, consistently playing an essential role in revealing the internal structures of atomic nuclei and in establishing modern pictures of their structures. To date, its application, however, has been strictly limited to stable nuclei (with some exceptions such as 3H), leaving short-lived unstable nuclei unexplored*.

Following nearly two decades of development, we have successfully achieved a ground-breaking milestone: the first electron scattering experiment on an online-produced radioactive isotope at the SCRIT electron-scattering facility of RIKEN RI Beam Factory in Japan**.

The SCRIT facility, designed to explore the internal structures of short-lived exotic nuclei by electron scattering, employs a novel ion-trapping technique, SCRIT (Self-Confining Radioactive Isotope Ion Target) ***. Using only ~107 ions of an exotic nucleus, the SCRIT technique enables us to achieve a luminosity of approximately 1027 /cm2/s, which is the minimum required for realizing elastic electron scattering for medium-heavy nuclei.

I will present the recent achievements and the current status of the SCRIT facility, and outline many research possibilities awaiting exploration at the SCRIT facility as well.

If time allows, I will also provide an overview of the ongoing low-energy electron scattering project, ULQ2 (Ultra-Low Q2), in Sendai. This project aims to determine precise proton charge radius by low-energy electron scattering (Ee = 10 - 60 MeV) covering the lowest-ever momentum transfer, Q2.

Notes:

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Search and analysis of the Double hit events

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The work focuses on the "double-hit" experimental approach in the registration and analysis of ternary decay events, particularly in the context of fission fragment interactions with a solid-state foil. The methodology employed in the experiment involves a double-armed time-of-flight COMETA-F spectrometer equipped with an MCP time detector and 28 PIN diodes for precise energy measurements. the double-hit registration approach means that two fragments, with an open angle between them 5 degrees or less, were detected in the same PIN diode during one registration gate of 200 ns. The minimum time interval between the fragments timestamps should not exceed 30ns. An algorithm is described for retrieving these events from the collected data, emphasizing the importance of peak detection and analysis through various software tools developed at the Flerov laboratory. Additionally, it addresses the challenge of distinguishing genuine double-hit events from random coincidences with alpha particles, which constitute a significant portion due to their prevalence in 252Cf decay. A method for filtering out these random coincidences by analyzing energy and velocity data associated with each detected particle is presented here. Thus, for the first time the experiment

demonstrates directly that the partners of the break-up in the solid-state foil fly with very low angular divergence as was hypothesized earlier for the CCT products.

Notes:

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exotic structure studies of light neutron-rich nuclei via direct nuclear reaction

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In order to study exotic structures of light unstable nuclei, we have developed a Large Acceptance Charged particle detector array at Peking University, LACPU, which is suitable for simultaneous measurement of various different direct nuclear reactions induced by radioactive beams on protons and deuterons in inverse kinematics [1-3]. In this talk, we will show the preliminary results of the first experiment using LACPU at RIBLL1, Institute of Modern Physics, China, including properties of LACPU, differential cross sections of elastic scattering [3] and single-nucleon transfer reactions [4] with radioactive beams 15C,16C,16N impinging on protons and deuterons. We will also discuss the update plans of LACPU, as well as some experimental proposals in the future.
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Notes:

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Manifestation of ternary clusterization in binary spontaneous fission of ^{252}Cf

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New ternary cluster mode in binary fission is suggested. This mode is the abnormal binary decay which is characterized by a much lower TKE value, a much higher excitation energy of heavy fission fragment and,thus, larger neutron multiplicity. Employing this mode, one can describe the strong enhancement of the 8-11 neutron evaporation channels for Mo+Ba and Zr+Ce pairs in spontaneous fission of ^{252}Cf.

Notes:

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α-decays of even-even actinides and superheavy nuclei to the first rotational 2^+ states of daughter nuclei

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The alpha-decays of even-even isotopes of actinides and superheavy nuclei to the ground 0^+ and first 2^+ states of their daughter nuclei are studied. The conditions for the maximum intensity of alpha-decay from the ground state to the lowest 2^+ state are analyzed in detail based on existing experimental data. For the alpha-decays of heavy nuclei up to Og, the half-lives and population probabilities of the 0^+ and 2^+ states of the daughter nucleus are described and predicted employing the preformed cluster model.

Notes:

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Multi neutrons transfer in reaction 6Li(68 MeV) on Be target

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The results of experiments on studying nucleon and cluster transfer processes in the reactions of the 6Li (68 MeV) ions with the 9Be target nuclei are presented. The angular distributions for the reaction channels 9Be(6Li,6Li)9Be, 9Be(6Li,7Li)8Be, 9Be(6Li,8Li)7Be, Be(6Li,α)11Bg.s., s. have been measured. To describe the possible contributions of sequential transfer of nucleons and alpha clusters, as well as direct transfer of the 2n cluster, the Coupled Reaction Channel method (FRESCO) is used.The spectroscopic amplitudes are obtained for the configurations of (7Li+d), (7Li+n), (6Li+2n) 8Li+p in the 9Be, 8Li , 7Be and (6Li+α) in the 10B nucleus. The results of the theoretical analysis are in agreement with the experimental data and indicate a strong correlation between a neutron and an α-cluster and two neutron in the transfer processes. A review of similar experiments on the similar study of the di-neutrons is given.

Notes:

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Role of the atomic mass in the breakup of weakly-bound halo nuclei

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In probing the internal structures of halo systems through breakup reactions, the attention is largely reserved to the ground and continuum structures of the weakly bound projectile. It is shown that some breakup features can be revealed by focusing on the projectile atomic mass, which is found to be a significant quantitative parameter in the breakup process

Notes:

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CsI-bowl: an ancillary detector for exit channel selection in gamma-ray spectroscopy experiments

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A particle detector array designed for light-charged particles, known as the CsI-bowl, was built for exit channel selection for in-beam gamma-ray spectroscopy experiments. This device is composed of 64 CsI(Tl) detectors, organized in a structure reminiscent of a tea-bowl. High quantum efficiency photodiodes, characterized by their minimal mass, were employed to collect scintillation light. Its design, construction, particle identification resolution, and its effectiveness in relation to exit channel selection are described in this paper. In source tests, the optimal figure of merit for the identification of gamma-particles and gamma-rays using the charge comparison method was found to be 3.3 and 12.1 for CsI detectors coupled to photodiodes and avalanche photodiodes, respectively. The CsI-bowl demonstrated effectiveness in identifying particles, specifically the emission of protons and -particles in the 58Ni(19 F, xpyn) fusion–evaporation reaction, thereby enabling the selection of the desired exit channels.

Notes:

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Microscopic Analysis of Elastic Scattering of One-Proton Halo Nucleus 17F on Different Mass Targets

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An analysis of cross sections of elastic scattering of 17F on 12C, 14N, 58Ni, and 208Pb nuclei at energy 170 MeV and on 208Pb at various energies is carried out by using the microscopic optical potentials (OPs) [1]. The proton and neutron density distributions of the exotic nucleus 17F are computed in the framework of microscopic models. The real part of the OP is calculated by a corresponding folding procedure accounting for the antisymmetrization effects, while the imaginary part is obtained on the base of the high-energy approximation [2]. In the hybrid model of the optical potential developed and explored in our previous works [3,4] the only free parameters are the depths of the real and imaginary parts of the OPs obtained by fitting the experimental data. A good agreement of the theoretical results with the available experimental data is achieved pointing out clearly to a peripheral character of the scattering.

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A real time pulse processing DAQ for neutron wall modular detector on RIBRAS experiments

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In order to potentiate the experiments with Brazil Radioactive Ion Beam (RIBRAS), new VME (Versa Module Euro Card) Data Acquisition (DAQ) modules characteristics to control, triggering and data acquisition will be described. The DAQ should be defined to include the Double/Single Sided Silicon Strip Array and Neutron Wall detectors with maximum readout efficiency, no dead time, data selection and event synchronization.
CAEN digitizer modules for VME provide features like zero suppressed readout and overflow suppression. Zero suppression, once enabled, prevents conversion of value which is lower than user defined threshold. Overflow suppression, once enabled, aborts the memorization of data which constitutes an ADC overflow.
Adding FPGAs (field programmable gate array) to data acquisition provides pre- and post-algorithmic processing on data. The hardware elements chosen should have features that make the modules easy to program and handle.
A feasibility analysis of using this experimental setup to investigate the dineutron-cigar configuration in reactions with light radioactive nuclei is presented.

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Étude phénoménologique des hadrons lourds on utilisant les modèles de potentiels

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Les baryons omega b moins composé de deux quark strange et d'un bottom est un baryon lourd qui fascine les physiciens depuis sa découverte en 2009.Cependant ce n'est que récemment, grâce à l'expérience LHCb(Large Hadron Collider beauty)au Large Hadron Collider(LHC)par le CERN(Conseil Européen pour la Recherche Nucléaire), que des états excités excités du baryon omega b moins ont été découvert avec précision sans précédent. Les baryon omega b moins se désintègre en baryons moins légers et muons, l'expérience de LHCb a permis de mesurer expérimentalement les masses et les largeurs naturelles de plusieurs de ces états excités.

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Recent results of Dubna collaboration: E1 toroidal mode, K-isomers in No isotopes, wavelet analysis of monopole excitations

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A short review of some recent results of collaboration Dubna – Darmstadt – Erlangen - Bratislava - Prague – Johannesburg is presented. Theoretical analysis is performed within fully self-consistent quasiparticle random-phase approximation method with Skyrme forces.
As the first item, the exotic toroidal E1 mode is outlined. It is shown that this vortical mode is a general feature of atomic nuclei [1,2]. The overlap of the toroidal mode with pygmy dipole resonance is discussed. Using Darmstadt's (e,e') data, we show that this mode can be observed in inelastic scattering of electrons to back angles [3].

Next, K isomers in No isotopes are analyzed. It is shown that widely disputed 8- isomer in 254No can be unambiguously assigned as two-quasiparticle neutron configuration 7/2+[624], 9/2-[734].

Finally, wavelet analysis of iThemba (☒☒☒') data [4] on monopole excitations in prolate 24Mg and oblate 28Si nuclei is presented. To discriminate different physical effects, the region of monopole giant resonance and region of the deformation-induced monopole-quadrupole coupling are considered separately. The impact of Landau damping to wavelet scales is scrutinized.

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Notes:

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Probing Dynamics of Fusion-Fission Process in Heavy to Very Heavy Nuclei

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Studies in heavy-ion induced fusion-fission process has established itself as one of the major branches of low and medium energy nuclear structure and reaction physics. A plethora of dynamical processes manifest through the fusion-fission of two atomic nuclei over a wide range of projectile energy. The process of fission followed by fusion of two heavy nuclei or survival of the Compound Nucleus (CN) against fission and formation of Evaporation Residues (ER) are deeply connected with various factors like, nuclear Shell Structure, Target-Projectile mass asymmetry, projectile energy, Angular Momentum distribution in the CN etc. Other than studying the dynamical effect associated with fusion and subsequent fission (or survival against fission) of heavy CN, there is also the long-standing desire to understand formation of very heavy or Super Heavy Elements (SHE). In this talk we plan to review the present status of heavy-ion induced fusion-fission processes at energies above the Coulomb Barrier. We would like to touch upon aspects of fission followed by complete and incomplete fusion and processes like fast and quasi-fission. We will be primarily drawing from our measurements carried out at Inter University Accelerator Centre, New Delhi using the Hybrid Recoil mass Analyser (HYRA) coupled with the TIFR 4π Sum-Spin spectrometer [1]. We will provide a brief introduction to the subject of heavy-ion induced fusion followed by fission process and its wider ramifications in low and medium energy nuclear physics. We will summarise what we have learnt so far and what are the unresolved mysteries. Example to support the current understanding of the subject will be primarily from our very recent measurements of angular momentum gated Evaporation Residues from the heavy 186Pt and very heavy 240Cf nuclei. Detailed analysis using Statistical Model analysis and Dynamical approach will also be presented. We will also discuss the role of nuclear viscosity in the survival of the CN against fission.

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Notes:

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Magnetized nuclei in explosive nucleosynthesis

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Nucleosynthesis at large magnetic induction relevant for core-collapse supernovae, and neutron star mergers is considered. For respective magnetic fields of a strength up to ten teratesla atomic nuclei exhibit linear magnetic response due to the Zeeman effect. Such nuclear reactivity can be described in terms of magnetic susceptibility [1]. Susceptibility maxima correspond to half-filled shells. The neutron component rises linearly with increasing shell angular momentum, while the contribution of protons grows quadratically due to considerable income from orbital magnetization. For a case j = l + 1/2 the proton contribution makes tens of nuclear magnetons and exceeds significantly the neutron values which give several units. In a case j = l – 1/2 the proton component is almost zero up to g-shell. Respectively, a noticeable increase in the generation of corresponding explosive nucleosynthetic products with antimagic numbers is predicted for nuclei at charge freezing conditions. In the iron group region new seeds are created also for the r-process. In particular, the magnetic enhancement of the volume of 44Ti isotopes is consistent with results from observations and indicates the substantial increase in the abundance of the main titanium isotope (48Ti) in the Galaxy's chemical composition. Magnetic effects are proved to result in a shift of the r-process path towards smaller mass numbers, and an increase in the volume of low mass nuclides in peaks of the r-process nuclei.

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Notes:

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High-effective γ-ray spectrometer ELIADE for the nuclear resonance fluorescence studies at at ELI-NP.

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The structure of a nucleus can be inferred from its decay patterns and the partial decay widths of excited states leading to the ground state. A standard method of in-beam γ-ray spectroscopy at charged particle accelerators relies on γ-γ coincidences, often correlated with the charged particles or neutrons produced in the same reaction. In charge-particle-induced reactions, J = 1 states are typically weakly populated, and the sensitivity of measurements may be insufficient to detect weakly branching transitions. This poses challenges in studying the decay behavior of excitation modes, such as the nuclear scissors mode and the Pygmy Dipole resonance.
However, J = 1 states can be effectively populated through nuclear resonance fluorescence (NRF), a two-step process involving the resonant absorption of a γ-ray by a nucleus followed by the re-emission of γ-radiation [1]. Typically, a γ-ray beam is generated via bremsstrahlung, but specific nuclear levels can be uniquely excited using a mono-energetic photon beam, such as that produced by Compton laser back-scattering. At the Extreme Light Infrastructure Nuclear Physics (ELI-NP) in Romania, the combination of a mono-energetic γ-ray beam from the VEGA machine [2] and the highly effective ELIADE γ-ray spectrometer [3] enables access to weakly populated low-lying nuclear states and transitions with small branching ratios.
The VEGA system is expected to deliver a γ-ray beam with a continuous energy range up to approximately 19.5 MeV and a total flux of 10^11 /s. Its linear polarization of 95% and an average relative bandwidth of 0.5% will significantly enhance experimental capabilities for studies below the particle emission threshold in stable nuclei. The ELIADE γ-ray spectrometer consists of eight Compton-suppressed segmented clover detectors and four Compton-suppressed CeBr3 detectors. The custom-designed DELILA triggerless digital data acquisition system operates with commercially available CAEN digitizers.
In my presentation, I will briefly review the Day 1 experiments and then discuss the ELIADE γ-ray spectrometer. I will present results from implementing various add-back schemes, cross-talk corrections, and anti-Compton rejection techniques, using both standard γ-ray sources and a custom high-energy γ-ray source.

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[3] D. A. Testov, A. Dhal, C. Petcu at al., Il Nuovo Cimento C 47 (2024) 60

Notes:

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Low-energy spectra of nobelium isotopes

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The low-energy multipole spectrum in isotopes 250-260No is investigated in the framework of fully self-consistent Quasiparticle-Random-Phase-Approximation (QRPA) method with Skyrme forces (SLy6, SkM* and SVbas) is applied. The main attention is paid to nuclei 252No and 254No, where we have most of the experimental spectroscopic information [3,4]. In addition to low-energy one-phonon collective states (lm=20,22,30,31,32,43) and K-isomers (K⊠ = 2-,8-,3+). In general, a good

agreement with the experimental data is obtained. It is shown that, in the chain 250–260No, features of 252No and 254No exhibit essential irregularities caused by a shell gap in the neutron single-particle spectra and corresponding break of the neutron pairing. The low-energy pairing-vibrational Kπ = 0+ state is predicted in 254No.

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Notes:

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Search for beta-delayed proton emission from 11Be

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Even though β-delayed proton emission is a phenomenon which typically occurs for neutron-deficient nuclei, the energy window for this process is also open in a few light, neutron-rich isotopes. Particularly interesting in this respect is 11Be, which is also a one-neutron halo nucleus [1]. Several channels for β-delayed particle emission from this isotope are open, including the proton branch, with Q_p ~ 280 keV. The branching ratio (BR) for the latter process is important for the determination of the Gamow-Teller strength at high excitation energy and for testing models that predict a direct relation between βp emission and the halo structure. Indirect observations based on accelerator mass spectrometry (AMS) resulted in conflicting values for this branching ratio [2, 3]. The direct measurement of the βp BR and energy spectrum was reported recently in Ref. [4] but the results disagree with the most recent finding of Ref. [3].
We carried out an experiment to search for β-delayed protons from 11Be, using the Warsaw Optical Time Projection Chamber. The measurement was performed at HIE-ISOLDE facility in CERN, where a large amount of 11Be ions was implanted into the OTPC detector. The final results of this experiment will be presented and discussed [5].

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Notes:

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Investigation of the structure of the lowest quadrupole excitations in Ge isotopes

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At present, a lot of experimental information has been accumulated on the structure of low-lying excited states in Ge isotopes. Interest in these nuclei is due to the fact that with an increase in the number of neutrons there is a transition between spherical and deformed forms of the nucleus that determine their structure. On the other hand, microscopic calculations show that Ge isotopes are soft in relation to triaxial deformation. In this report, we analyze the properties of low-lying 2+ states in isotopes of 70-88Ge. Calculations were carried out by constructing and diagonalization of the collective quadrupole Hamiltonian. The surfaces of potential energy and mass parameters were calculated in the relativistic mean field model with two parameterization of the energy density functional: PC-PK1 and NL3. The results of the calculations are compared with the experimental data and the results obtained within other approaches.

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Study of the spatial dimensions of 6Li nuclear states by measuring differential cross sections for the 10B(7Li,6Li)11B reaction

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The angular distributions of the 1-n transfer reaction 10B(7Li,6Li)11B, as well as the elastic scattering of 7Li, were measured at E_lab = 58 MeV. Experiment was done using U-400 accelerator beam of the FLNR JINR, Dubna.
The attention was paid to ground state (g.s.) and excited (J= 0+, T= 1, E= 3.56 MeV) state of 6Li which is an isobar analogue state (IAS) of 2n-halo nucleus 6He.
Angular distribution for 1-step direct reaction 10B(7Li,6Li)11B with excitation of the 3.56 MeV state (6Li*) is present for the first time.*
The DWBA analysis of the differential cross section of the 10B(7Li,6Li)11B the 6Li_g.s. and 6Li(3.56 MeV) transition was performed. The optical model potentials were obtained by fitting of measured elastic scattering data and evaluating parameters for the output reaction channels. Phenomenological approaching based on solving an approximate equation for the reaction form factor was used to determine its radial dependence and empirical values of asymptotic normalization coefficient (ANC). Obtained values of ANC's for the 6Li_g.s. and 6Li*(3.56 MeV) states are similar to literature one. Comparison of the radial dependences of form factors shows that the wave function of the 6Li nucleus in excited (J= 0+, T = 1, E = 3.56 MeV) state has increased spatial dimension compared to the ground state, and in both cases some larger spatial size than the ground states of the 11B and 10B.Within the framework of our analysis, we can confirm that the radius of the 6Li nucleus in the 3.56 MeV state is larger than in the ground state.*
This result, obtained within the framework of the ANS analysis, is an argument in favor of the existence of a halo in the 6Li(3.56 MeV) state, while the question of a halo in 6Li_g.s. still leaves open.

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Breakup effects on fusion. Reduction methods and quantum-mechanical methods for the CF and ICF calculation

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We discuss the effect of weakly bound projectiles' breakup (BU) channels on complete and total fusion. For that, we report our fusion method based on the Wong formula, which allows for comparing reduced experimental data to the universal fusion function to find the effect of the BU channel on fusion. We report a recent improvement to the Wong formula to upgrade our reduction method and introduce the classic line benchmark for energies above the Coulomb barrier. The new method is also used to study the effect of CN probability on the fusion cross section and to study the hindrance of the fusion cross section of super-heavy nuclei.
A new theoretical method for the calculation of complete (CF) and incomplete fusion (ICF) recently proposed by us will be presented. This method is based on the continuum discretized coupled channel method plus a classical statistic to derive the corresponding probabilities. The method will be used to derive the CF and ICF of the reactions induced by 6,7Li on heavy targets. The capability to describe the experimental data for the reactions induced by neutron halo projectiles will also shown. Finally, we will also show that from the inclusive alpha emission cross section from 6Li + 90Zr at near barrier energies, the deuteron-ICF can be derived, and the theoretical prediction agrees very well with this indirect experimental quantity.

Notes:

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Investigating lattice sites and charge states of Fe in InGaN via 57Mn+ implantation

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$In_xGa_{1-x}N$ is a highly versatile material with tunable properties, widely used in modern optoelectronics[1−3]. Doping it with iron (Fe) introduces new possibilities for tailoring its properties, potentially enabling advancements in electronics, optoelectronics, and spintronics. In this study, ^{57}Fe emission Mössbauer Spectroscopy (eMS) was used to probe the lattice site, charge state and magnetic behaviour of Fe in $In_xGa_{1-x}N$. Temperature- and angle-dependent eMS measurements were conducted at ISOLDE/CERN using radioactive $^{57}Mn^+$ ($t_{1/2}$ = 1.5 min) ions which decay to ^{57}Fe. Our analysis of the $In_xGa_{1-x}N$ spectra for concentrations x = 3, 9, 16, 18, 30 and 34% revealed that more than 55% of the Fe species were Fe^{2+} in a cation site (In/Ga) stabilized by a nitrogen-vacancy. Moreover, each recorded spectra exhibited paramagnetic Fe^{3+} features similar to those seen in nitrides[4] and metal

oxides[5,6]. Further analysis of Fe^{3+} revealed slow-spin lattice relaxation. A T^2 temperature relation of the relaxation rates was observed, akin to a two-phonon Raman process. This presentation will also explore how changes in concentration influence hyperfine interactions.

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Notes:

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Effect of the entrance channel on the excitation function of charged particle induced nuclear reactions

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The effect of the entrance nuclear reaction channel was investigated from the perspective of the excited level population in the compound nucleus. A detailed comparison between analog reaction channels that are supposed to form the same compound nucleus was explained. Results showed that nuclei have a long-term "memory" of the entrance channel than expected by the usual model assumption. The large effect of the entrance channel may be associated with the slow-varying isospin degree of freedom during pre-equilibrium reactions and the diversity of the spin distribution among different reaction configurations.

Notes:

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Cage motion of Iron (Fe) in Silicon (Si)

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Due to its negative impact on semiconductor devices, iron (Fe) is one of the most thoroughly investigated impurities in silicon. It is a usual unintended impurity in silicon manufacturing, functioning as a fast diffuser and severely lowering carrier lifetimes, especially harmful for solar cells applications [1]. It is still unclear how

defects or other impurities interact with substitutional and interstitial Fe under implantation conditions. Obtaining an understanding of the behaviour of metal impurities, such as Fe, in silicon can result in methods for improving gettering procedures, which transfer metallic impurities to less hazardous areas of devices. This motivates investigation of the fundamental properties and behaviour of Fe in silicon at the atomic scale. Techniques such as emission Mössbauer spectroscopy and emission channelling provide valuable insights into the behaviour of dilute probe atoms in these contexts. We demonstrate, using 57Fe Mössbauer spectroscopy following implantation of 57Mn (T½ = 1.5) min. that substitutional Fe in silicon is not located on the ideal substitutional site, but exhibits cage motion or jumps via saddle sites, located 0.17(3) Å from the ideal substitutional site. In the temperature range from 300 K to 500 K, the jump rates follow an Arrhenius behaviour, with rates in the vicinity of 10^7-10^8 Hz and an activation energy of 0.18(3) eV. Our data also suggest compressive strain on substitutional sites and relaxing strain on interstitial sites when the implantation is below ~450 K. These findings provide new insights into the atomic-scale behaviour of Fe in silicon, which is essential for improving material processing and device performance.

Notes:

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Characterization of ternary and quaternary particle emission in spontaneous fission of ^{252}Cf

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In this study, the energy spectra and yields of various ternary and quaternary particles produced during the spontaneous fission of ^{252}Cf were measured and analyzed. Particles with atomic numbers Z = 1 to 6 were clearly identified, including hydrogen and helium isotopes such as ^{1}H, ^{2}H, ^{3}H, ^{4}He, ^{6}He, and ^{8}He. Distinct energy distributions were observed for each particle type, and Gaussian fitting was applied to estimate their yields and energies. The analysis successfully quantified the yields of ternary particles, including ^{1}H, ^{2}H, ^{3}H, ^{4}He, ^{6}He, ^{8}He, as well as heavier fragments like lithium (Li), beryllium (Be), boron (B), and carbon (C).
In addition to ternary particle emissions, this study investigated quaternary fission (QF) processes in ^{252}Cf. Two main pathways were identified: pseudo-quaternary fission, resulting from the decay of unstable light charged particles (LCPs) such as ^{7}Li, *^{8}Be*, and $^{9}Be^*$, and true quaternary fission, characterized by the independent emission of two LCPs. Angular distributions of α-particle coincidences from ^{8}Be decays were analyzed, and the results aligned with the predicted decay kinematics of ^{8}Be from both its ground and first excited states.
Although the statistics were limited, the energy spectrum of (α, t) pairs from the second excited state of ^{7}Li was successfully analyzed and compared to the ternary Li particle data. The study reported yields and energy spectra of particles from these processes.

Notes:

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On the trapping of cold neutrons in nano-scaled Fabry-Perot resonating cavities & neutron lifetime considerations

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Relatively to the atomic constituents' counterparts, the neutron is singular as it is sensitive to the four fundamental interactions: strong, weak, electromagnetic, and gravitational. This multi-sensitivity makes neutron wave-matter optics a particularly versatile tool for testing quantum mechanics [1-4], specifically and fundamental physics concepts in general. The lifetime of a free neutron defined via its beta-decay ⟨τn⟩ is of a pivotal importance within the standard model & cosmology.
Indeed, the precision on the neutron lifetime is of a paramount importance as it regulates the precision of the 1st element of the Cabibbo–Kobayashi–Maskawa matrix, central to the standard model. The two major methods used to measure ⟨τn⟩ while trapping free neutrons, namely, the beam and the bottle methods give different neutron lifetime values; ⟨τn⟩Beam ~ 888.0 ± 2.0 s , that obtained by the bottle technique is smaller; of about ⟨τn⟩Bottle ~ 879.4 ± 0.6 s. In addition of the persistent difference of ~10 s persists for years, even if the two methods have been modified to enhance the experimental accuracy. This latter was shown to be enhanced if one could trap cold neutrons in nanostructured Fabry-Perot resonators.
This contribution reports on the de Broglie wave-matter quantum duality coupled to the Fermi total reflection phenomenon in addition to the tunneling & trapping of cold neutrons in such nano-resonating cavities. This quantum mechanics trapping driven phenomenon allows trapping times of cold neutrons with a precision governed by the Heisenberg uncertainty of about 10-12 s [5].
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Maaza et al, Journal of Neutron Research -1 (2023) 1–16 1 DOI 10.3233/JNR-220015

Notes:

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Post-decay processes in radiopharmaceutical precursors studied via nuclear spectroscopy

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Modern radiopharmaceuticals are actively used for diagnostics and therapy in nuclear medicine. The concept of a modern radiopharmaceutical allows incorporating radionuclides with similar properties to the same precursors. Radiopharmaceutical precursor and its stability play a major role in applicability of such a drug. Post-decay processes, namely Auger and conversion electron emissions, may

cause a change in local environment which can lead to release of the daughter from the radiopharmaceutical and, therefore, difficulties in its application.
The present work highlights several medically relevant isotopes – 44Sc and 111In coupled with the chelators. 44Sc (t1/2 = 4.04 h) is a radiometal with favourable decay properties for positron emission tomography (PET) and 111In (t1/2 = 2.8 d) is already in the clinical use for diagnostics via single photon emission computed tomography (SPECT). Moreover, 111In is a well-established probe nucleus in perturbed angular correlation of γ-γ rays (PAC), which allows for the study of hyperfine interactions and, hence, is a unique technique when analysing post-decay processes in radiopharmaceutical precursors. Also, the study demonstrates feasibility of 44mSc/44gSc radionuclide generator induced by post-decay processes. The radionuclide generator yield was measured by γ-spectroscopy and equals to 9.8±1.0%. This result indicates the influence of post-decay processes on the initial chelate complexes for the elements with medium Z and significantly changes the overall trend.

Notes:

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Recent Studies of Light Exotic Nuclei at the Fragment Separator ACCULINNA-2 (FLNR, JINR)

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Recently the extremely neutron-rich systems 7H and 6H were studied in the direct 2H(8He,3He)7H [1,2] and 2H(8He,4He)6H [3] transfer reactions with a 26 AMeV secondary 8He beam produced at the fragment separator ACCULINNA-2 (FLNR, JINR)[4]. The missing mass spectra and center-of-mass angular distributions of 7,6H, as well as the momentum distributions of the 3H fragment in the 7,6H frames, were reconstructed.

An experimental evidence is provided that two resonant states of 7H are located in its spectrum at 2.2(5) and 5.5(3) MeV relative to the 3H+4n decay threshold. Based on the energy and angular distributions, obtained for the studied 2H(8He,3He)7H reaction, the weakly populated 2.2 MeV peak is ascribed to the 7H ground state (g.s.). It is quite possible that the 5.5 MeV state is the 5/2+ member of the 7H excitation 5/2+−3/2+ doublet, built on the 2+ configuration of valence neutrons.

The supposed 7.5 MeV state can be another member of this doublet, which could not be resolved in [1].

The measured missing mass spectrum of 6H shows a broad bump at ≈ 4−8 MeV above the 3H+3n decay. This bump can be interpreted as a broad resonant state in 6H at 6.8(5) MeV. The obtained spectrum is practically free of 6H events below 3.5 MeV. The steep rise of the 6H spectrum at ≈ 3 MeV allows us to derive the lower limit for the possible resonant-state energy in 6H to be 4.5(3) MeV. According to the paring energy estimates, such 4.5 MeV resonance is a realistic candidate for the 6H ground state. The obtained results confirm that the decay mechanism of the 7Hg.s. (2.2 MeV) is the "true" (or simultaneous) 4n emission. The resonance energy profiles and the momentum distributions of fragments of the sequential 6H ⟶ 5Hg.s. + n ⟶ 3H+3n decay were analyzed by the theoretically updated direct four-body-decay and sequential-emission mechanisms. The measured momentum distributions of the 3H fragments in the 6H rest frame indicate very strong "dineutron-type" correlations in the 5Hg.s. decay.

Very recently in the experiment [5] a peak, reported as "resonance-like structure" in 4n system, was observed in the 1H(8He,pα)4n reaction at E(4n) = 2.37 MeV with Γ = 1.75 MeV. We will present the results of studying low-energy continuum of 4n system using the data previously analyzed for the studies of 7H and 6H systems [6]. Evidence for a hump in the 4n continuum at 3.5 ± 0.7 and 3.2 ± 0.8 MeV was observed in the 2H(8He,6Li)4n and 2H(8He,3He)7H⟶3H+4n reactions, respectively. The obtained statistics is very low (6 and up to 40 events) corresponding to very low cross sections of few microbarns or tens of microbarns. The background conditions for the 2H(8He,6Li)4n reaction are shown to be good, favoring the physical nature of the observed events. The 2H(8He,3He)7H⟶3H+4n process transforms to the 2H(8He,6Li*)4n reaction in the limit of the highest 7H decay energies. The population of the low-energy region in the 4n spectrum is found to be correlated with the population of the lowest 6Li states in the 3He + 3H continuum. The results of theoretical calculations of 8He in a five-body α+4n and of 4n in a four-body hyperspherical models will be presented. The 8He wave function is shown to contain strong specific correlations, which may give rise to very low-energy structures in 4n continuum in extreme-peripheral reaction scenarios.

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Notes:

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Characterisation of the first 1/2+ excited state in ^{9}B through R-matrix analysis

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Although the ^{9}Be | ^{9}B isospin doublet has been studied along many years, the observation and prediction of the first 1/2+ state in ^{9}B remains inconclusive. Different reactions have been used, where the experimental values oscillate between 0.80 to 1.90 MeV.

An experiment was proposed to measure the charge exchange reaction of ^{9}Be(^{3}He,t)^{9}B at the K600 spectrometer, iThemba LABS. This experiment combines the high-resolution spectrometer (K600) at 0° and a high efficiency detector array CAKE. Data analysis is performed by reconstruction of the low-lying excitation region in ^{9}B through the momentum-analysis of the tritons, detected at the FOCAL PLANE in coincidence with the detection of the protons by CAKE.

Future work includes R-matrix analysis, required to unambiguously identify the first 1/2+ state in ^{9}B.

Notes:

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Fingerprints for chirality-parity violation in atomic nuclei with reflection-asymmetric triaxial particle rotor model

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Since the pioneering work of nuclear chirality by Frauendorf and Meng in 1997 [1], candidate chiral doublet bands in more than 50 nuclei have been reported [2]. Based on the microscopic relativistic density functional theory, the phenomenon of multiple chiral doublets (MχD) was predicted [3]. The observation of MχD bands with octupole correlations in ^{78}Br further shows nuclear chirality can be robust against octupole correlations and encourages the exploration of the simultaneous chiral and reflection symmetry breaking in a reflection-asymmetric triaxial nucleus [4].

In this talk, the developed reflection-asymmetric triaxial particle rotor model (RAT-PRM) will be introduced [5]. This model is applied to investigate the nuclear Chirality-Parity (ChP) violation, which simultaneously breaks chiral and reflection symmetries in the intrinsic frame. The fingerprints for the ChP violation including the nearly degenerate quartet bands and the selection rules of the electromagnetic transitions are provided [6]. By using the RAT-PRM, the observed low-lying positive- and negative-parity structures in some nuclei have been studied [7,8].

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Notes:

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The study of the spontaneous fission of heavy and superheavy nuclei

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As a result of a recent experimental series on SHELS separator (FLNR JINR), new experimental data about spontaneous fission was obtained for a range of heavy nuclei. The isotopes of interest were synthesized in complete fusion reactions (244,246Fm, 250,252,254No, 256Rf, 260Sg) and multi-nucleon transfer reactions (Am isomers). The modern SFiNx system and planned SHE Fission TPC detector aimed to investigate the SF properties of short-lived superheavy nuclei on a GRAND gas-filled separator (SHE Factory) will be discussed.

Notes:

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Role of nn and three-body interactions on the ground-state structure of 22C halo system

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In an effort to contrbitute towards a better understanding of the dynamics of three-body weakly-bound systems, we present an analysis of the effect of three-body and nucleon-nucleon interactions on the ground-state binding energy and wave function. It is found that the for a deeper three-body interaction, the 22C $\longrightarrow$ 20C + n + n remains bound even when the neutron-neutron interaction is switched off, unlike what would be intuitively assumed. These results shed more light on the relevance of the three-body force in a three-body weakly-bound system. We believe this conclusion would be valid for other three-body weakly-bound neutron systems.

Notes:

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Probing the silver isotopic chain with mass- and laser spectroscopy

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A campaign of measurements has been performed at the IGISOL facility, Accelerator Laboratory of Jyväskylä, exploring a long chain of silver isotopes resulting in measurements of charge radii, electromagnetic moments, spins, masses and excitation energies [1,2]. Different production mechanisms have been used, including fission, light- and heavy-ion fusion-evaporation. When combined with different experimental techniques, we have been able to probe the evolution of nuclear structure between the two neutron shell closures, N = 50 and N = 82.

Collinear laser spectroscopy has been performed on 113-123Ag, while in-source resonance ionization spectroscopy has explored neutron-deficient isotopes from 95Ag to 104Ag, crossing the N = 50 shell closure for the first time [3]. High-precision mass measurements across the same range of neutrons with the JYFLTRAP Penning trap mass spectrometer, combined with the laser spectroscopy data, allow for unambiguous ordering of nuclear states, with implications for earlier nuclear decay spectroscopy measurements. A new isomeric state was found in 118Ag and the atomic mass of 95Ag has been directly determined for the first time. The experimental data has provided stringent tests for theoretical calculations, including energy density functionals and state-of-the-art ab initio calculations [4].

Most recently, we have performed studies on the N = Z nucleus 94Ag, addressing a long-standing puzzle in the nature of the isomeric states, particularly the high-spin (21+) two-proton emitter. This achievement required a combination of all techniques available at the facility, resulting in almost background-free spectroscopy with rates below 1 ion every 10 minutes. The same methodology has also been applied to the neighboring N = Z 92Pd, and we keenly await the opportunity to apply our techniques to explore the doubly magic self-conjugate N = Z nucleus 100Sn in the coming years.

This presentation will summarize the results from this campaign and highlight future plans.

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Notes:

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Status of SCRIT facility for electron scattering measurement of short-lived nuclei

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SCRIT facility [1] is a unique facility specifically designed for electron scattering measurement of short-lived nuclei. In 2023, we published the world's first result [2] of the electron scattering measurement of short-lived nuclei 137Cs.
In this presentation, we will show the current status of the SCRIT facility, and the future plan for upgrade in order to further measurement of much shorter-lived nuclei. The key development is the upgrade of the electron beam power to activate the photofission of Uranium to create the short-lived nuclei. Current electron-beam power is up to 20 W, but we are now installing a larger power supply for Klystron to accelerate high current electron beam.
In this poster, we will introduce the SCRIT facility and upgrade plan in more detail.
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[2] K. Tsukada, et al., Phys. Rev. Lett. 131, 092502 (2023).

Notes:

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Exploring the Spectroscopy of the Low- and Intermediate-Spin States in \(^{148}\)Sm.

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Despite the extensive experimental and theoretical studies that have been conducted on the low-lying positive-parity 0_2^+, 2_2^+, and 4_3^+ states in the transitional deformed nuclei, their microscopic identity remains unclear. Properly understanding the nature of these states remains one of the greatest challenges in nuclear structure physics. In order to gain a deeper understanding of how such states are formed, ^{148}Nd(^{4}He, 4n)^{148}Sm fusion reactions have been carried out at the iThemba Laboratory for Accelerator Based Sciences (LABS) to populate the low and intermediate spin states in the ^{148}Sm nucleus. The AFRODITE γ-ray spectrometer used in this reaction comprised of 9 high-purity germanium detectors (HPGe), five positioned at 90° and four at 135° with respect to the beam direction. The data analysis has been carried out using both the MT-sort for sorting obtained data into γ-γ matrices and Radware software packages for decay scheme analysis. The work has extended the decay scheme of ^{148}Sm with approximately 33 γ-ray transitions, 28 new energy levels, and further made a few adjustments on both low- and intermediate spin states. Additionally, this work supports the alternating parity structures that earlier authors had observed and reported. The previously reported γ-band heads have also been further investigated, and the present analysis partially agrees with some of the proposed γ- band heads; however, no new structures have been observed on top of the γ- band head. This work has further conducted a systematic comparison of the even-even isotones in the N = 86 region to further confirm the behavior of transitional nuclei. The ^{148}Sm and its neighboring isotones exhibit the characteristics of spherical and vibrating nuclei, such behavior gives rise to mixed nuclear excitation. An improved γ-ray spectrometer with augmented low- and high-photon detectors would provide more information about the γ- bands observed in the ^{148}Sm nucleus.

Notes:

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Simulation of rare-earth ion effects on the radiation shielding parameters using Phy-X/PSD,XCOM, and Geant4 softwares in the X-ray region

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Abstract
The radiation shielding properties of the glass system 32GeO2-15B2O3-3ZnO-5P2O5-45Tb2O3 doped with Ho2O3, Pr6O11, Er2O3, Nd2O3, Dy2O3, and CeO2 within the X-ray energy range of 0.03–0.3 MeV have been investigated.The linear attenuation coefficient (LAC) of the glasses was calculated using Phys-X/PSD,XCOM, and Geant4 softwares at different energies. It was found that the LAC of the GeO2-B2O3-ZnO-P2O5-Tb2O3 glass system increases after incorporating the RE oxides. The LAC of the samples depends on the types of dopants and the density of the RE

oxides. It was found that the glass doped by H2O3 (coded asT45-Ho) has higher LAC than the other glasses with RE, while the glass not being doped by any rare earth ion (coded as T45) has the lowest LAC. The effective atomic number (Zeff) results demonstrated that the Zeff for the glasses doped with the RE oxides are improved relative to the Zeff for the reference glass (i.e., glass without RE). The glass with Er2O3 (coded as T45-Er) has slightly higher Zeff than the other glasses with RE oxides, while T45-Ce has the minimum Zeff. The results showed that rare-earth dopants, especially Ce and Nd, significantly improved the shielding capabilities of the glass systems, with notable increases in MAC and Zeff values compared to undoped glasses. These findings highlight the potential of rareearth-doped glasses for enhanced radiation shielding applications, providing a lightweight and efficient alternative for protective materials in various industries.

Notes:

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Nuclear spectroscopy projects at center for exotic nuclear studies (CENS)

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Center for Exotic Nuclear Study in the Institute of Basic Science was recently founded to study fundamental questions in astrophysics and nuclear physics through investigations of radioactive atomic nuclei. The center is composed of four groups: experimental nuclear structure, experimental nuclear reaction, experimental nuclear astrophysics, and nuclear theory.
In the experimental groups, many detectors are currently under development/planned which can be applied for the nuclear spectroscopic study at new accelerator facility RAON, such as Clover HPGe detector array (ASGARD), Co-axial Ge detector array, Si detector array (STARK and STARK-Jr), LaBr3 detector array (KHALA), conversion electron detector array (SCEPTER) and neutron detector array (PANDORA II). Several projects utilizing detectors such as decay station and in-beam gamma-ray spectroscopy have recently started for low-energy branches at RAON. Also, many international collaboration projects are ongoing, such as the IDATEN project utilizing the LaBr3 detector array from Korea and the UK, forming the largest LaBr3 array at RIBF RIKEN. The current status of the detector system development for nuclear spectroscopy and possible setups will be presented.

Notes:

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ROLE OF NUCLEAR INTERACTIONS ON THE GROUND-STATE STRUCTURE OF A THREE-BODY SYSTEM

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In the study of three-body weakly-bound systems, a three-body interaction is always introduced to take care of the dynamics that cannot be accounted for by two-body interactions. In order to get some insight into these dynamics, in this presentation, we study the relevance of the three-body interaction as the number of neutrons in the three-body system increases, considering ^{6}He systems.

It is found that by removing this interaction from the structure of the system, the ground-state binding energy of the ^{6}He system drops by about 80%. This shows that the three-body interaction plays a significant role in the dynamics of a three-body weakly-bound neutron-rich system.

Notes:

Key words: Three-body system, Three-body interaction, Binding Energy

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Experimental study of multinucleon transfer reactions in the interaction of heavy ions with ^{238}U

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Nowadays multinucleon transfer reactions (MNT) are considered as an alternative approach to produce and investigate of new nuclei, including far from the line of stability. The formation of new neutron-rich nuclei in the region of heavy and superheavy nuclei is of particular interest. The use of uranium as a target in the reactions with heavy ions is one of available methods for the production of such superheavy nuclei in MNT reactions.

In Flerov Laboratory of Nuclear Reactions of Joint Institute for Nuclear Research at modified Time-of-Flight (ToF) spectrometer CORSET [1] MNT reactions were experimentally investigated in collisions of heavy ions such as ^{136}Xe [2] and ^{209}Bi with ^{238}U at the incident energy ≈ 8 MeV / nucleon. Due to correlated measurements using ToF-ToF and ToF-E methods, mass and energy distributions of primary and secondary binary MNT fragments have been obtained in a selected angular range. Together with binary reaction products 3-body events have been registered, which originated from sequential fission of heavy excited MNT fragment. The analysis of such events allowed to restore primary mass distributions of fissioning heavy MNT fragments with masses up to A = 279. The obtained experimental results will be presented.

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Notes:

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Development of CENS silicon sensor and STARK commisioning at RAON

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The Silicon Telescope Array for Reaction studies in Inverse Kinematics (STARK) is currently in development at the Center for Exotic Nuclear Studies. Its primary objective is to conduct comprehensive nuclear reaction experiments, encompassing elastic scattering and neutron transfer reactions. The array comprises 40 double-sided, resistive silicon strip detectors, as well as 12 single-sided, non-resistive strip detectors. These detectors are strategically organized into three concentric rings, collectively providing extensive angular coverage for experimental investigations.
In this study, we designed PN-junctions with high electric fields on n-type substrates to operate single-sided strip detectors which can be installed in the STARK detector array, capable of withstanding breakdown even at approximately 200 volts while maintaining low leakage current. Additionally, we designed and fabricated sensors with 8 channels over a wide area of approximately 77 x 42 mm². The design and test results for various in-house multi-channel silicon strip sensors fabricated in Korea. Development of CENS silicon sensor and STARK commisioning at RAON will be presented.

Notes:

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Development and testing of a FEBIAD ion-source for the LERIB project

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Radioactive Ion Beams (RIBs) play an important role in advancing nuclear physics by offering unique insights into nuclear reactions. The interdisciplinary nature of RIBs research, along with its potential impact on fundamental and medical physics, positions RIBs facilities as essential drivers for enhancing our understanding of nuclear phenomena. Two methods are commonly used for radioactive isotope production: in-flight and ISOL (Isotope Separation On-Line) techniques [1]. After production of a nuclide, it has to be separated from unwanted by-products and transported away from the harsh production environment.
The ISOL techniques, uses an ion source to further separate the unwanted by-products, and produce a radioactive ion beam. The ion-sources dedicated to the production of Radioactive Ion Beams (RIB) have to be highly efficient, selective (to reduce the isobar contamination) and fast (to limit the decay losses of short-lived isotopes). An offline test-facility needed to the development of a Forced Electron Beam Induced Arc Discharge (FEBIAD) ion-source. The FEBIAD ion-source is a type of plasma ion-source that has the advantage of being able to ionize most elements on the periodic table through electron impact ionization, based on the Forced Electron Beam Induced Arc Discharge design [2].
The future aim of the LERIB project at iThemba LABS is of the production of radionuclide isotopes such as Terbium and Actinium, which are used in medical therapy or/and diagnosis. Through the combination of element-sensitive ion source and mass separation (magnetic dipole) would in principle allow the extraction of a pure beam, only containing the isotope of interest.
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Notes:

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EXPERIMENTAL STUDY OF INTERACTION MECHANISMS IN THE REACTIONS WITH HEAVY IONS

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The reaction mechanisms have been investigated intensively in many reactions with heavy ions. Several processes can take place at the interaction of two colliding nuclei. The main of them are fusion-fission, quasifission, fast fission, the formation of the evaporation residue, deep inelastic collisions and, finally, quasielastic and elastic scattering.
A big set of the experimental data obtained in very different nuclear reactions were measured with use of double-arm Time-Of-Flight spectrometer CORSET [1], which allows to measure binary processes with high accuracy. The experiments were carried out in FLNR JINR at U-400 and U-400M accelerators, and in other European and American scientific centers as well. The investigated compound nuclei formed in the reactions last from neutron-deficient ^{178}Pt up to superheavy nucleus with Z=122. Many of the reactions were measured in wide energy range, below and well above the Coulomb barrier. The contribution of different processes in the mass-energy distributions of the reaction products is mainly defined by the entrance channel characteristics, such like mass asymmetry of the reaction partners, Coulomb factor (Z_1Z_2), angular momentum and excitation energy of the compound system, etc. It was shown that in some case it is possible to distinguish different mechanisms and extract their corresponding mass-energy distributions. Moreover, the applied experimental methods give the possibility to deduce the cross-section values of different processes.
The detailed and complex analysis of mass and energy distributions of the fusion-fission fragments indicates that not only spherical proton and neutron shells influence on the behavior of mass and energy distributions, but deformed proton shells either. In quasifission process which conquers with fusion-fission the influence of shell effects was also observed.
Possible ways of the set-up development will be also discussed in the presentation. The proposed upgrade of the spectrometer would significantly enlarge the facilities for experimental investigations of the reaction mechanisms observed in reactions with different entrance channel properties, and allow investigations of the structure both reaction products and evaporation residues.

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Notes:

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Measurements of differential cross sections of inelastic scattering of 14.1 MeV neutrons on light nuclei using the tagged neutron method

Authors: Yuri Kopatch[1]; Nikita Fedorov[2]; Dimitar Grozdanov[3]; Pavel Prusachenko[2]; Polina Filonchik[4]; Ivan Ruskov[3]; Vadim Skoy[2]; Tatiana Tretyakova[5]; Petr Kharlamov[5]; Alexandr Andreev[6]; Grigory Pampushik[6]; Constantin Hramco[2]

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A study of the inelastic scattering of neutrons with an energy of 14.1 MeV on the light nuclei was carried out at the TANGRA facility at JINR (Dubna) using the tagged neutron method (TNM) [1]. The D-T neutron generator ING-27 with built-in position sensitive detector of α-particles was employed as a source of tagged 14.1 MeV neutrons. Different types of detector systems were used to register gamma quanta and scattered neutrons from reactions induced by the neutrons hitting the target used. The γ-rays were measured by means of two high-purity germanium (HPGe) detectors and four $LaBr_3$ scintillators positioned at specific angles [2]. The most complete data were obtained with a carbon target, for which the scattered neutrons and γ-rays were measured by an array of plastic scintillator detectors surrounding the graphite target. The neutron/gamma separation and determination of scattered neutron energies were done by the time-of-flight method.
New results on differential cross sections of γ-ray emission, as well as neutron-gamma angular correlations will be presented.
This work is supported by the RSCF grant N 23-12-00239.

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Notes:

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The Development and Application of CIAE's Cyclotrons for the medical isotopes production

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Since the establishment of the first cyclotron in China in 1958, the China Institute of Atomic Energy (CIAE) has developed a series of high-current cyclotron devices, which are playing a crucial role in the development of nuclear science disciplines and applications of nuclear technology in China. In 1996, CIAE had developed the first proton cyclotron of 30 MeV/350 μA in China for medical isotope production and 57Co,67Ga,111In,201Tl and other radioisotopes were produced successfully by this cyclotron. The 14 MeV PET cyclotron was built in 2012 and lots of isotopes for the PET such as 18F, 11C, 13N, 89Zr were produced by this machine. The 100 MeV cyclotron of CIAE-100 was developed in 2014 in CIAE, which is the largest compact cyclotron in the word. The maximum of beam current is 520 μA and the beam power is 52kW for CIAE-100. 68Ge was produced successfully and several experiments for the isotope production of 225Ac were finished by CYCIAE-100. The first 14MeV/18MeV cyclotron with mA level was developed independently by CIAE in 2021 and it was used for the treatment of boron neutron capture therapy (BNCT). In order to produce the isotope such as 68Ge, 225Ac, 223Ra, etc, a 75MeV cyclotron with the beam current of 800μA will be built by CIAE in China. The proton energy range of 30 ~ 75MeV will be extracted and the beam power will be got 60kW for 75MeV cyclotron. Many kinds of the medical radioisotopes such as 68Ge/68Ga, 223Ra, 225Ac, 213Bi, 82Sr/82Rb, 67Cu, 44/47Sc will be produced by 75 MeV cyclotron.

Notes:

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Analysis of neutron and proton halo breakup cross sections

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We use the continuum discretized coupled channel method to study in detail the similarities and differences between neutron and proton, total, nuclear and Coulomb breakup cross sections in the breakups reaction of 8B>7Be+P and 8Be>7Be+n with the difference target masses (12C, 28Si, 58Ni, 181Ta, 208Pb and 238U). Our preliminary results reveals that neutron halo breakup cross sections are larger than the proton halo breakup cross sections. On the other hand, we also found that the continuum continuum couplings are more stronger in the neutron halo breakup cross sections than in the proton halo breakup cross sections.

Notes:

Nuclear Reactions

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Dynamics of multi-nucleon transfer processes in the ^{56}Fe + ^{208}Pb reaction

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The report is devoted to the theoretical study of the main characteristics of the ^{56}Fe + ^{208}Pb reaction at $E_{lab} = 340$ MeV within the multidimensional dynamical model based on Langevin equations [1]. Calculation results are compared to available experimental data on energy, atomic number and angular distributions of projectile-like fragments [2]. Better agreement of theoretical and experimental data has been reached by varying the model parameter: relaxation time of neck degree of freedom. Influence of this model parameter on the kinetic energy of fragments is discussed in the report.
This improvement of the model allows us to describe more properly multinucleon transfer processes in similar systems including ^{208}Pb nucleus, such as ^{58}Ni, ^{64}Ni + ^{208}Pb. Cross sections of heavy neutron-rich nuclei with the closed neutron shell $N = 126$ obtained in the reactions under study have been calculated and compared with corresponding cross sections obtained in the reactions ^{136}Xe + ^{198}Pt, ^{208}Pb.

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Notes:

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How far are we with Auger emitting Isotopes as the next frontier in Nuclear Medicine ?

Authors: Jan Rijn Zeevaart[1]; Cathryn Driver[2]; Hein Fourie[3]; Zoltan Szucs[4]

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Auger electron (AE) radiopharmaceutical therapy or Targeted Auger Therapy (TAET) may have the same therapeutic efficacy as alpha-particles for oncologic small disease, with lower risks of normal-tissue toxicity. The seeds of using AE emitters for RPT were planted several decades ago yet it is no anywhere near clinical use. The furthest is probably Tb-161 [1] which a combination of beta emission supplemented with AE (often referred to as Lu-177+) and not pure TAET.
This paper will attempt to give an overview of isotopes considered aspects in terms of half-life, AE energy deposition, co-emission of gamma, theranostic pairs and availability. This is based on recent literature on this topic [2,3].
Lastly the mechanism of action for AE has always been believed to be through double strand breaks in the DNA. It has been recently demonstrated that this may not been universally true in every situation [1,4].

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Notes:

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Two-neutron-transfer to ^{178}Yb and Population of ^{178m2}Hf via Incomplete Fusion

Authors: Simon Mullins[1]; Bongani Maqabuka[2]; Robert Bark[3]; Sergei Bogolomov[4]; Simon Connell[2]; Efremov Andrei[4]; Istvan Kuti[5]; Elena Lawrie[3]; Kobus Lawrie[6]; Siyabonga Majola[2]; Jozsef Molnar[5]; Sean Murray[7]; Barna Nyako[5]; Paul Papka[None]; Rainer Thomae[None]

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The DIAMANT light-charged-particle detector from ATOMKI was coupled with the AFRODITE gamma-ray spectrometer at iThemba LABS in a collaboration enabled by a bilateral agreement between the governments of South Africa and Hungary. This facilitated the study of incomplete fusion reactions in the bombardment of a Ytterbium-176 target with a beam of 50 MeV Lithium-7 ions. The beam was generated as a collaborative effort between ion source experts at iThemba LABS and the Flerov Laboratory for Nuclear Reactions (FLNR) of the Joint Institute for Nuclear Reactions (JINR), Dubna.

Particle-Identification (PID) spectra from DIAMANT generated from the ATOMKI custom-built VXI electronics clearly show the detection of protons, tritons and alpha particles, which, when gated on, allowed the selection of gamma-ray coincidences detected with AFRODITE when the respective complementary Helium-6, Helium-4 (α) and triton fragments fused with the target.

Analysis of the charged-particle-selected gamma-ray coincidence data enabled the identification of Hafnium-180 in the proton-gated Eγ -Eγ correlation matrix, as well as Hafnium-178, including the band based on the $T_{1/2}$ = 31a, $K^{\pi} = 16^{+}$ four-quasiparticle state. Hafnium-178 is also evident in the triton-gated matrix, which suggests that this nucleus is populated via two incomplete fusion channels, this one in which the fused fragment is Helium-4, and the other in which a Helium-6 neutron-rich fragment fuses with the Ytterbium-176 target.

The relative contribution from the (^{7}Li,p4n) fusion evaporation channel is unclear, but there is other evidence for Helium-6-induced reactions in the population of neutron-rich Ytterbium-178 whereby two neutrons have been transferred to the target. The ground-state band of Ytterbium-178 can be clearly observed in both the proton-gated and alpha-gated matrices, which supports the assignment of the ^{176}Yb(^{7}Li,αp)^{178}Yb reaction. The deuteron yield is comparatively weak which has hampered the unambiguous confirmation of the ^{176}Yb(^{7}Li, αd)^{177}Yb reaction.

The comparatively strong population of Hafnium-178 via the two reaction channels discussed above has allowed the population ratio Iγ(proton-gated)/ Iγ(triton-gated) of the ground-state, two-quasiparticle $K^{\pi} = 8^{-}$ and four-quasiparticle $K^{\pi} = 14^{-}$ and $K^{\pi} = 16^{+}$ bands to be extracted as function of spin . There is evidence for a marked increase in relative population of the $K^{\pi} = 16^{+}$ band when compared to the other lower-spin band structures.

Notes:

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Quarks in Nuclei: From Neutron Halo to the Boundary of Nuclear Stability

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In the framework of the semi-empirical quark model of nuclear structure that is based on the quark model of the nucleon, the Strongly Correlated Quark Model (SCQM) [1] we construct nuclei from light to heavy ones, including halo nuclei. Nucleons inside nuclei are bound due to junctions of SU(3) color fields of quarks [1]. According to SCQM, arrangement of nucleons within nuclei reveals the emergence of the face-centered cubic (FCC) symmetry [2]. The model of nuclear structure becomes isomorphic to the shell model and, moreover, composes the features of cluster models. Binding of nucleons in stable nuclei are provided by quark loops which form three and four nucleon correlations. Three nucleon correlations are responsible for the structure of "halo" nuclei. Quark loops leading to four-nucleon correlations are responsible for binding energy enhancement in even-even nuclei. In turn, four-nucleon correlations can be considered as virtual alpha-clusters. In this way all inner closure shells are rearranged into the face-centered cubic lattice with alternating spin-isospin layers. For medium and heavy nuclei the arrangement of nucleons in alternating spin-isospin layers is modified by Coulomb repulsion of protons. This effect together with quark/nucleon correlations leads to deviation from the shell model expectations. The model describes well quadrupole moments of nuclei, although, deformation of nuclei is much more complicated. Moreover, it shows that neutron and correspondingly matter distributions are deform essentially larger. The model can predict the boundary of the maximal numbers of proton and neutron excess, i.e. proton and neutron drip lines.

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Notes:

I need 25 minutes for presentation

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Determining the resonance states 0^+ of the Boron isotope 8B from partial cross-sections using the Jost-matrix approach.

Authors: Tshegofatso Tshipi[1]; Sergei Rakitianski[2]

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When attempting to extract resonance parameters from the energy-dependent cross-section data, one must fit the data at scattering (real) energies -physical sheet of the Riemann surface- afterwards then perform an analytic continuation to the unphysical sheet where the resonances are located.

When we are dealing with a multi-channel problem that consists of charged particles, the corresponding Riemann surface becomes complicated, i.e. having intricate interconnected sheets. This is due to the square-root and logarithmic branching points at the threshold energy. By using the Jost matrix approach, we can isolate the problematic factors that are responsible for branching, therefore making it easier to explore all the sheets of the Riemann surface. In this way we can accurately locate the resonance parameters. In this approach, the resonance parameters are obtained as zeros of the Jost function (matrix) on the unphysical sheet.

We used the R-matrix and Jost matrix approach to determine the two-channel 0^+resonance state of Boron-8. The R-matrix predicted a single state, while the Jost approach predicted the existence of two nearly overlapping states (one of which matches with the R-matrix result). We believe that the reason why the R-matrix did not pick up the second state is that it has a simplified analytic structure. This is based on the knowledge that it estimates the resonance parameters using only of the real energies, which is not enough to capture the intricate interconnected sheets of the Riemann surface.

In practice, we recommend using the R-matrix to parameterize the data (since it requires fewer parameters), then use the Jost approach to do analytic continuation to the unphysical sheet to determine resonance parameters. By combining these two approaches, it will be able to obtain accurate results.

Notes:

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Fission isomers among fission fragments - new results in studies of their break-up in the solid-state foils

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2 Joint Institute for Nuclear Research, 141980 Dubna, Russia

`In our previous publications [1-4] we presented experimental evidences of rare ternary decay`

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Notes:

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Highlights from INFN-LNL, the Status and the Future plans of the SPES project

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Faical Azaiez LNL-INFN, Legnaro-Padova, Italy

INFN-LNL is a large scale facility that offers for users access to up to 5 accelerators covering a large range of ions (from proton to Uranium) and a large range of energy (few hundreds of KeV to few Tens of MeV per nucleon). The flagship project of LNL is SPES (Selective Production of Exotic Species) that aims at the realization of an accelerator facility for research in the fields of Fundamental Physics and Interdisciplinary Physics usings ISOL (Isotope Separation On Line) type of rare isotopes. SPES aims also at building a facility that will be dedicated to Research and Development of innovative radioisotopes for medical diagnostics and therapies.

In my talk the status and future plans of the SPES project as well as some highlights from LNL related to the AGATA measurements campaign will be presented.

Notes:

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Reaction cross sections for light proton-rich nuclei

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Light nuclei away from the valley of stability are characterized by low binding energies for valence nucleons, leading to the formation of an extended matter distribution that, in some nuclei, appear as exotic configurations like halo (e.g. ^{8}B and ^{11}Be) and borromean (e.g. ^{6}He and ^{11}Li) structures. These exotic structures manifest themselves in a nuclear collision as a narrow momentum distribution of the fragments after breakup and enhancement of the interaction cross section. These signatures are readily apparent at energies around the Coulomb barrier (V_b).

In this talk I will cover some of the recent experimental results with exotic nuclei with emphasis on proton-rich nuclei and limitations of reduction methods often used to compare the reduced reaction cross sections among the systems.

Notes:

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Recent achievements regarding the dynamics of weakly bound nuclei at energies around the Coulomb barrier

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During the last 8 years, we have carried out a series of experiments in different laboratories involving reactions with weakly bound nuclei, mostly halo nuclei, impinging in medium mass and heavy targets at energies in the vicinity of the Coulomb barrier. For several years, the analysis of this kind of reaction has shown a degree of differences in the elastic scattering comparing with stable similar nuclei in the same conditions.
On the other hand, the reaction products appearing in some of these reactions have shown the preference to follow not always the same process, when the reaction is measured in a wide angular range. The global conclusion till this moment shows that, not all the halos follow the same reaction processes when their dynamics is tested at barrier energies. In the present work, recent visited cases will be presented, as well as a brief description of the instrumentation developed for such studies.

Notes:

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Evidence for multiple octupole correlations in nuclei

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High spin states of odd odd 152Eu were populated using the 150Nd(7Li, 5n) reaction with the beam energy of 42 MeV. Two positive and two negative parity rotational bands were observed in this nuclues, as well as two sets of E1 linking transitions between the opposite parity bands 1&3 and bands 1&4. Based on the measured lifetimes of the levels, it is found the B(E1) values in 152Eu is relatively large (larger than 10^-5 W.u.), which indicate multiple octupole correlations exist in 152Eu. A systematic comparison with neighboring odd A nuclei shows that BE1 in 152Eu is significantly reduced, perhaps due to changes in the number of nucleons that alter the positions of the nucleus's center of charge and center of mass.

Notes:

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Excitation of ^{93m}Mo secondary beam ions in HIRFL

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Nuclear Excitation by Electron Capture (NEEC) was predicted by Goldanskii and Namiot as the inverse process of internal conversion in 1976[1]. It was expected to play an important role in the isomer depletion, which is a potential path for releasing nuclei energy stored in isomer[2].
The first experimental observation on NEEC was reported in the slowing down process of ^{93}Mo[3]. The observed isomer depletion probability was too large to be reproduced by Coulomb excitation, and thus attributed to NEEC. However, it also failed to be reproduced by following theoretical works[4,5]. On the experimental side, a comment was addressed on the influence of complex γ background which may cause the overestimation of isomer depletion probability[6]. Later, an independent experiment was performed using a ^{93m}Mo secondary beam, but no isomer depletion was observed with an accuracy of 2×10^{-5}, which was reported as the upper limit of the excitation probability[7]. However, this measurement was performed with lower recoiling energies than the previous experimental work.
A refined experiment has been performed with higher recoiling energy and purity of the ^{93m}Mo isomer beam. Both lead and carbon foils were used to stop the ^{93m}Mo ions. Isomer depletion is observed, and the excitation probability is about $2 10^{-5}$ *for lead, and* $3 10^{-6}$ for carbon. These results agree well with the calculated probabilities for inelastic reactions, which are suggested to the main mechanisms exciting the ^{93m}Mo isomer during its stopping process.

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Notes:

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Involving low energy accelerators in exotic nuclei research

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In this presentation a brief review is made of the two main accelerator facilities that participate in the experimental nuclear physics program at IFUNAM in Mexico.
I will briefly describe our participation in the study of the unbound di-nucleon systems (**2n and 2He**) using traditional coincidence methods.
The use of the activation with charged particles followed by AMS (AFAMS) to study the **11Be** nucleus, as well as other applications.
The study of rotational bands in light nuclei taking advantage of our supersonic gas jet target.
The upgrade of our 5.5 MV single-ended electrostatic (Van de Graaff) accelerator with a new Electron Cyclotron Resonance Ion Source, in collaboration with JINR will also be described, together with its applications to the production of monoisotopic targets of noble gases.

Notes:

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Reaction cross sections for light proton-rich nuclei

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Light nuclei away from the valley of stability are characterized by low binding energies for valence nucleons, leading to the formation of an extended matter distribution that, in some nuclei, appear as exotic configurations like halo (e.g. 8B and 11Be) and borromean (e.g. 6He and 11Li) structures. These exotic structures manifest themselves in a nuclear collision as a narrow momentum distribution of the fragments after breakup and enhancement of the interaction cross section. These signatures are readily apparent at energies around the Coulomb barrier (Vb).
In this talk I will cover some of the recent experimental results with exotic nuclei with emphasis on proton-rich nuclei and the (possibly) limitations of the reduction method often used to compare the reduced reaction cross sections among the systems.

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A new region of fission isomers in medium-mass nuclei

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In a long series of experiments, in different settings, we have observed the Coulomb induced break-up of the fission fragments (FFs) in the solid foils [1, 2]. The break-up occurs with a delay after the initial binary fission event of the mother system. The fusion-fission channel is excluded as a cause of the break-up at the typical energies of the FFs undergoing the break-up which are approximately 1 MeV per nucleon. In our experiments, the time-of-flight between the FF's source and the foil where

the break-up takes place provided an estimate of the delay. This value can be regarded as a lower estimate of the lifetimes of the shape isomer states of the FFs undergoing the break-up. It is estimated to be up to 400ns. The discussed in this work results on the induced break-up of the medium-mass nucleus from the shape isomer state have not been observed experimentally before, and there are no theoretical predictions of the observed effect.
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Notes:

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Recent Research Developments at RAON: Focus on KoBRA and NDPS

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The RAON facility includes multiple experimental systems. These systems include the Korea Broad Acceptance Recoil Spectrometer and Apparatus (KoBRA), focused on rare ion beam (RI) research, and the Nuclear Data Production System (NDPS), a neutron production system.
KoBRA operates with stable and rare isotope beams at low energies of 1–40 MeV/u, facilitating experiments in nuclear physics. Following the first commissioning of the KoBRA facility in 2023, several experiments were completed in 2024. These experiments utilized a 40Ar primary beam with a 12C target, producing and identifying rare isotope beams. The production cross sections and momentum distributions of the RI beams were measured. Additional research included 40Ar(p,p) scattering to evaluate models that describe nuclear reactions at low energies. The capacity for single-event effect (SEE) testing was also demonstrated by irradiating space-grade semiconductors with heavy ion beams at various Linear Energy Transfer (LET) values. Furthermore, the first commissioning of the ISOL beam was completed, and the 25Na ISOL beam was accelerated through SCL3 and identified at KoBRA.
NDPS, which recently completed commissioning, established neutron production capabilities at RAON. KoBRA and NDPS contribute to the research conducted at RAON, supporting fundamental and applied studies in nuclear and neutron physics.

Notes:

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Physics with the K600 at iThemba LABS

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The K=600 magnetic spectrometer at iThemba LABS is a high resolution kinematically corrected magnetic spectrometer for light ions. It has been used in nuclear reaction and structure studies since its installation in 1994. Over the years its capabilities has been expanded and it now has the capability to measure inelastically scattered particles and reactions at extreme forward angles that includes zero degrees, making it one of only two facilities worldwide (the other being at RCNP, Japan)

where high energy resolution is combined with zero degree measurements at medium beam energies. The advantage of such measurements is the selectivity it provides to excitations with low angular momentum transfer. The recent addition of coincident particle and gamma detection capabilities further enhances the selectivity of the K=600 magnetic spectrometer, and opens up a host of new opportunities to be explored, some of which will be discussed in more detail.

Notes:

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Terbium-149 production: a pragmatic view of its preparation for medical application

Authors: Nicholas van der Meulen[1]; Cristina Mueller[1]; Ulli Koester[2]

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Terbium-149 has been proposed as an attractive candidate for Targeted Alpha Therapy (TAT) in nuclear medicine [1], due to its favourable physical decay properties (T1/2 = 4.1 h, Eα = 3.97 MeV, 17%; Eβ+ mean = 720 keV, 7%) [2]. While preclinical studies continue to demonstrate its therapeutic potential [3-5], it was also shown that it can be used for positron emission tomography [4]. The absence of daughter nuclides emitting relevant quantities of α-particles, an advantage over other radionuclides envisaged for TAT, make it a promising radionuclide, despite its limited development to date.

Terbium-149 has been produced at CERN-ISOLDE via spallation in a tantalum target induced by high-energy (1.4 GeV) protons, followed by diffusion, effusion and ionization of the spallation products and subsequent on-line mass-separation. The mass 149 isobars have been collected in zinc-coated gold/platinum/tantalum foils and shipped to Paul Scherrer Institute (PSI), where terbium-149 was chemically separated from its isobaric impurities and the collection material. This was optimized over the last decade using cation exchange and extraction chromatography, respectively [4-6]. The quality of the radionuclide produced was assessed by means of radiolabelling experiments (at molar activities up to 50 MBq/nmol with >99% radiochemical purity), together with γ-spectrometry and inductively coupled plasma measurements. Radionuclidic purity was determined to be up to 99.8%.

The collection of mass separated-terbium-149 and the subsequent radiochemical separation process has steadily improved over the years, such that higher activities can be collected and isolated, while the quality of product can ensure more efficient labelling of tumour-targeting small molecules. While only CERN-ISOLDE and TRIUMF-ISAC currently produce this radionuclide with limited available beam time, the interest in the radionuclide remains high. New facilities (IMPACT-TATTOOS and ISOL@MYRRHA, respectively) plan to upscale and produce large activities of interesting radionuclides, including terbium-149, towards medical research and potential clinical application.

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Notes:

Under the topic "Isotopes in Nuclear Medicine".

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Evaluating DNA damage and repair mechanism in TP53 wild-type and mutant medulloblastoma cell lines after AMG232 treatment combined with photon irradiation

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Abstract
The tumour suppressor protein p53, encoded by the TP53 gene, plays a vital role in preventing tumour development. However, in numerous cancers, TP53 mutations or dysregulations result in compromised p53 functionality. AMG232, a potent MDM2 antagonist, has garnered attention for its potential to enhance tumour cell radiosensitivity. This study aimed to assess AMG232's efficacy in sensitizing medulloblastoma (MB) cells to photon irradiation via activation of the p53 pathway. Human MB cell lines, ONS-76 (TP53 wild-type) and DAOY (TP53 mutant), were exposed to photon irradiation and treated with AMG232, both as single and combined therapies. DNA damage was quantified through gamma-H2AX foci assays, revealing a significantly higher number of DNA damage foci in DAOY cells compared to ONS-76, indicating greater DNA damage and delayed repair kinetics. Notably, combined AMG232 and photon irradiation treatment resulted in a marked increase in DNA damage in ONS-76 cells relative to either treatment alone. In contrast, DAOY cells exhibited significant sensitivity to AMG232, independent of irradiation. The results suggest that AMG232 effectively enhances MB cell radiosensitivity, particularly in cells with functional TP53, while showing potential as a standalone treatment in cells with TP53 mutations. These findings indicate that AMG232 could be a valuable adjunct to radiotherapy in the management of high-grade brain tumours such as MB.
Keywords: p53 pathway, medulloblastoma, AMG232, DNA damage, photon irradiation

Notes:

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Linear heavy ion accelerators for low-energy physics

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The high intensity heavy ion linac is an attractive instrument for the nuclear investigation. The high energy linac can be effectively used for the rare isotope production (for example – FRIB facility in MSU, USA). The low energy linac (~ 7 MeV/nucleon) can be used for multi-nucleon transfer reactions investigation. In particular, the reactions study is important for understanding the so-called 3rd peak of the distributions of the astrophysical p-process. The project of the room temperature heavy ion cw-linac is based on the technology which is under development in framework of compact accelerator driven neutron source DARIA setup. The talk presents the linac structure as well as the current status of the cw RFQ and DTL development in framework of DARIA project.

Notes:

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Hypernuclear structures in relativistic mean field model

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Prof. Ting-Ting Sun
I will talk the recent development of the Green's function method in the RMF and RHB theory both in spherical and axially deformed cases, as well as the applications for the study of single-particle resonant states, pseudospin symmetries, halo and deformed halo in exotic nucle.

Notes:

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Mapping shape co-existence in the rare-earth, N<98 regions.

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The shape coexistence effect in the rare earth region has been extensively studied in nuclei such as lead (Pb), mercury (Hg), platinum (Pt), and osmium (Os). In these nuclei, the excited 0+ bands appear at low energy and serve as intruder bands in the shape coexistence model. This phenomenon has also been observed in the lower mass region around $Z \approx 64$ and $N \approx 90$. However, there remains an unobserved gap in shape coexistence for nuclei within the range of $70 < Z < 78$.
Therefore, this research is devoted to extending the conversion-electron studies into the yet-to-be-measured Hf isotopes, and the N<98 region. In particular, 164Hf has been chosen, as relatively little is known about this nucleus from electron capture (EC)-decay where the 0+ states could be measured. There are two measurements this research proposes to study the excited states of 164Hf using the iThemba LAB's facilities. The excited low spins, non-yrast, states of 164Hf are populated through the EC-decay of 164Ta (formed using the 141Pr(28Si,5n) reaction) using the Tape-Station facility. In the other measurements, the higher spins, yrast, states of 164Hf are populated directly through the in-beam (20Ne+148Sm) reaction at the AFRODITE facility. The two measurements complement each other. CERN ROOT code was successfully developed to analyze the data. A new "gamma" band and several transitions have tentatively been observed and added to the level structure of 164Hf. The preliminary results of the angular distribution ratios and polarization to measure the spins and parities are in agreement with previously known states and give confidence for the newly observed state. The half-lives of previously and newly observed gamma-ray transitions are measured and agree with previously measured ones.

Notes:

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Theoretical wonder for New Facilities with Rare Isotope Beams

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The existence limit of nuclei and the origin of the heavy elements are fundamental problems in modern science. The relativistic density functional theory starts from a universal density functional and has achieved great successes in describing many nuclear phenomena. New physics wonder may result from the strong coupling between theory and experiment perspectives. In this talk, the predictive power of PC-PK1 is demonstrated, physics around the neutron drip line and N=Z nuclei are discussed, status of the DRHBc mass table collaboration is introduced as well as the effects of the continuum and deformation and the related topics. Relativistic density functional theory in 3D lattice and its time-dependent version for Linear-chain, Chiral dynamics, Fission, etc are briefly mentioned. Strategy to build density functional based on QCD-spirited interaction and ab inito calculation are outlined.

Notes:

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Migration behavior of silver in SiO2-SiC double layer

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In nuclear fuels, thin film diffusion barriers are necessary to prevent the release of radioactive waste products. The combination of chemically stable silicon carbide (SiC) and silicon oxide (SiO2) layers was considered to be beneficial in preventing the release of silver from TRISO particle fuel, at normal reactor operating temperatures (between 800 and 1000 ℃). However, it is important to investigate the efficiency of the SiO2–SiC double layer at higher temperatures, similar to temperatures under accident conditions. In this study, 300 keV silver (Ag) ions were implanted into polycrystalline SiC to a fluence of 1×1016 ions/cm2 in vacuum at room temperature and 600 ℃. The as-implanted SiC samples were coated with SiO2 layers to a thickness of about 100 nm, using DC magnetron sputtering. After SiO2 deposition, the samples were subjected to sequential isochronal annealing at temperatures ranging from 1100 to 1400 ℃ in steps of 100 ℃ for 5 hours, using a vacuum tube furnace. The thickness of the SiO2 layers before and after annealing as well as and the migration behavior of Ag in the SiO2–SiC double layer were investigated using Rutherford backscattering spectrometry (RBS) and annular bright-field scanning transmission electron microscopy (ABF-STEM). Our investigations show no diffusion of Ag in SiC after annealing at 1100, 1200 and 1300 ℃. However, annealing at temperatures from 1100 to 1300 ℃ caused partial sublimation of SiO2 layer and thermal etching of SiC surface. Moreover, RBS results showed that annealing at 1400 ℃ resulted in the complete sublimation of SiO2 layer from the surface of SiC, while thermal etching of SiC caused a shift in the Ag depth profile towards the surface. This indicates that SiO2 is not suitable for use as an additional diffusion barrier for SiC where temperatures in a nuclear reactor can reach 1600 ℃ during accident conditions.

Notes:

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Theoretical study of superheavy nuclei with the Dinuclear System model

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This research investigates fusion reactions, focusing on the complex dynamics of nuclear fusion below and above the Coulomb barrier, and the formation of superheavy elements. Using the Dinuclear System model, the study aims to understand how multi-neutron transfer channels impact fusion cross-sections and contribute to the identification of tetra-neutron states in weakly-bound neutron-rich systems like 14Be and 16Be. Additionally, it explores the production of superheavy nuclei through fusion reactions, considering internal degrees of freedom such as vibrations and deformations, which influence fusion dynamics and stability against fission. A coupled differential equation approach is used to compute transmission coefficients and cross-sections based on phenomenological potentials or folding density techniques. This research advances theoretical insights into fusion reactions and superheavy element formation, potentially offering new perspectives in nuclear physics and fusion energy applications

Notes:

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NICA heavy ion collider at JINR (Dubna): Physics and Lyrics

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"The present status of the project of NICA project, which is close to commissioning at JINR (Dubna) is given. The main goal of the NICA project is to provide colliding heavy ion beams for experimental studies of hot and dense strongly interacting baryonic matter and spin physics.
The proposed physics program concentrates on the search for possible manifestations of the phase transitions and critical phenomena in the energy region, where the excited matter is produced with maximal achievable net baryon density, and clarification of the origin of nucleon spin. The NICA collider will provide heavy ion collisions in the energy range of √ sNN =4÷11 AGeV at average luminosity of L=1·10^27 cm^− 2·s^− 1 for 197Au79+ nuclei and polarized proton collisions in energy range of √ sNN =12÷27 AGeV at luminosity of L ≥ 10^32 cm^−2·s^-1. The collider ring and the first IP detector are now in the final stage of assembly and start of commissioning. Challenges for physics study, expected observables and phenomena to measure, results of first experiments on fixed target set-up, time-line for 2025, details of start-up configuration, challenges of beam parameters and luminosity preservation are presented in the talk."

Notes:

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Studies of light exoti c nuclei at FLNR JINR

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Studies of the light exotic nuclei is an important part of
scientific program of Flerov Laboratory of Nuclear Reactions
(JINR, Dubna, Russia).
In 1996-2017 it was realised at ACCULINNA fragment separator,
based on U-400M accelerator. In 2018 a new ACCULINNA-2 fragment
separator was commissioned. The novel results concerning quite
"problematic" lightest neutron-rich systems 4n, 6H, 7H , and 7He
were obtained at ACCULINNA-2 in the recent years.
In 2024 the scientific program of ACCULINNA-2 facility restarts
with commissioning of upgraded U-400M accelerator.

Notes:

Something about "Current and future facilities" as well

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Development of a detector system at ACCULINNA-2 fragment separator

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Modern detector systems of light charged particles (E~1÷45 AMeV) and neutrons (E<30 MeV) for the experiments with radioactive beams at ACCULINNA-2 fragment-separator were designed and developed [1-4]. Using such technique new information about low energy spectra of the several neutron rich nuclei 7H, 7He and 8,9Li was obtained [5-7]. Main characteristics of these detectors and its future application are presented.

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Notes:

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Pecularities of formation of ternary fission fragments

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Formation mechanism of ternary fission fragments in the spontaneous ternary fission of 252Cf is described in the framework of trinuclear system model. It is shown that the fission barrier dynamically changes during the evolution of trinuclear system and during the motion of third nucleus in the decay mode. Competition between binary fission and the formation of a trinuclear system, which is responsible for the ratio of spontaneous ternary and binary fission yields, is introduced.

The Coulomb break-up of the dinuclear system in isomeric state in the field of third nucleus(foil), observed in the experiments at FLNR JINR, is explained. The very important (and very needed) role of experiments on ternary fission in understanding the nuclear decay modes and for further developments of theory is noted.

Notes:

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Examining the Structural and Optical Properties of Co3O4 Nanostructures Prepared in Different Solvents

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Abstract:
The focus of the present work is based on the study of the structural and optical characteristics of Co_3O_4 nanostructures prepared using the hydrothermal approach in distilled water, methanol, acetone, and isopropyl alcohol solvents. Various solvents were employed to prepare Co_3O_4 nanostructures to investigate their influence on the morphology, crystallinity and optical properties of the samples. Scanning electron microscopy (SEM), X-ray diffraction (XRD) and UV-Vis spectroscopy analysis techniques were used to investigate these properties. The spinel cubic structure of Co_3O_4 was observed from XRD results, and different crystallite sizes were calculated from XRD results. The SEM images revealed that the obtained samples consists of different morphologies ranging from spherical to rod like depending on the type of solvent used. Different types of solvents also resulted to different particle size distribution as well as the physical and chemical properties of the samples. The Uv-Vis data revealed that the optical properties also depend on the solvent used when synthesizing the samples, hence variation in the optical band gap was observed. The results obtained in this study indicates the significance of the solvents during sample preparation and that the desired properties can be controlled and obtained depending on the solvent used.

Notes:

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Properties of heavy nuclei by laser spectroscopy methods.

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A new setup, based on stopping nuclei in the gas cell and subsequent resonance laser ionization and separation by magnetic field or time of flight is under stage of realization at JINR Flerov Lab. This

setup is devoted to synthesis and study of new heavy nuclei formed in low energy multi-nucleon transfer or fusion reactions.

The heavy nuclei are very important for nuclear physics investigations, for the understanding of fusion – evaporation processes, stability of heavy nuclei, limits of existence of heavy and superheavy nuclei, astrophysical nucleosynthesis and r-process. The properties of heavy nuclei as nuclear shape and size is a key point in constructing of nuclear models and predictions of properties of new nuclei. Ionization potentials and mobility of atoms and ions of heavy elements are extremely important in understanding their chemical properties and role of relativistic effects.

A creation and launch of this facility will open a new field of research in low-energy heavy-ion physics, and new horizons in the study of unexplored "north-east" area of the nuclear map. It could be helpful also for finding a new way for production of heavy and superheavy nuclei and investigation of their properties.

Notes:

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Possibilities of production and isolation of the promising Auger emitter 195mPt for potential application in radiotheranostics

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Recently radionuclides emitting Auger and conversion electrons have gained a lot of attention in radiotherapy. If their decay is accompanied by soft ⊠-radiation those radionuclides can potentially be used for theranostics which implies combination of therapy and diagnostics in a single medical procedure with the same radioisotope and is currently considered extremely advantageous strategy for cancer treatment. Such radionuclides are known with the examples like 67Ga, 117mSn, 123I, 86Y(90Y), 64Cu(67Cu), 124I(131I), 195mPt and some of them are already successfully used in clinical practice.
195mPt emits one of the highest numbers of Auger electrons and γ-radiation appropriate for detection which makes it an ideal candidate for theranostics. Introduction of 195mPt into cisplatinum would enhance therapeutic effect at a lower cytotoxicity [1]. However, there is so far no suitable method to produce 195mPt with a sufficient yield and specific activity high enough to meet the requirements for carrying out radionuclide therapy. In this work we investigate two perspective ways to produce the radioisotope of interest and characterise nuclear reactions involved with respect to their cross sections.
The first method takes advantage of photonuclear production by irradiation of natural Pt with bremsstrahlung at the microtron MT-25 (JINR, FLNR) according to the reactions 196Pt(γ,n)195mPt and 195Pt(γ,γ')195mPt. Photonuclear method is a powerful and effective tool to produce isomeric radioisotopes with high yield particularly relevant for nuclear medicine. The results of the flux-weighted average cross section <σ> determination for the reactions mentioned will be presented. It is important to add here that we have increased the initial specific activity by one order of magnitude with the respective chemical yield of 80% using a target mixture of cisplatinum and cryptomelane with latter serving as a recoil nuclei catcher and further separation of these two target components.
The second approach aimed to boost the specific activity of the radioisotope studied is indirect production of no-carrier-added 195mPt by double neutron capture reaction of enriched 193Ir at a reactor by the nuclear process 193Ir(n,γ)194Ir(n,γ)195mIrβ- ⟶ 195mPt. This approach was proposed by the American researchers but was not characterised numerically [2]. Our work is a detailed study of the process mentioned by an activation technique at IBR-2 reactor (JINR, FLNP) and contains the first results of the unknown cross sections determination for the reaction 194Ir(n,γ)195mIr. We have found the reaction 194Ir(n,γ)195mIr resonance neutrons cross section to be 2900 b substantially prevailing the corresponding value for thermal neutrons with the specific activity of 195mPt after 17

days of irradiation of 20 mg of 193Ir at IBR-2 amounting to 38.7 MBq/(mg Pt), making a reactor with a higher flux of fast neutrons to be a preferential condition for 195mPt production [3].

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Notes:

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First observation of rotational bands in the nucleus 231U

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(Dated: November 20, 2024)

The
-ray spectroscopy of uranium nuclei far from stability is compromised by large ssion cross sections and competition from electron conversion. However, by using a recoil detector to discriminate against the ssion background, together with the afrodite
-ray spectometer array, we have
observed the rst rotational bands in 231U, to date the lightest odd uranium nucleus shown to exhibit collective structure. Excited states were populated in the 232Th(,5n) reaction at a beam energy of 52 MeV. The data analysis revealed three rotational bands, interpreted as the ground-state band [633]5=2+, yrast band [752]5=2, and an excited band [631]3=2+. These conguration assignments are supported by Cranked Shell Model calculations and the electromagnetic properties of the bands. The excitation energy of the [752]5=2 band head is suggested to be 113.0 keV.
PACS numbers: 21.10.-k,21.10.Re, 23.20.Lv, 27.70.+q

Notes:

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In a search for the true identity of low-lying positive parity states in the A~160 mass region.

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For many years, the first excited 0+ bands of well-deformed nuclei were understood as "β -vibrations", following the seminal works of Bohr and Mottelson [1, 2]. Nevertheless, over the years it has become apparent that low-lying 0+ bands could also arise due to other effects such as shape-coexistence, and quadrupole pairing [3, 4, 5].

In this work, I will present a comprehensive dataset comprising of low-lying positive parity bands (β and γ bands) in even-even isotopes with N ~ 88 to 92 and proton numbers Z ~ 62 (Sm) to 70 (Yb). In order to produce a complete and definitive microscopic picture of the so-called β bands as well as other related low-lying positive parity excitations, an extensive systematic review is performed for these nuclei. The implication of the findings on the interpretation of the first excited 0+ states and other related low-lying positive-parity excitations is there from discussed.

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Notes: